The Design and Implementation of an Automatic Inflatable Abdominal Binder

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Abstract
Orthostatic hypotension represents as a drop of standing blood pressure, which is due to the blood pooling in the lower body while standing. It is common among the elderly and patients with autonomic dysfunction of blood pressure control. Usually, treatments include volume expansion and vasoconstrictor drugs, compression garments and postural adjustment. The challenge for the treatment of orthostatic hypotension is that vasoconstrictor drugs can cause supine hypertension, compression garments are uncomfortable over long time and postural adjustment renders working disability. As another non-pharmacological alternative, shortlasting compressing of the abdomen during standing only can relieve the symptoms without affecting supine blood pressure. However, no portable and auto-adjustable abdominal binder is currently available for orthostatic hypotension patients. The aim of this work is to design and implement an abdominal binder which can precisely detect the sitting-standing transition and automatically inflate the binder when standing and deflate the binder when sitting or lying.

Introduction
Orthostatic hypotension is defined as a consistent drop of standing blood pressure (over 20mmHg systolic/10mmHg diastolic blood pressure), [1] which is due to the blood pooling in the lower body during standing as shown in Figure 1. Blood can move from the chest to the abdomen which has a large venous capacity, and in turn of this fluid shift and pooling cause lower venous return, decrease in ventricular filling and cardiac output and consequently in a drop of blood pressure. Under normal condition, it can be detected by baroreceptors resulting in tachycardia and vasoconstrictor to neutralize the above symptoms when upright. Orthostatic hypotension is caused by the failure of above phenomena, termed baroreflex failure. Severe cases can lead to syncope when upright, morbidity or even fatality. It is common among the elderly and those with low blood pressure.[2] The treatment of orthostatic hypotension is targeted to raise standing blood pressure without causing supine hypertension, increasing standing time and enabling daily activities performance. However, no perfect treatment exist yet. Volume expansion and vasoconstrictor drugs can raise the standing blood pressure but induces supine hypertension as well. Postural adjustment like crossing legs when standing helps but disables walking.[3]

As a non-drug alternative, compressing the abdomen can relieve the symptoms according to Tanaka et al., Denq et al., Yamamoto et al. and Smit et al.. [4,5,6,7] The compression can reduce the venous capacitance and increase total peripheral resistance.[4] If compared with abdomen which has a large blood reservoir, the compression of legs does not help much as venous capacity of legs is too small.[7] Some compression garments made of elastic materials including stockings and tight pants, can also reduce orthostatic symptoms but they are inconvenient and uncomfortable to wear.[3,4,6] However, existed air-compression waist binders are either too large to wear daily or needed to be pump up manually. Here, we designed and implemented a waist binder which can precisely detect the sitting-standing transition, and automatically inflate when standing and deflate when sitting. The binder consists of an Arduino platform, an air pump, two valves, a accelerometer, a pressure sensor, and a waist binder with a bladder (Figure 2).

Figure 1. Standing causes blood being pulled downwards by gravity, which in turn leads to low blood pressure. When there is no enough blood in the brain, syncope occurs.
Methods

Hardware Design and Implantation
The device consists of an Arduino Uno microprocessor board, a triple axis accelerometer (SparkFun MMA8452Q), a digital pressure transducer (Honeywell 005PG2A5), a miniature diaphragm pump (Parker T2-04), two miniature pneumatic solenoid valve (Parker X-Valve® 8mm) and three lithium-ion rechargeable batteries (Biopower LP-063450) as shown in Figure 3.

