Prototype Development and Evaluation for the Pressure-Relieving System of the Regular Wheelchairs

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***Abstract*—This study was undertaken to investigate the efficiency of pressure decreasing on a prototype electrical controlled tilt-in space pressure-relieving system proposed in this research. The system is designed for seated regular wheelchair users to perform pressure relief. Twelve able-bodies participants in the study, and two ways of measuring was adopted: 1) The tilting angles were continuously varied from 0^0 to 90^0; 2) The serial of 10 postures during the pressure reduction process which are 0^0, 10^0, 20^0, 30^0, 40^0, 50^0, 60^0 , 70^0, 80^0, and 90^0 in posterior direction for non-senior participants (age＜65), and senior participants (age over 65) adopted only 7 postures (0^0 to 60^0).**

The preliminary result shows that: 1) In the ischial tuberosities area, the pressure decreases while the tilting angles increasing; 2) In the ischium-coccyx area, the pressure shows increasing trend while the tilting angles increase from 10^o to 30^o, and then the pressure decreases dramatically at the tilting angles of 40^o and beyond. This is due to some subjects were in slouched postures while the tilting angles were larger than 0^oduring the process; 3) While conducting the pressure relieving process, subject must keep the feet naturally flagging and not put them on the footrests of the wheelchair. The slouched sitting position should be corrected during the pressure relieving process.

Keywords: assistive device, wheelchair, ischial tuberosity, sacrum-coccyx, pressure sore.

I. INTRODUCTION

The pressure sore is the major cause of admissions to hospitals for patients with impaired mobility and sensory functions, and for elderly patients. In Taiwan, the senior citizens (age 65 and over 65) have reached 7% of the total population in 1993, and it became an aging society. In 2005, there were 320 thousand people with physical / psychological disorders at the age 65 and over 65, and these patients were at the high risk of pressure sore crisis.

The most common assisting device for disabled people is wheelchair. It is a mobility assisting device, and it can compensate the mobility for those who don't have it. The wheelchair is designed for disabled person to transport, not to keep the person sitting on it.

In Taiwan, the average age of the long-term disabled senior citizens who use wheelchairs is 75 (years old), and they are not able to do the pressure relieving exercise by themselves in the result of the limbs obstacle (76.4%). Most of the wheelchair users purchase the wheelchairs by the families or by themselves（85.9%）. Only 14.1% has consulted with the professionals[1]. Patients need to be educated on how to use wheelchair properly and on when to seek for the help for the wheelchair maintenance in order to reduce the chance of getting injured by the incorrect wheelchair operations.

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The amount of the regular wheelchair users is over 79% in total wheelchair users. However, there is no pressure relieving feature equipped on the regular wheelchairs. Hence, 22.9% of the users have complications, and 28.1% of the complications are related to pressure sores. In addition, 54% of the pressure sores locate on the ischial tuberosities area, and the worst complication is the septicaemia which is associated with a high mortality rate. Although putting pressure on the body is the major factor for developing the pressure sores, many investigators have contributed to our recognition that the cause for the pressure is multi-factorial. In general, it can be divided as pressure and tissue endurance parts, and age （≧65 yrs）is a factor can affect both parts. This is due to the elderly patients have low sensory/cognition, low mobility, and low tissue endurance[2].

When a patient is in a sitting position, the pressure evolves from the both sides of the ischial tuberosities and ischium-coccyx areas. To aim at the regular wheelchair users to prevent from getting the pressure sores, in general, it can be achieved by doing push-ups, leaning sideways or forward voluntarily. Unfortunately, most of the wheelchair users do not have the ability to perform the pressure relieving exercises on their own because of the recent surgical intervention, medical contraindications, and/or severely decreased upper extremity strength and endurance. Moreover, these activities increase the risk of falling. A normal person will change the sitting position in different time intervals for getting comfortable posture. However, for those disabled or elderly populations who have to sit on the wheelchair for 3 to 10 hours everyday are not able to change the sitting posture on their own. The worse the sitting posture is, the worse the impact on their health[3] .

