Development of sit-to-stand assistive chair using a pneumatic cylinder: a feasibility test

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Objective: The purpose of this study was to develop and investigate the feasibility of a sit-to-stand assistive chair using a pneumatic cylinder.

Design: Cross-sectional study.

Methods: The sit-to-stand assistive chair was developed to assist the sit-to-stand movement by rising up of the chair by a pneumatic cylinder. After the user is seated on the chair, if the pneumatic cylinder pulls the seat plate when standing up, the spring of the pneumatic cylinder, which has been stretched, assists in rising the rear end of the seat plate so that the user can stand conveniently and comfortably. A feasibility test was performed in 10 healthy adults. The electromyographic muscle activation of the trunk and lower extremity muscles was analyzed, which included the erector spinae, rectus abdominis, quadriceps, tibialis anterior, gastrocnemius when standing up from sitting using the developed chair and standing up without using the developed chair.

Results: As a result, the sit-to-stand assistive chair using a pneumatic cylinder was developed. In the feasibility test, the use of the developed chair had a decrease in rectus abdominis, quadriceps, tibialis anterior activation compared to those who did not use the device in the healthy adults.

Conclusions: The sit-to-stand assistive chair using a pneumatic cylinder may be helpful to reduce the activation of the rectus abdominis, quadriceps, tibialis anterior muscles when performing a sit-to-stand movement. Through the results, the efficacy of the sit-to-stand assistive chair can be confirmed. In the future, further studies are warranted to investigate for the safety and efficacy of its use in the elderly population or those who are disabled.

Key Words: Assistive device, Disabled, Elderly, Pneumatic, Standing

Introduction

Movements that occur from a standing or sit-to-stand position are movements performed repeatedly used more often than walking in daily life \cite{1,2}, and requires more muscle strength and movement than walking or climbing stairs. Therefore, these movements are one of the most difficult movements for used during daily life activities \cite{2}.

This motion involves the following steps: moing the center of the body forward, the hip joint is flexed to the maximum as the buttocks are removed from the chair, the flexed knee joint begins to go into extension and as the ankle joint goes into dorsiflexion, the ankle moves to maximum plantar flexion as the knee and hip joint are almost extended and the standing position takes place, and the posture is stabilized in a total of five stages \cite{3}. In order to perform these movements, the erector spinae, quadriceps femoris, the hamstrings, and the glutaeus maximus muscles play the most important roles \cite{4}.

However, when the muscle strength of the lower extremities is weakened or pain occurs due to degenerative or chronic diseases caused by aging, it is difficult to perform these movements \cite{5}. In addition, persons who is handicapped with hemiplegia or hemiparalysis due to a stroke or...
with quadriplegia or lower limb paralysis due to spinal nerve damage, etc. also have difficulty performing these movements. In the past, devices that can assist with standing have been developed [6-8], but there is a limit to commercialization due to relatively cumbersome use and expensive purchase cost due to use of an electric motor.

The pneumatic cylinder used in this device is a device operated by compressed air and has a disadvantage in that it exhibits a limitation in mechanically high pressure [9], but it has the advantage of being able to control the force and speed without limitations, and it is economical and reliable and so it is widely used in the industry [10]. In this study, in order to compensate for the limitations of the existing device, a sit-to-stand assistive chair device was developed using an economical and easy-to-use pneumatic cylinder, and the feasibility of the device was investigated.

Methods

Sit-to-stand assistive chair

Device structure

The device consists of the leg components, a seat plate, seat plate moving slide, back frame, handle for fixing and releasing, and a pneumatic cylinder (Figure 1).

A standing seat plate is installed on the upper part of the leg which slides to allow the seat plate to move when standing on both sides, a handle for fixing and releasing are attached, and a pneumatic cylinder that can pull the seat plate behind the back frame is attached (Figure 1). The standing seat plate was designed so that the rear end of the seat plate can be raised from 25° to 35° so that patients with problems such as knee joint disease, low back pain, and general weakness can sit in a stable manner without strain applied on the knee joint and lower limbs. In addition, it is possible to fixate or release the cylinder by using the operation handle.

Device algorithm

When the user operates the fixing and release handle after sitting on the seat plate of the standing assistance device, the pneumatic cylinder pulls the seat plate and the back of the seat plate rises in the vertical direction, allowing the user to stand with little force. In addition, when seated, the spring of the pneumatic cylinder is stretched by the user’s weight, and the seat plate is lowered to the original position (Figure 2).

Feasibility test

In this study, the activity of the trunk and lower extremity muscles when standing without using the developed device and when standing with the developed device was analyzed using surface electromyography (EMG) in 10 healthy adults, and the general characteristics of the participants in this study are shown in Table 1.

Surface EMG (Trigno wireless EMG; DELSYS Inc.,
Natick, MA, USA) was used to assess the muscle activity of the trunk and lower extremities when standing. According to the DELSYS guidelines, an EMG sensor was attached to the erector spinae, rectus abdominis, quadriceps femoris, tibia-

lis anterior, and the gastrocnemius muscles and was set to 1,926 HZ using 12 channels of the surface EMG.

The order of the use of the standing assistance device was randomly determined to prevent bias, and each subject performed 3 repetitions of standing for a total of 6 times (Figure 2). A rest-period of at least 10 minutes was provided for each set of standing.

In order to minimize skin resistance, the skin was cleaned at the electrode attachment sites prior to application of the electrodes. All collected data were analyzed using descriptive statistics.

