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# Design and construction of a sit-to-stand support device for the elderly

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## Abstract

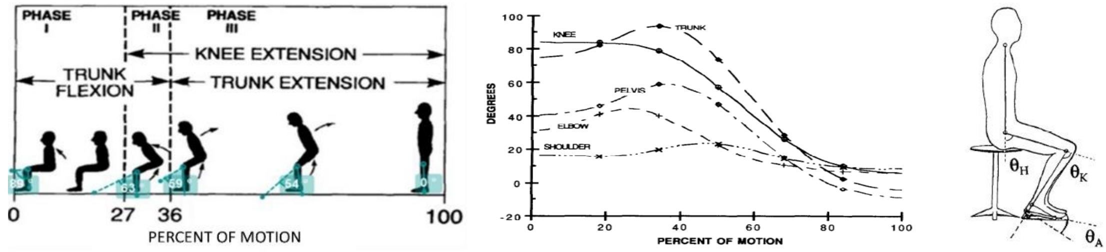
Home-bound elderly people are those who can get around by themselves at home or may need some help from a caregiver. A cane or walker is often used to provide support for activities in the home. The sit-to-stand movement from a bed to a walker or from a chair to a walker can be difficult for the elderly due to loss of skeletal muscle mass and reduction of muscle strength and function. The objective of this study was to design and construct a support device for the elderly to help them stand-up while transferring from a chair or bed to a walker in order to reduce the muscular exertion that may cause muscle injury or increase the risk of falling. The design idea was to use a controllable triangular air cushion for lifting and lowering the subject. This study adopted the biomechanical analysis of sit-to-stand and air-compression control. This design of the stand up and sit down support device for the elderly consists of two main parts: hardware and software. The hardware comprises the user interface, the control unit, and the display unit. The software was developed with a microcontroller with C programming language. Using Kinovea software to evaluate the functional test, it was found that the designed device can perform the sit-to-stand biomechanics phase from phase I to the middle of phase III. The performance test showed that the time duration, when measuring from the start until the maximum pressure of the triangular air cushion was reached, was approximately 1 minute. The electrical safety test results revealed a 20 µA leakage current, which met the IEC standard of 60601-1.

***Keywords***: *assist device; biomechanics; design and construction; elderly; sit-to-stand; support device.*

## 1. Introduction

The elderly population is on track to increase tremendously. They can be categorized into three groups: the bed-bound, the homebound, and the healthy. The homebound are those who can function independently inside their home. Nineteen percent of older Thais are considered part of the homebound elderly group (Foundation of Thai Gerontology Research and Development Institute (TGRI), 2014). The daily life of this group is inside the home, using a walker and a wheelchair to support their regular activity. This elderly group can perform everyday routines by themselves. However, diseases often found in the elderly, such as the loss of skeletal muscle mass, muscle strength, and function (Tieland, Trouwborst, & Clark, 2018), make everyday tasks difficult and reduce physical performance in the elderly. Sit-to-stand (STS) is a frequent human activity and is important to obtain the vertical posture needed in so many everyday activities (Lee, Mehta-Desai, Oh, Sanford, & Prilutsky, 2019). The STS action from a chair or bed to a walker is a frequent daily task for the elderly. It requires strong exertion from the knee and shoulder muscles, which may cause injury to a muscle or induce a frozen shoulder. Nakano et al. (Nakano, Otonari, Takara, Carmo, & Tanaka, 2014) studied to verify when the functionality of the elderly begins to decline. They found that both genders of the elderly in their 60s and 70s have similar mobility, physical performance, balance, and muscle strength. It is in their 80s that functionality in the elderly starts to decline.

The biomechanics of STS in the elderly (Millington, Myklebust, & Shambes, 1992) is divided into three phases, determined from the kinetic data shown in Figure 1 (a) and the relationship of the changing of degree of each joint during the STS transition according to the percent of motion shown in Figure 1(b). For example, the knee angle (the solid line of Figure 1(b)) was measured according to the $\theta_K$ shown in Figure 1(c). The first phase starts with the upper body as the body mass moves toward the feet to maintain balance. The knee angle is about 90 degrees, and the movement is from 0–27% of the total. The second phase starts when the hip and knee extensor muscles are activated by throwing the weight forward and slowly lifting. This phase occupies about 36% of the movement of the complete motion. The knee angle here changes to between 75 and 85 degrees. Most of the muscle activity is used during this phase. The final phase is where the thighs are used to stand up and leave the chair. The knee angle here changes from 0-75 degrees. At the end of this phase or percent of motion is 100, the leg and trunk joints are straightened and $\theta_K$ is equal to 0 degree, as shown in Figure 1 (a).