Although many wheelchairs have build-in pressure-relieving function in the commercial market, the price for this additional function is far beyond the price of the regular wheelchair itself. Therefore, there are limited usages in the general wheelchair users and the health care institutes that already have many regular wheelchairs.

A number of literatures have described the pressure relief interventions by different methods under different conditions[4]-[9]. However, there is no device designed for the regular wheelchair users to have pressure relief intervention. To counter this problem, we have developed an electrical controlled tilt-in space pressure-relieving system which is designed for the regular wheelchair users, shown in Fig.1 and Fig.2. No adjustments or modifications to the regular wheelchair are needed to connect with the proposed system. The purposes of the current study are： 1) To determine what is the best sitting posture for the significant pressure reduction while repositioning; 2) To evaluate the characteristics of the pressure-relieving system in different tilting angles by a pilot testing for the pressure distribution on the ischial tuberosities of the seated subjects.

II. EQUIPMENTS AND METHODS

As the system is titling in posterior direction, the seated body weight （W） will separate as two component weights ：

1. the vertical weight（W_2）. The pressure is this weight divided by exerted area, and it will decrease as the tilt angle a_1 increasing. Therefore, the pressure relief purpose can be achieved by this simple theory.

$$W_2 = W \sin(90^0 - a_1) \tag{1}$$

2. the second component weight will exert along the chair back, as a shear force. This shear force has no influence on the buttocks pressure.

The system design and the prototype

The design principal of the system is 1. No adjustment or modification of regular wheelchair is needed to connect with the proposed system. 2. There must be no safety concern while system is operating. 3.The system can reduce the working load of caregivers and the system operation have to simple and easy to learn。The components of prototype system and their functions show as Fig. 1。

Subjects

Twelve male volunteers with able-bodies participated in the study. Six subjects are elderly (≥65years). The mean age was 80±3.16 years. The mean sitting body weight was 35.2±7.20kg, mean height 166±9.77 cm. There were six subjects, 3 males and 3 females, under 65years. The mean age was 31.3±9.35 years. The mean sitting body weight was 43.5±9.55kg, mean height 166±9.71cm.

The experimental equipment

The prototype electrical controlled tilt-in space pressure-relieving system is shown in Fig.1 and Fig.2. The wheelchair is regular type (Model : WCFF1802S-PU/1, Kang Fu Trading Co., Ltd., Taiwan). Pressures were recorded by RS Scan F-Scan pressure plate system: 1. F-scan USB plate (pressure sensor plate 0.5(L)×0.4(W)×0.008(H)m with a 64×64 senor matrix), Fig.3; 2. Interface box, Fig.3; 3. F-scan analysis software, Fig.3. The pressure plate measured the pressure distribution from the ischial tuberosities and ischium-coccyx areas at the body-seat interface. Each measuring area is 3.07 cm × 3.07 cm (5 senors×5sensors). A hard wood plate is placed between the pressure plate and wheelchair soft-plastic seat to prevent sling or hammock effect and can protect the pressure plate. The integration of the prototype system and F-Scan pressuring system is shown in Fig. 4.

Pre-Test

A pre-test took place before the experiment, and there are two purposes of it:

A. To set up the experimental conditions （the standard seating position and others）：
   1. The subject must keep the feet naturally flagging and not put them on the footrests of the wheelchair while the pressure-relieving process is taking place. If the subject put their feet on the footrests, part of low limbs weight will shift to buttock and results in pressure increasing, shown as Fig. 5(a) and (c). On the other hand, as the subject keeps the feet naturally flagging, the low limb weight is even distribution on thigh and buttock areas and results in pressure decreasing, shown as Fig. 5(b) and (d).
   2. The subject places their head and trunk against the long backrest of the prototype system, and then the part of body weight can shift to back, shown as Fig. 6(a) and (c).The pretest result shows the pressure on ischial tuberosities and ischium-coccyx areas can have almost three times difference between these two head positions, shown as Fig. 6.

B. To ensure/verify the system pressure-relieving function and the limitation of tilting angle.
   1.The pressure measuring adopted the successive non-stop tilting from 0° to 90°. By this way we can ensure that the pressure on three measuring areas cohere with eq.(1) prediction, the weight shafting effect increasing as tilt angle increasing in posterior direction .
   2. The limitation of system tilt in posterior direction.