Results

When using the standing assistance device, the activity of the right rectus muscle was 4.4%, the activity of the left quadriceps muscle was 2.1%, and the activity of the right fe-

mur was found to decrease by 16.9%. In addition, the activity of the right anterior tibialis muscle was decreased by 16.3% (Table 2).

Discussion

In this study, a standing assistance device was developed using a pneumatic cylinder that can assist with standing, which is a movement that includes sitting and standing, and the activity of the trunk and lower extremity muscles that appear when standing up was analyzed using the device for 10 healthy adults. The validity of the device was investigated.

As a result, it was found that the activity of the right rectus abdominis, the right and left quadriceps femoris, and right anterior tibialis muscles decreased when standing with the device compared to standing without the device. The decrease in muscle mass that occurs as aging progresses decreases by about 10%-15% every 10 years until the person reaches their 70s, and decreases more rapidly to 25%-40% every 10 years after the 70s age range [11]. In addition, degenerative arthritis of the knee, one of the most common diseases caused by aging, is known to occur in 30% of the elderly [12]. Due to such aging effects, sitting and standing, which requires more muscle strength and movement than walking or climbing stairs, is one of the most difficult movements performed in the daily activities of the elderly [2].

This difficulty in standing can be seen similarly to those with disabilities such as hemiplegia and lower limb paralysis. Various types of assistive devices have been developed to assist with standing for the elderly or the disabled population who have limited standing abilities [6-8]. In order to

| Table 2. Differences in electromyographic muscle activation between non-used and used the developed device (N=10) |
|---|---|---|---|---|---|---|---|---|
| Subjects | Erector spinae (%) | Rectus abdominis (%) | Quadriceps (%) | Tibialis anterior (%) | Gastrocnemius (%) |
| | Lt. | Rt. | Lt. | Rt. | Lt. | Rt. | Lt. | Rt. |
| 1 | 0.90 | 6.93 | 2.74 | 0.45 | 1.80 | 11.63 | 1.80 | 0.45 |
| 2 | 6.40 | 2.79 | 6.95 | 7.05 | 5.43 | 10.64 | 9.76 | 2.57 |
| 3 | -0.49 | -43.86 | 13.88 | 45.69 | -32.78 | -9.57 | 17.19 | 36.62 |
| 4 | -3.71 | -3.76 | 19.60 | -7.48 | -6.75 | -16.86 | 14.11 | -12.31 |
| 5 | 8.81 | 8.29 | 10.10 | 29.00 | 6.53 | 46.39 | 29.25 | -39.31 |
| 6 | 0.17 | 0.60 | 17.04 | 39.38 | -47.83 | -64.40 | 0.19 | -9.54 |
| 7 | -14.26 | -23.79 | 23.66 | 2.58 | -38.57 | 21.72 | 4.29 | -50.00 |
| 8 | -0.57 | 0.49 | -10.76 | 9.42 | -41.10 | -35.72 | -12.33 | -15.85 |
| 9 | -33.03 | 41.78 | -13.67 | -22.33 | 22.39 | 22.70 | 52.70 | 26.41 |
| 10 | 2.54 | 35.53 | 7.55 | -37.69 | -9.68 | -16.75 | -3.85 | 3.27 |

Lt.: left, Rt.: right.
supplement the limitations of existing devices, this study attempted to develop a standing assist device using a pneumatic cylinder, and also investigated the validity of the developed device.

In the device developed in this study, when the user sits on the seat plate of the device and operates the control panel, the pneumatic cylinder pulls the seat plate and the rear of the seat plate rises in the vertical direction. By attaching a camera follower, the front part slides backwards when the rear part of the seat plate rises to assist the vertical elevation of the rear seat plate so that the user can stand up with little force, and even when the user sits on the device, as the attached pneumatic cylinder is pushed back, the angle of the seat plate is reduced so that it can descend downward. Because the device operates only with the power of a pneumatic cylinder, the elderly or a person who is disabled who have difficulty standing due to paralysis, muscle weakness, and degenerative arthritis can use it easily without restrictions on the use of electricity or location, and the price is also cheaper compared to the other device used.

In addition, as a result of examining the feasibility of the developed device, it was found that the activity of the right rectus abdominis, the right and left quadriceps femoris, and right anterior tibialis when standing with the device decreased compared to when standing without using the device. This reduces the use of the rectus abdominis muscle, the quadriceps muscle [4], and the anterior tibialis muscle [16], which are one of the most important muscles used when the development device is standing up. It shows the possibility that it can be used as an assistive device that can assist with the standing movement of the elderly or the disabled population.

However, since this device cannot provide assistance according to the user’s weight or physical disability, it will have to be continuously improved and developed, and the improved and developed device will be compared with other similar devices for differentiation and verification for excellence.

In addition, since the evaluation for the validity of this device was conducted on healthy adults only, it is necessary to continue to investigate for the validity of its use within the elderly population or those who are disabled who have difficulties with standing.

In this study, a standing assist device using a pneumatic cylinder was developed, and as a result of the validity evaluation of the developed device, it was found that the activity of muscles used when standing was decreased. These results show the potential that the device can be used for standing assistance.

However, as many studies have not been conducted yet, in the future, along with the improvement and development of this device, it will be necessary to verify the effectiveness and safety of the device by conducting an evaluation for validity on subjects who have difficulty with standing.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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