(a) (b) (c)

**Figure 1** (a) The biomechanics analysis phase of the STS motion in the elderly, (b) the relationship of the changing of degree of joints during the STS transition according to the percent of motion, (c) the definition of joint angles based on the subjects' standardized starting positions (Roebroeck, Doorenbosch, Harlaar, Jacobs, & Lankhorst, 1994)

Sütçü et al. (Sütçü et al., 2019) studied the differences between the activation levels of related muscles and biomechanical properties of people with muscle disease (muscular dystrophy, myopathies, etc.) and a healthy group during sit-to-stand. They found that the STS pattern of both groups was similar, but the duration was longer and the muscle activation levels were higher in the group with muscle disease, possibly caused by the fatigue and muscle deterioration in this group.

Many innovations assist the STS movement in the elderly. Ruszala and Musa (Ruszala & Musa, 2005) evaluated four types of STS equipment: a stand-and-walk aid, a chair lifter, a stand-and-turn aid, and a walking harness. The task duration varied for each equipment type, from 0.5 to 6 minutes. These devices were used to manually assist patients during clinical treatment activities.

Qureshi et.al. (Qureshi, Masood, Rehman, Owais, & Khan, 2018) designed and developed the phase of the lower-limb robotic exoskeleton to assist paralyzed individuals. Both exoskeleton legs were attached to a supporting frame with passive universal joints, which provide 3 DOFs per limb. The sit-to-stand and stand-to-sit movements were controlled by a switch control method, and the feedback was provided from the current measurement.

Li et.al. (Li, Xue, Yang, & Guo, 2019) proposed sit-to-stand assist devices to support elderly or impaired patients in STS transfer and rehabilitation activities in daily life and also to reduce caregiver tasks. Their research had three stages. First, a sit-to-stand motion experiment was conducted, with the trajectory and orientation of the knee, hip, and shoulder tracked and registered. Second, they summarized the sit-to-stand motion rule, dividing the sit-to-stand motion mechanism into four phases—original, balance, rising, and stable—and providing the motion trajectory of the end-effector for sit-to-stand assisting devices. Finally, a 3-DOF sit-to-stand robot prototype was designed. In all stages of the STS movement, users can get improved recovery instruction. However, the robot may require a large working area that is appropriate for patient recovery.

Sa-adprai and Rungroungdouyboon (Sa-adprai & Rungroungdouyboon, 2020) developed a STS trainer to support users in standing from variable levels. The time duration of the observed movement was 2.5 seconds. This device produces movement and speed naturally. It can also support the body weight from the ground, making the standup movement easier.

In this paper, we present a novel device for supporting the stand-to-sit and STS movement. The concept of the design was to control the inflation or deflation of a triangular air cushion for lifting the user up or lowering them down, using an electronics control.

## 2. Objectives

The objectives of this study are to design and construct a sit-to-stand support device for the elderly. We also aimed to evaluate the design of the device to verify the operation as the degree of knee angle changes during use. Kinovea software was used to identify the biomechanics phase of sit-to-stand, and the time duration using the designed device to support STS was measured.

## 3. Materials and methods

The material of the support device was composed of electronic and microcontroller elements: a 3-channel relay module, an air compressor, two solenoid valves, switches, and a 0.96” OLED display. The microcontroller used in the design was an Arduino UNO R3. The triangular air cushion was chosen to lift the lower limb of the subject.

### 3.1 Operating principle

The concept was the inflating or deflating control of a triangular air cushion for lifting or lowering the user. A block diagram of elderly support devices from STS is shown in Figure 2. The control switches (SW1–SW3) were used to control the equipment operation. The microcontroller was the main component that controlled all the operations, such as the relay module, the air compressor, solenoid valves 1 and 2, and the display. The triangular air cushion was used to support the elderly in both sit-to-stand and stand-to-sit, and the pressure sensor measured air pressure in the tube, which was connected to the air cushion.

