A Study on the Force and Center of Gravity of the Transfer-Lift for the Human Stability of Spine Patients

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***Abstract*—People are demanding quality health care as their living standards are improved and the elderly population is increasing. In addition, many people with disabilities and older people want to use good rehabilitation aids. In this study, we developed "patient lift" for human stability. The developed lift has been studied focusing on the user's "power and gravity center" and the result is designed to lead to the stability of the lift. Therefore, all designs have been designed to optimize the driving torque and lift height according to the patient's weight for patient safety. In addition, static stability analysis for the developed lift was conducted. The analysis program was ANSYS, ABACUS. The analytical conditions for the lift are based on the test evaluation method according to ISO 10535. The final designed lift was tested through an internationally accredited laboratory to determine whether the test was appropriate for static safety modeling.**

***Index Terms*—patient lift, human stability, gravity center, ANSYS, ABACUS, ISO 10535**

I. Introduction

More than half a million people worldwide suffer from spinal cord injury each year. The number of patients with spinal cord injuries is rapidly increasing every year due to automobile accidents, falls, and work disasters. The spinal cord delivers signals from the brain to the whole body, which is a phenomenon in which parts of the body are paralyzed as the spinal cord is damaged by an accident or illness. Patients with paraplegia in the lower back are injured and the signal from the brain is not transmitted to the legs. They usually use a patient lift for movement.

In addition, the elderly population is increasing year by year due to improvement of medical technology and health status. The global aging index is expected to reach 82 points in 2050, starting at 26 points in 2005.

* Aging index = elderly population (65 years old or older) / youth population (0 ~ 14 years old) X 100

Even if the patient is not a spinal cord injury, elderly people are also increasingly using patient lifts for movement. However, patient lift users are experiencing more than 100 crashes each year in one country. The causes of the accident are due to the misalignment of the center of gravity of the patient lift.

There are cases where some advanced techniques are used to walk with electric stimulation to paraplegic patients, and there are cases where VR is used for rehabilitation training.

However, most elderly and spinal cord injured patients still wish to use a safe lift.

In this study, we designed the patient lift considering the user convenience by increasing the safety of human body by studying the force and the center of gravity of the transfer patient lift. In addition, the designed lift is designed to conform to the international standard ISO 10535.

The design has a model of overall lift with primary structural design. The secondary design was designed to optimize the driving torque and lift height according to the patient's weight for patient safety. The third design was designed for user's convenience. In addition, the final designed lift was tested through an internationally accredited testing laboratory to determine if the test evaluation based on static safety modeling is appropriate.

II. Materials and Methods

A. Primary Structure Design : Overall Structure

First, the patient transfer device was subjected to joint position analysis for the optimization of the driving torque and the maximum height after a simple primary structure design.

The primary structural design is as follows.

The operating range of the patient transport device was designed to allow patients to move to a wheelchair or bed. Accordingly, the minimum and maximum height of the lift arm are 350 mm and 1,850 mm, respectively. The maximum range in which the wheelchair of various sizes used by the patient can enter the lift is 1,000 mm. In addition, the width of the leg support was set to 550 mm to secure mobility to a door with a small lift, and it was designed to be capable of folding and unfolding in a one-touch manner without using a tool.

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In addition, when the lift is abnormal, a safety device capable of safely lowering the patient by the manual descent device is provided.

The primary structural design is shown in Fig. 1 and Table I.