According eq.(1), it predicts that the more tile angle adopts, the more weight shafts, and this results in the pressure decreasing on three measuring areas. Due to the physiology difference in each patient, we need to do a check-and-balance between the tilting angles/reduced pressure and how much the bodies can take. After experimenting with several senior patients, it was noticed that the patients started experiencing some dizziness and discomfort as the tilting angles reached 60^{o} or more. The degree of sixty becomes a threshold angle in this research project. It is highly recommended to pay close attention to the reactions from the patients as approaching/over the threshold degree. From the non-senior patients, the research was able to gather the pressure variance data for all tilting angles (0^{o} to 90^{o}). We only gathered the data from the senior patients to the 60^{o}.

The experiment

All measurement took place while the subjects sat on wheelchair at rest (tilt angle 0°) in a standard seating position. In each posture (different tilt angles), the seating pressure was calculated by averaging four readings over two minutes (2sec/4 readings). The experiment procedures are （A）Subject personal information registration and the experiment process exposition;（B）Proceed with all tilting angles - For non-senior patients, the angles are 0^{o}, 10^{o}, 20^{o}, 30^{o}, 40^{o}, 50^{o}, 60^{o}, 70^{o}, 80^{o} and 90^{o}. The patients remain at every angle for eight seconds for data gathering. For senior patients, we only measured the pressures for seven angles, i.e. 0^{o}, 10^{o}, 20^{o}, 30^{o}, 40^{o}, 50^{o} and 60^{o}.

III. RESULTS AND DISCUSSIONS

The reduced seated pressure (ΔP) is derived by the pressures lessened at all other tilt angles comparing to the pressures at the neutral position 0^0 (P_0) as the reference the point at both the right and left ischial tuberosity, and sacrum-coccyx. The percentage of the reduced seating pressure is: ($\overline{P}$)

$$\overline{P} = \left(\frac{\Delta P}{P_0}\right) \times 100\% \tag{2}$$

For the three measuring areas of the non-senior subjects, Fig. 7 and Fig. 8 display the average pressure and the average percentage of the reduced pressure at the different tilt angles. Fig. 9 and Fig. 10 display the same information for the senior subjects.

Fig. 8 shows the percentage of the reduced pressures for the non-senior subjects. On sacrum-coccyx, it increases with the angles increasing. However, shown as Fig. 10, it goes up for the senior subjects from 10^0-30^0 degrees but comes down dramatically when the system angles are more than 30^0. This is because the four out of the six senior subjects were used to sitting in the wheelchairs in the 'slouched' posture. The seated posture determines how/where the pressure points distributed [10] and the reduced pressure is minimized for the four senior-subjects with the slouched sitting posture.The impact did not show when the system was in the 0^0. Once the system has tilt angle in posterior, the subjects' bodies start to 'sank'. They slipped forward until they were sitting on their sacrum-coccyx. The pressure shows its peak at tilt angle 20^0. The trend lasts until 30^0. After 30^0, the subjects slipped toward the back of the wheelchair, so the angle of the pelvis was regained. After 30^0, the effect of the slouched posture weakened, it no longer has visible impact on the reduced pressure. The slouched posture was not observed in the non-senior subjects group.

IV. CONCLUSIONS

This research provides the design concept of the prototype regular wheelchair tilt-in space pressure-relieving system and completes the structure of the system. Twelve able-bodies participated this experiment. According to the analysis from the measuring data, we have following conclusions: 1) In the ischial tuberosities area, the pressure decreases while the tilting angles increasing; 2) In the ischium-coccyx area, the pressure shows increasing trend while the tilting angles increase from 10^o to 30^o, and then the pressure decreases dramatically at the tilting angles of 40^o and beyond. This is due to some subjects were in slouched postures while the tilting angles were larger than 0^oduring the process;3) While conducting the pressure relieving process, subject must keep the feet naturally flagging and not put them on the footrests of the wheelchair. The slouched sitting position should be corrected during the pressure relieving process.