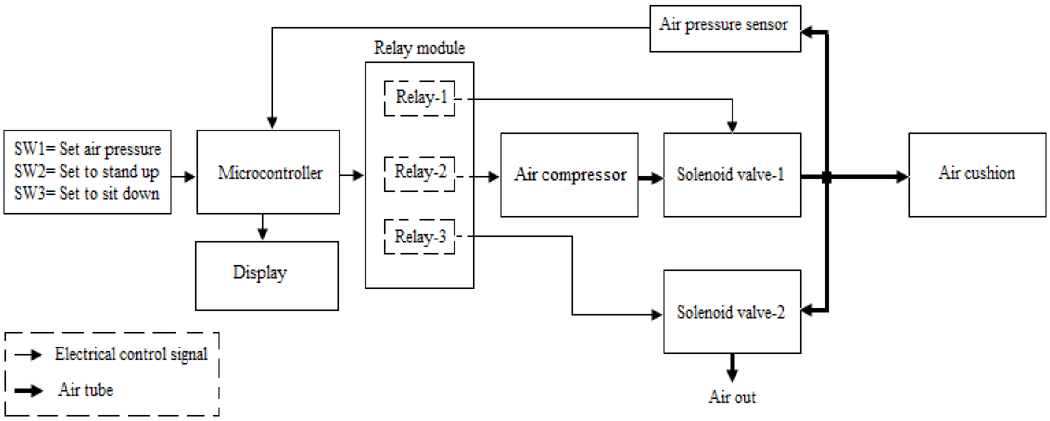


**Figure 2** Block diagram of the elderly support device from sit-to-stand

### 3.2 Hardware and software parts

### *3.2.1 Hardware design*

*1) Control switch (SW1-SW3)*

A control switch (SW1) was used for the user weight setting, which was connected to a voltage divider and a microcontroller pin A3. The body weight range of the elderly affects the inflation control of the air cushion, resulting in a knee angle in the range of phase II or higher (Figure 1 (a)). When this switch has been set for each weight level, the microcontroller reads the voltage level from the voltage divider. The maximum pressure was set according to the user weight.

Another control switch (SW2) was used to set the inflation of the air cushion. This switch connected the 5V supply voltage, the resistor (R7), and a microcontroller pin (D10). When SW2 was pressed, resulting in the microcontroller input was in logical high. The microcontroller then sent control signals as follows: 1) from D13 to relay-1, to supply the 12V direct current to solenoid-1; this caused the solenoid valve-1 to operate, or open, which moved the air compressor to compress air through this valve to the air cushion, and 2) from D12 pin to relay-2 to supply the 220Vac alternating voltage to the air compressor, which caused the air compressor to compress air into the cushion.

A control switch (SW3) was used to set the deflation of the air cushion. This switch connected the 5V supply voltage, the resistor R8, and a microcontroller pin D9. When SW3 was pressed, resulting in the microcontroller input was at a logic high, the microcontroller sent the control signal from the D11 pin to relay-3 to supply the 12V direct current to solenoid-2. This caused the solenoid valve-2 to open, and as a result, the air inside the air cushion was released through this valve.

#### *2) Pressure sensor module*

The pressure sensor module measured the air pressure inside the air cushion and turned it into an electrical signal for the microcontroller to process. If the measured air pressure was equal to the pressure set by SW1, solenoid valve-1, solenoid valve-2, and the air compressor stopped working, and air was trapped in the air cushion.