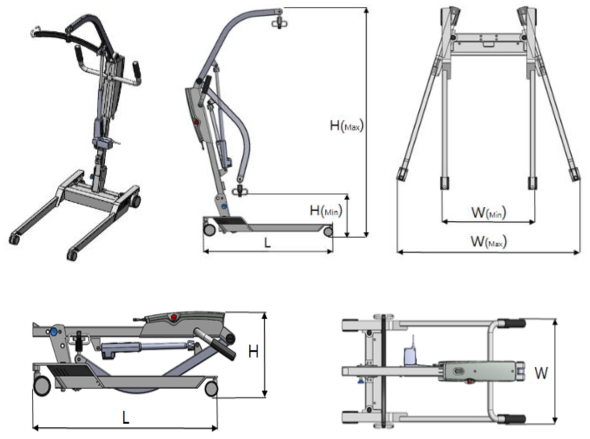


Figure 1. The Drawing of the Unfolding and Folding of the Patient Lift

TABLE I. PATIENT LIFT DESIGN SPECIFICATION

	L	W		H	
		Min	Max	Min	Max
unfold	1,100mm	550mm	1,000mm	350mm	1,860mm
fold	1,100mm	550mm		350mm	

Patient transport lifts are designed to facilitate easy folding and unfolding and storage even in confined spaces. The following is the sequence of how the lift is folded.

1) Lower the lift actuator to the end and press the hanger end groove on the ball plunger bracket attached to the lift column.

2) Remove the lift column ball lock pin, fully fold the lift, and then combine it to secure it in the same position.

3) Keep the lift upright.

Use inverse order to unfold the lift. These three movements made it easy to fold and unfold.

Figure 2. Lifting folding sequence for patient

B. *Secondary Structure Design : Patient Stability*

After the primary structure design, the joint position analysis was performed to optimize the driving torque and the maximum height of the patient feeding device. he analysis program was ANSYS, ABACUS.

The joint position constraints for drive force and maximum height optimization are as follows. The height of D, the part shown in the figure, is set to 1,800 mm or more on the ground. The folding of D is 300mm of the driving part and it should be folded completely when driving. The length of the driving part, B-C, is fixed to the product specification. Accordingly, the designed product can be designed to be smaller than the drive force 5540N of the existing products [1][2].

Also, when designing the product, the influence of the change of the joint position was also predicted. A, which is the center of rotation of the designed product, increases drive force and shortens the upper link toward the + x direction. On the other hand, the rotational center point A of the designed product decreases in the + y direction as the driving force decreases, but the upper link becomes longer, which is advantageous in securing the height of D. Also, the force was reduced by adjusting B and C. D at the patient's position was away from the base and was not safe and exposed to danger such as abalone. Conversely, if D approaches the base, the safety of the user is ensured, but the space occupied by the patient is narrowed. When the B-C connecting line, which is the upper and lower joints of the driving part, is directed in the + x direction, the driving force is reduced but the space for boarding is narrowed [3][4].

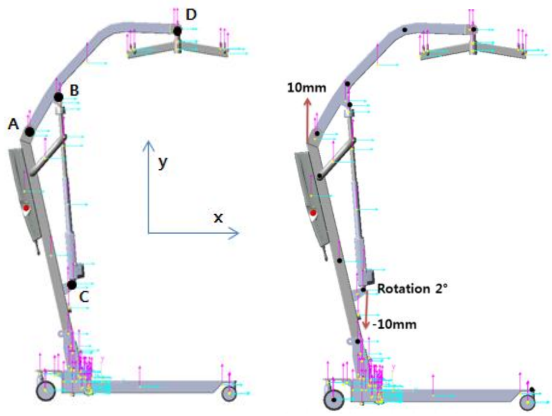


Figure 3. Joint position analysis model for trial 15

TABLE II. POSITION ADJUSTMENT DIMENSIONS PER JOINT

Trial No	A-X	A-Y	BC-X	BC-Y	B-ZROT	C-ZROT
Default	0(mm)	0(mm)	0(mm)	0(mm)	0(°)	0(°)
1	0	0	20	0	0	0
2	0	0	-20	0	0	0
3	0	0	0	20	0	0
4	0	0	0	-20	0	0
5	20	0	0	0	0	0
6	-20	0	0	0	0	0
7	0	20	0	0	0	0
8	0	-20	0	0	0	0
9	0	0	0	0	2	0
10	0	0	0	0	-2	0
11	0	0	0	0	0	2
12	0	0	0	0	0	-2
13	0	20	0	-20	0	2
14	20	20	0	-20	0	2
15	0	10	0	-10	0	2