The code was written in Arduino 1.0.1 and uploaded to Arduino Uno microprocessor board to control other components on the board. The accelerometer reads out accelerations on three axes and the microprocessor can 'translate' the values to sitting or standing. The pressure sensor is used to monitor the pressure, to prevent the over-compression of the abdomen. If the pressure in the belt is above the threshold pressure, pumping stops. The threshold is currently set as 50 mmHg which may change based on different health condition of the patient. The valves are used to release pressure. If seated, the valves open to deflate the bladder. The pressure sensor and two valves are connected to the bladder and pump using a customer-made four way connector and a three way connector. The algorithm is shown in the following flow chart(Figure 3).
Standing and Sitting Recognition

The blood pressure would only drop significantly when changing position to standing. In order to help to increase the standing blood pressure, the bladder only need to be inflated in upright position. Thus we only need to distinguish between sitting/supine and standing regardless of the movement. There are two ways to achieve this using one accelerometer: one is to place the accelerometer on the thigh to check the tilting angle of thigh and the other is to place it on the waist to read the acceleration and calculate the velocity and distance.

If the accelerometer is placed on the thigh as shown in Figure 4a, the accelerometer's built-in landscape function and easily detects the orientation of the device. When siting, the upright vector on the accelerometer is perpendicular to the gravitational vector and the acceleration is 0g. When standing, the upright vector on the accelerometer is parallel to the gravitational vector and the acceleration is -1g.

If the accelerometer is placed on the waist, it would be more complicated to implement. More details about siting and standing recognition using one triaxial accelerometer on the waist is in the appendix. Currently, the acceleration data on the waist was recorded in another health monitor device using a SD card and later processed using Matlab R2012a. The data was converted to units of acceleration “m/(s*s)”. The mean centered data, where thresholded. Values below a dynamic threshold was identified as noise and set to zero. The velocity and distance of change was calculated using integration procedures.

Results and Discussion

Currently, we choose to place the accelerometer on the thigh. People can put the device in their pocket after putting on the waist binder. As long as people don’t stand or walk in a way that one leg is perpendicular to another leg, the accuracy of the device is very high. In the future, the accelerometer and all other components would be mounted on the binder. The current algorithm based on the orientation of the thigh would be changed to acceleration of trunk during sitting-standing transition.
figure 5. The upright acceleration (upper trace), the mean corrected, filtered, and denoised upright acceleration (second trace), the upright velocity (third trace) and upright distance change (bottom trace) recorded with the accelerometer on the waist during repeated pattern of sit to stand maneuvers.

According to the acceleration data measured on the waist (Figure 5), the highest velocity during the sitting-standing transition is around 0.7m/s and the distance is around 0.27 m. The integrated value shows peaks corresponding to the transition. The proposed algorithm is simple and will be implemented in the Arduino platform later. There is one disadvantage of our method. Since we used only one vector for the upright direction, the tilting of the device can cause lower upright vector acceleration values. As shown in Figure 6., the inclination θ angle is not 0°, and it changed with the movement. This problem needs to be solved, if we want to derive the accurate moving distance and velocity in the upright direction. As shown in Figure 6, the siting phase after the second peak has an inclination θ of about 10° which reduces the value of our measured upright vector during recording. Consequently, as shown in Figure 5, the standing phase after the 3rd is significantly smaller than other standing phase.
The radius $r$, inclination $\theta$, azimuth $\phi$ changes in the sitting and standing repeat pattern. The data was recorded with the accelerometer on the waist.

The response time for the device to inflate and deflate while standing and sitting is less than 1s. It took around 30 s to inflate the bladder to the 40 mmHg threshold pressure more than 40 s release the pressure. The current valves have small opening and low throughput which results in longer releasing time. We propose to change these valves with bigger valves in the next generation of the device.

The size of the device is a little bit too large and inconvenient to put in the pocket. The next generation will use a smaller Arduino platform to reduce the size. Also, a Bluetooth interface will be implemented to connect with the cell phone to allow of individual setting of pressure threshold.

The device will be further tested in patients. Heart rate, blood pressure, fluid shifts and other physiological parameters will be measured in patients wearing the binder.

**Conclusion**
Overall, we successfully made a abdominal binder, which can precisely detect the sitting-standing transition, and automatically inflate when standing and deflate when sitting.

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**Reference**


**Appendix**

*Study of Posture Recognition Using one Triaxial Accelerometer*

ANOTHER FILE