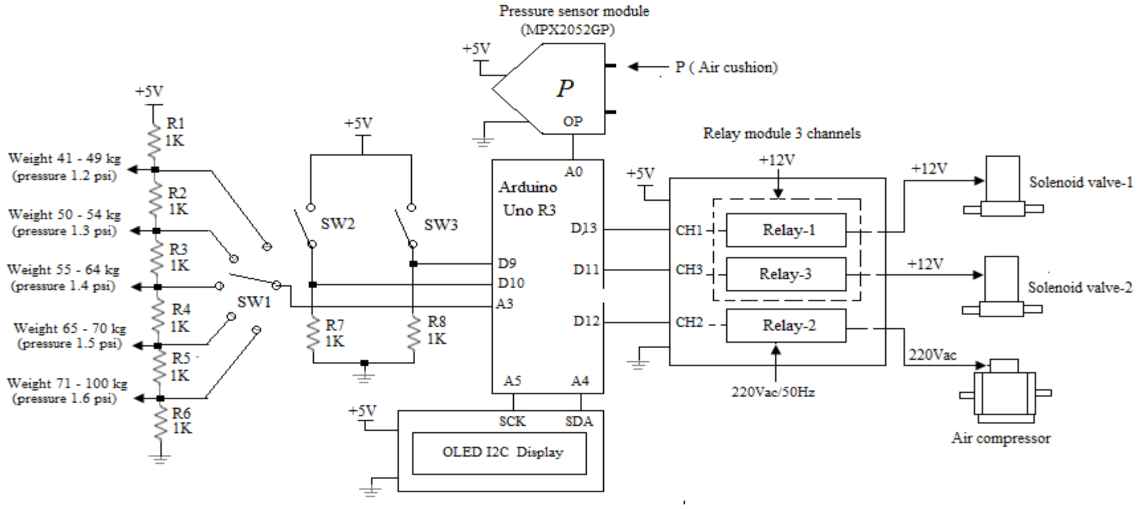


**Figure 3** Interfacing of control switch (SW1 - SW3), OLED I2C display, 3-channel relay module, and pressure sensor module with microcontroller

### *3.2.2 Software design*

The software to control the operation of the equipment was programed with C- language. There were four main functions in the operating of this device: 1) read the maximum pressure level from SW1, 2) compress air into the cushion when the "UP" button switch (SW2) is pressed, 3) release air from the cushion when the "DOWN" button switch (SW3) is pressed, and 4) hold the air inside the cushion when the pressure of the air inside the cushion reaches the set maximum pressure level. The flow chart of the device is shown in Figure 4.

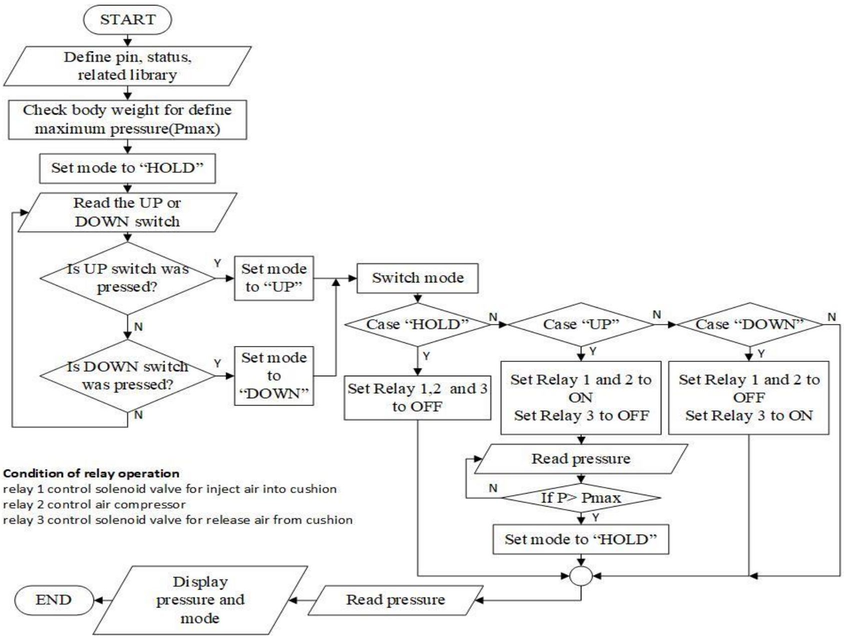


**Figure 4** Main flow chart of operating process

The flow chart begins by defining the related pin, library and status and then checking the selector switch (SW1) to define the maximum pressure. The operation mode is set to HOLD, and then the "UP" or "DOWN" buttons are used (SW2 and SW3). When the "UP" button (SW2) is pressed, the operation changes to "UP" mode. Relay 1 and relay 2 are set to ON, and relay 3 is set to OFF since relay 1 controls the opening of solenoid valve-1 to inject air into the cushion and relay 2 turns on the air compressor. Relay 2 controls the closing of solenoid valve-2 to keep the air in the system. The "UP" mode starts by filling air into the cushion until the maximum pressure is reached. Then the air compressor stops working, and the operation is changed to "HOLD" mode. When the "DOWN" button (SW3) is pressed, the operation changes to "DOWN" mode. Relay 1 and relay 2 are set to OFF, and relay 3 is set to ON. Solenoid valve-1, for injecting air into the cushion, is closed, and the air compressor is turned off. Solenoid valve-2, to release air out of the cushion, is opened. The operation is changed to "HOLD" mode after the user releases the button.