TABLE III. RESULT OF POSITIONING BY JOINT

Trial No	Max height (D mm)	height gap (D mm)	Max Force (N)	Force gap(N)
Default	1797	0	5538	0
1	1698	-99	5464	-74
2	1893	96	5439	-99
3	1914	117	6190	652
4	1700	-97	5024	-514
5	1874	77	5499	-39
6	1717	-80	5450	-88
7	1722	-75	5152	-386
8	1886	89	6009	471
9	1809	12	5440	-98
10	1785	-12	5636	98
11	1878	81	5229	-309
12	1707	-90	5671	133
13	1712	-85	4600	-938
14	When the lift is folded, the BC line reaches the dead point for point A			
15	1860	63	4904	-634

Table 2 shows the results of modeling changes in design parameters for user safety. A total of 15 simulations were conducted and the 15th design value was set. Although the results of the 14th simulation show better results at load, they show problems at maximum height. The actuator load and displacement for the design values of 15 are shown in Fig. 2 and Fig. 3, respectively.

The patient lift joint position requirements for drive torque and maximum height optimization are:

Case 3 is the most optimized height dimension with a maximum height of 1,914 mm. However, the driving force was 6,190N and exceeded the default value of 5,538N. Case 13 is the most optimal force with a driving force of 4,600N. However, the maximum height of 1,712mm was below the default value of 1,797mm, which was not suitable for the optimization conditions.

As a result, case15 with a maximum height of 1,860mm and a driving force of 4,904N was found to satisfy all the conditions.

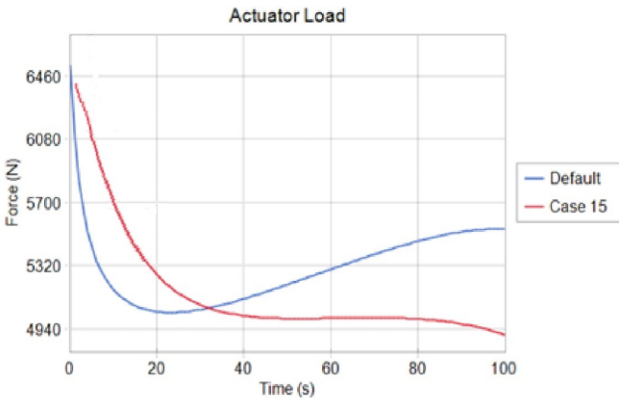


Figure 4. Comparison of default values and actuator force in case 15.

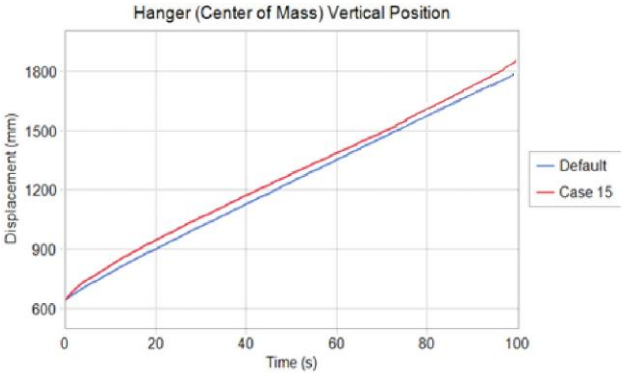


Figure 5. Default value compared to the maximum height of case 15

C. Driving Part Design : Sling and Controller

We proceeded to develop a wrapping cloth type sling to wrap the patient's body. The part of the patient's legs is made of wrinkles with cushioning material, so that it is designed so that there is no discomfort to the legs during lifting [5]. The developed sling was selected nylon material which can reduce the friction force with patient's clothes to the minimum, and it was designed to be easy to wear and detach. In addition, we added a head-support part that can be attached and detached in consideration of the safety of the patient who cannot hold his neck. This supports the patient's neck when lifting, so it can prevent safety accidents such as throat backing. The webbing of the sling that surrounds the body is designed as three contact points, and the strap is designed to slip so that the patient can sit comfortably in accordance with the center of gravity when lifting [6][7].