Further study for the system must be done to assess how the tilting angles affect users physiologically and psychologically, and to organize the system's standard operation procedure including a full-scale and statistical significance research for the care givers as well as the subjects. The subject should be included in the further study also

REFERENCES

[1] Ming-Hsia Hu,Chih-Ching Hsieh,Rong-Ju Cherng,Sheue-Yuh Wu,Ying-Tai Wu, Wheelchair Usage and Checkout Survey of Long-term Disabled Clients. Formosan Journal of Physical Therapy, 2006. **31**(2): p. 98-111.

[2] L.F. Chao,Hsueh-Erh Liu, *Introduction the Relevant Dangerous Factors of Bed Sore and the Predicting Scale of Assessment.* Chang Gung Nursing, 1994. **5**(2): p. 35-43.

[3] Mayall, J.K. and G. Desharnais, Positioning in a Wheelchair：A Guide for Professional Caregivers of the Disabled Adult. Second ed., 1995: SLACK Incorporated.

[4] Douglas A. Hobson, Principles of Pressure Management. 1999, Department of Rehabilitation Science and Technology University of Pittsburgh. p. 32.

[5] Rachid Aissaoui,Michèle Lacoste,Jean Dansereau, Analysis of Sliding and Pressure Distribution During a Repositioning of Persons in a Simulator Chair. IEEE Transactions On Neural Systems And Rehabilitation Engineering, 2001. 9(2): p. 215-224.

[6] Zoras L., Manual tilt - Clinical applications, in Proc. 10th Canadian Seating Mobility Conf. 1995: Toronto, ON, Canada. p. 86-88.

[7] Douglas A. Hobson, Comparative effects of posture on pressure and shear at the body-seat interface. Journal of Rehabilitation Research and Development, 1992 29(4): p. 21-31.

[8] Henderson J. L.,Price S. H.,Brandstater M. E.,Mandac B. R., Efficacy of three measures to relieve pressure in seated persons with spinal cord injury. Archives of physical medicine and rehabilitation, 1994. 75: p. 535-539.

[9] D.C.M. Spijkerman,T. Terburg,R.H.M. Goossens,T. Stijnen, Effects of inflation pressure and posture on the body-seat interface pressure of spinal cord injured patients seated on an air-filled wheelchair cushion. Journal of Rehabilitation Sciences, 1995. 8: p. 8-12.

[10] KOO T. K. K.,MAK A. F. T.,LEE Y. L., Posture effect on seating interface biomechanics: Comparison between two seating cushions. Archives of Physical Medicine and Rehabilitation, 1996. 77(1): p. 40-47.

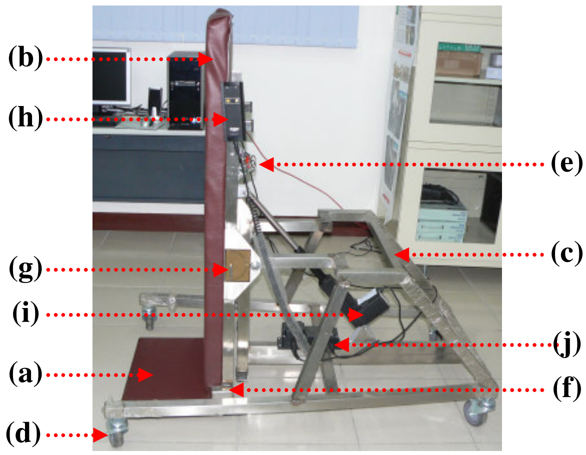

Fig. 1. The components of the prototype electrical controlled tilt-in space pressure-relieving system: (a)Basal support cushion, (b)Dorsal cushion, (c)Brace, (d)Wheels, (e)The bolts for fixing the wheelchair handles, (f)The casings for fixing the wheelchair tipping levers, (g)Angle indicator, (h)Controller, (i)System tilting servo, (j)Electrical motor.

Fig. 2. The prototype electrical controlled tilt-in space pressure-relieving system with regular wheelchair user.