### 3.3 Air cushion part

An air cushion was used to make it comfortable for older people who need help for sit-to-stand and stand-to-sit maneuvers. It inflates when air pressure is compressed and deflates when air pressure is released. For the design we chose a prefabricated air cushion, which can hold a maximum weight of 100 kg. When the cushion is deflated, its size does not disturb an elderly person using the bed or chair, and when it is inflated, the lower trunk support can lift approximately 16 cm. The air cushion's dimensions were designed so that it would fit comfortably in a normal chair or wheelchair. The air cushion's width and depth were then determined by the width and depth of a standard wheelchair measurement ("Standard Wheelchair Measurements," n.d.). In the sit-to-stand maneuver, the knee angle transition from phase I to the middle of phase III can change by around 20-25 degrees. The maximum angle of the inflated air cushion was 24 degrees, which was acceptable. The triangular air cushion has the dimensions shown in Figure 5.

**Figure 5** Triangular air cushion

3.4 Device characteristics and components

The completely sit-to-stand support device for the elderly was designed and constructed as shown in Figure 6(c). The air cushion was deflated and inflated as shown in Figure 6(a) and (b) respectively.

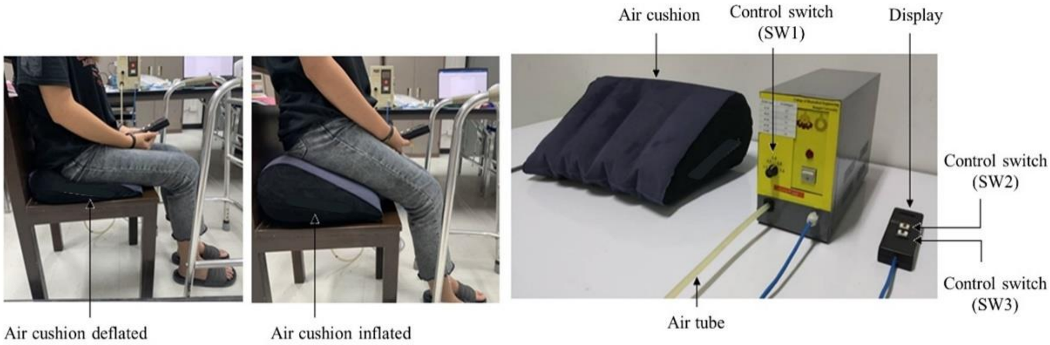


**Figure 6** The completely designed STS support device for the elderly

3.5 Testing procedure

Kinovea is a video player for sports analysis, a 2D motion analyzer tool that can be used in human movement analysis for both sports analysis and clinical assessment. Puig-Diví et al. compared the Kinovea program to AutoCAD to assess its validity (Puig-Diví et al., 2019). They found that the Kinovea software is a reliable and valid tool. The distance measurements are accurate for objects up to 5 m away and for an angle range between 45° and 90°. Kinovea software was chosen to measure the knee angle to verify the biomechanical phase at the beginning and end of using the prototyped device.

The testing procedure was divided into 5 parts: 1) the calibration equation of the sensor, 2) the accuracy of the pressure display on the designed device, 3) the knee angle measurement, 4) the time duration from when the prototyped device was started (the UP button pressed) to the end when the air compressor stopped and 5) an electrical safety test.

## 4. Results

4.1 The calibration equation of the sensor

Before using the sensor, we needed to calibrate the sensor reading with the standard device pressure and use the calibration equation in the processing unit, as shown in Figure 7.