Figure 6. Design of novel sling interface for patient lifting

The power supply uses a 24 V, 2.9 Ah dc battery, and the charging adapter has an output of dc 36v, 1A. The operating scheme consists of an electric cylinder drive, a led display drive, a battery charge circuit, and an emergency switch drive [8]. The motor in the actuator performs the normal rotation and the reverse rotation operation by the remote controller operation, the lift part of the driving part adjusts the height of the lift, and the spread part controls the width of the lift of the lift. Also, in case of emergency, the power is cut off by the emergency stop switch and all the operation is stopped [9][10].

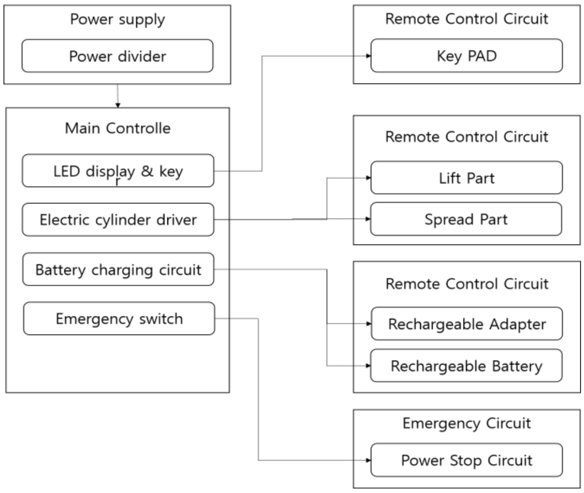


Figure 7. System diagram.

III. RESULTS

A. Test Standard

Static stability analysis for the developed lift was conducted. The analysis program was ANSYS, ABACUS. The analytical conditions for the lift are based on the test evaluation method according to ISO 10535.

The test contents according to ISO 10535 are as follows :

1) When the maximum load (120 kg) is given to the hoist, tilt the test plane gradually and measure the angle at which the hoist reads the equilibrium.

2) The hoist shall not lose balance at 10 ° front and rear, respectively, at the intended travel position.

3) The hoist should not lose balance at 7 ° forwards and backwards in the worst case.

4) The hoist should not lose balance at 5 ° in all directions.

The following are test methods for static stability:

1) The test shall be carried out for the front and rear of the direction of movement in a state in which the frame is in the movement position indicated by the manufacturer and the load is loaded in the most unfavorable position.

2) The test shall be performed for the front and rear when in the opposite direction. If there is a direction other than the intended direction of motion, this direction is regarded as forward.

3) The test shall be performed when the hoist is in the most unfavorable position for the wheel, CSP, base and brake.

4) Load-free state Place the hoist without load on the test surface with the wheel facing the stop fixture

5) Tilt the test plane gradually until the hoist loses equilibrium. Record the angle of tilt.

6) Repeat the test in the rear and side directions.

B. Forward Static Stability Test

The simulation result for this forward stability is shown in Fig. 8. As a result of the test, it can be seen that when the parallel arm which is the most unfavorable position of the lift is horizontal, it is conducted at about 14.6 degrees. Therefore, it was found that the developed lift satisfies the static stability criterion of 10 degrees.

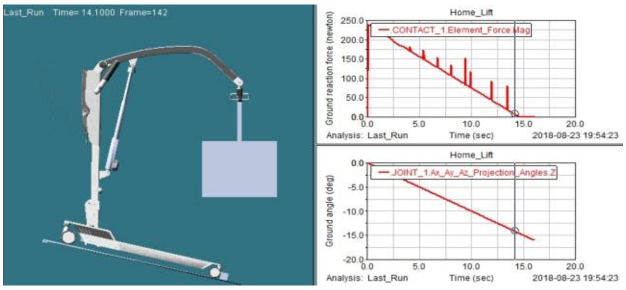


Figure 8. Simulation - Forward static stability test

C. Side Static Stability Test

The simulation results for lateral static stability are shown in Fig. 9. The lateral stability stability simulation was carried out in the same way as the forward stability. As a result of the test, it can be seen that conduction occurs at about 18.7 degrees. Therefore, it was found that the developed lift meets the side 7 degree static stability.

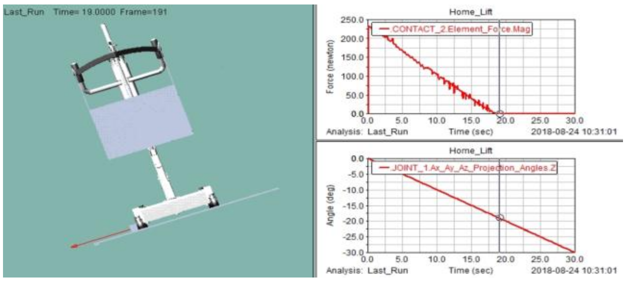
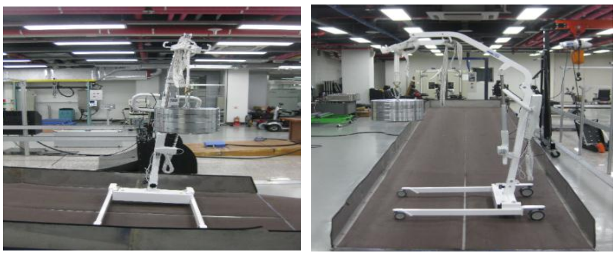


Figure 9. Simulation - Side static stability test

D. Field Test : ISO 10535

We conducted a performance test of the lift developed in accordance with ISO 10535. Fig. 10 shows the static stiffness test for the front, rear and side of the lift. The lift is located on an inclined plane for each direction and is loaded with a maximum load of 1.25 times (150 kg) for 5 minutes in the downward direction of the lift

(a) Forward - 10 ° (b) Backward - 10 °



(c) Side - 5 °

Figure10.Static stiffness test – Forward, Backward, Side

IV. CONCLUSIONS

The following conclusions can be drawn from the results of a patient lift study with improved user stability and convenience. The patient transport lift developed in this study was designed in a compact size to be used not only in a hospital or a nursing facility but also in a small space or a home. In addition, for convenient use, it is convenient to fold, unfold, move, and store one touch. In order to secure the competitiveness of the product, the appearance of the hanger, the handle, the arm, the lift leg, and the cover are designed with stability. We have adopted customized neck support sling for severed patients who can not tie their necks, and applied a high strength fabric with low friction between waterproof and patient clothes. The slid webbing of the three sliding contacts also helps the patient to be lifted to the most stable posture [11][12]. It is possible to safely lift the patient by ensuring the speed limit of the actuator's rise and fall, and developed a controller that applies the power auto off function and the backlash prevention function in standby mode. It is designed to adjust the angle of the legs and lift height automatically by simple remote control operation. We can simulate joint position adjustment using ANSYS, ABACUS analysis program to obtain optimum drive height and propulsion force. The optimum driving height and propulsion force could be expected to improve the patient's comfortable lifting and stability of the product without clinging to the bed or wheelchair [13][14][15][16]. In order to ensure a safe environment for the use of lifts by spinal cord patients and persons with disabilities, a static stability test according to ISO 10535 was performed [17][18]. All designs are designed to meet international standards for lift equipment.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, S. Yuk. And S. Lee; methodology, B. Hong and J. Song; software, B. Hong; validation, I. Hwang; formal analysis, G. Cha; investigation, S. Yuk; resources, S. Yuk; data curation, B. Hong; writing-original draft preparation, S. Yuk; writing-review and editing, S. Lee; visualization, S. Yuk; supervision, S. Yuk; project administration, S. Yuk; funding acquisition, S.Lee.

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