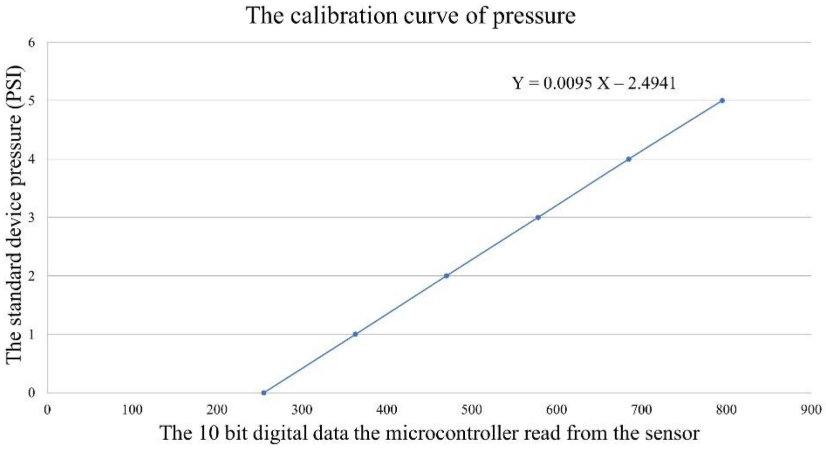


**Figure 7** The calibration curve of the digital data that the microcontroller read from the pressure sensor and the standard device pressure

For the maximum pressure of the load, we took the load to be a subject weight ranging from 40 to 100 kg pressured on the cushion. The maximum pressure was measured when the cushion was at maximum size with the subject weight. The result of maximum pressure was set according to the circuit in Figure 3.

### 4.2 The accuracy of the pressure display on the designed device

The accuracy of the pressure reading was confirmed by comparing the displayed pressure and the standard brand Additel model Digital Pressure Gauges 681. The testing was repeated three times, with the average pressure shown on the display. The pressure reading displayed correctly according to the standard device setting.

### 4.3 The knee angle measurement

The knee angle was measured by Kinovea software to verify that the designed device can support STS from phase I to the middle of phase III. The knee angle of the subject was measured during the use of the prototyped device from the start, when the air cushion was deflated, to the end, when the air cushion was fully inflated. The test was performed three times and calculated the average knee angle from start to finish, as shown in Figure 8. The result was shown in Table 1.

(a) (b)

**Figure 8** Kinovea software was used to measure the knee angle from (a) air cushion deflated to (b) air cushion inflated

**Table 1** Knee angle of the subject during use of the designed device measured from the pressing of the “UP” button to the stopping of the air compressor

| Subject | Subject weight (kg) | Max pressure (psi) | Knee angle | | | | | | Average knee angle | | Phase of STS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | | 2 | | 3 | | | | | |
| | | | Start | End | Start | End | Start | End | Start | End | Start | End |
| 1 | 43 | 1.2 | 90° | 41° | 90° | 41° | 90° | 41° | 90° | 41° | I | III |
| 2 | 47 | 1.2 | 90° | 42° | 90° | 42° | 90° | 42° | 90° | 42° | I | III |
| 3 | 48 | 1.2 | 90° | 45° | 90° | 45° | 90° | 45° | 90° | 45° | I | III |
| 4 | 50 | 1.3 | 89° | 45° | 89° | 45° | 89° | 45° | 89° | 45° | I | III |
| 5 | 54 | 1.3 | 88° | 47° | 88° | 47° | 88° | 47° | 88° | 47° | I | III |
| 6 | 55 | 1.4 | 90° | 47° | 90° | 47° | 90° | 47° | 90° | 47° | I | III |
| 7 | 56 | 1.4 | 90° | 43° | 90° | 43° | 90° | 43° | 90° | 43° | I | III |
| 8 | 63 | 1.4 | 89° | 58° | 89° | 58° | 89° | 58° | 89° | 58° | I | III |
| 9 | 65 | 1.5 | 90° | 52° | 90° | 52° | 90° | 52° | 90° | 52° | I | III |
| 10 | 75 | 1.6 | 90° | 50° | 90° | 50° | 90° | 50° | 90° | 50° | I | III |
| 11 | 78 | 1.6 | 90° | 50° | 90° | 50° | 90° | 50° | 90° | 50° | I | III |
| 12 | 80 | 1.6 | 90° | 46° | 90° | 46° | 90° | 46° | 90° | 46° | I | III |
| 13 | 83 | 1.6 | 90° | 50° | 90° | 50° | 90° | 50° | 90° | 50° | I | III |
| 14 | 85 | 1.6 | 88° | 50° | 88° | 50° | 88° | 50° | 88° | 50° | I | III |
| 15 | 100 | 1.6 | 90° | 54° | 90° | 54° | 90° | 54° | 90° | 54° | I | III |

### 4.4 Time duration

In the performance test, we focused on the time duration of the operating of the device from STS with a control chair height of 48 cm. We did not measure the stand-to-sit duration since this was dependent on the subject weight pressing on the cushion. The time duration was measured from when the “UP” button was pressed until the maximum pressure of each range was reached (the air compressor stopped). The test was performed three times per subject, and the average time was calculated. The results are shown in Table 2.

**Table 2** The time duration of the operating of the device from STS

| Subject | Subject weight (kg) | Maximum pressure (psi) | Time duration (min:sec) | | | Average time (min:sec) |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | |
| 1 | 43 | 1.2 | 0:56 | 0:59 | 1:00 | 0:58 |
| 2 | 47 | 1.2 | 1:00 | 1:00 | 1:02 | 1:01 |
| 3 | 48 | 1.2 | 1:00 | 1:05 | 1:00 | 1:02 |
| 4 | 50 | 1.3 | 1:17 | 1:17 | 1:19 | 1:18 |
| 5 | 54 | 1.3 | 1:21 | 1:02 | 1:25 | 1:16 |
| 6 | 55 | 1.4 | 1:26 | 1:24 | 1:26 | 1:25 |
| 7 | 56 | 1.4 | 1:26 | 1:26 | 1:27 | 1:26 |
| 8 | 63 | 1.4 | 1:23 | 1:22 | 1:23 | 1:23 |
| 9 | 65 | 1.5 | 1:18 | 1:02 | 1:23 | 1:14 |
| 10 | 75 | 1.6 | 1:07 | 1:06 | 1:01 | 1:05 |
| 11 | 78 | 1.6 | 1:15 | 1:15 | 1:16 | 1:15 |
| 12 | 80 | 1.6 | 1:13 | 1:12 | 1:14 | 1:13 |
| 13 | 83 | 1.6 | 1:14 | 1:13 | 1:15 | 1:14 |
| 14 | 85 | 1.6 | 1:16 | 1:15 | 1:14 | 1:15 |
| 15 | 100 | 1.6 | 1:15 | 1:13 | 1:13 | 1:14 |

### 4.5 The electrical safety test

Since the power supply of the designed device was an alternating voltage (220V 50Hz), an electrical safety test was needed. The safety test was performed on the ground system resistance and leakage current while the power was off and on with the Electrical Safety Analyzer. The parameters were measured with the electrical safety analyzer brand Fluke. The average ground device resistance was 0.2 Ω, and the average leakage current was 11.8

and 20 µA when the power was off and on, respectively, which is sufficient according to the IEC standard 60601-1.

## 5. Discussion

The prototype was compact and easy to use, as shown in Figure 6. The ergonomics of the chair or bed were not impacted by the deflated air cushion. The pressure value display was correct when compared with standard pressure gauges.

According to Figure 1(a) and (b), the knee angle in phase I was estimated at 80°-90°, in phase II it was 75°-80° degrees and in phase III it was in the range of 0°-75°. As shown in Table 1, we found that the average angle of the knee, when measured before using the designed device, was from 88°-90° which is phase I of the STS biomechanics. The average angle of the knee measured after the designed device had reached the maximum pressure was from 41°-58°, which is in the middle of phase III of the STS biomechanics. That means that the designed device can support the subject from STS from phase I to the middle of phase III.

As shown in Table 2, the average time was from 0.58 to 1.14 minutes. The time duration of the device was better than some commercial STS assist devices (Ruszala & Musa, 2005) but longer than the time duration of STS in normal people, which is about 2 - 2.5 seconds (Janssen, Bussmann, & Stam, 2002) Van Lummel et al. found that older adults have a significantly longer STS duration (Van Lummel et al., 2013).

For the electrical safety test, we test on the ground system resistance and the leakage current while the power was off and on. The designed device met the IEC standard 60601-1 for electrical protection.

## 6. Conclusion

The design and construction of the support device to help the elderly change position from sitting down in a wheelchair, chair, or bed to standing up at a walker was shown to work properly according to its design. The prototype was small and easy to use, and the deflated air cushion size did not disturb the ergonomics of the bed or chair. The device was suitable for people who's difficulty in standing may be associated with hip and knee extensor muscle weakness. Moreover, the device also assisted caregivers during sit-to-stand transfers of elderly people. The time duration of STS was also considered. The time duration of using the design device was approximately 1 minute. However, the slow movement will allow for better balance of the body, which is important for the elderly.

## 7. Acknowledgements

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