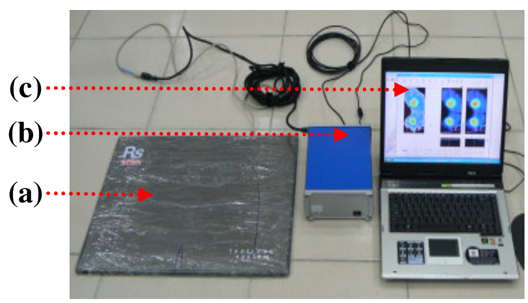

Fig. 3. RS Scan F-Scan pressure plate system: (a)F-scan USB plate, (b)Interface box, (c)F-scan analysis software

Fig. 4. The integration of experiment system. The wheelchair, the prototype electrical controlled tilt-in space pressure-relieving system, and RS Scan F-Scan pressure measuring system: (a) F-scan USB plate,(b)Interface box, (c)F-scan analysis software, (d)pressure-relieving system of the regular wheelchairs

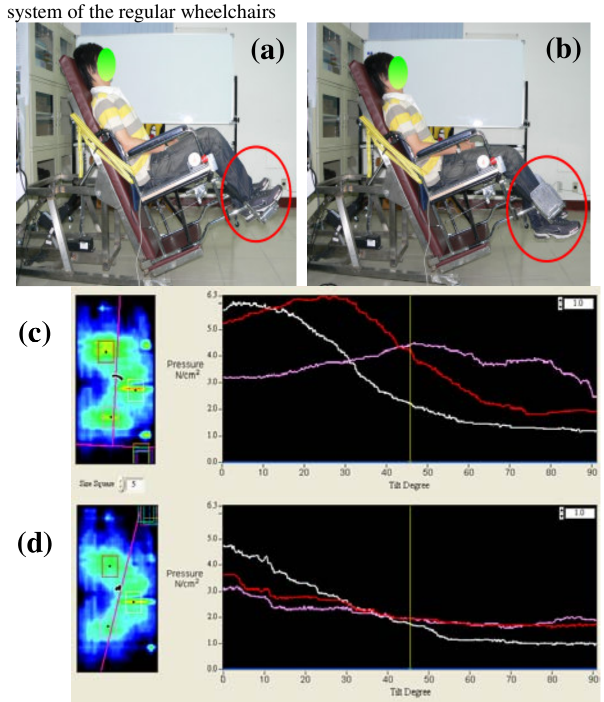

Fig. 5. Position of the feet will influence the seated pressure: (a)the subject put his feet on the footrests, (b)the subject keeps the feet naturally flagging, (c)the pressure curves of the subject in (a), (d)the pressure curves of the subject in (b) (All the pressure curves in right ischial tuberosity (red)，left ischial tuberosity (pink) and ischium-coccyx areas (white) as the tilt angles change continuously.)

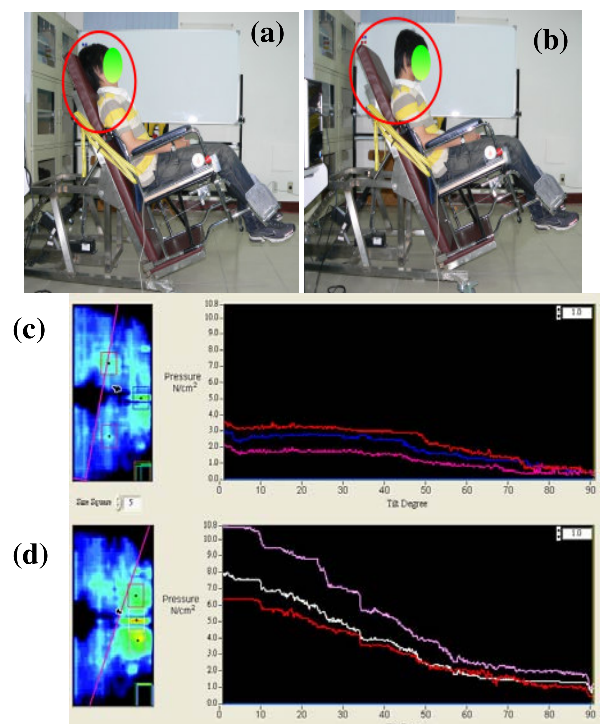

Fig. 6. Position of the head will influce the seated pressure: (a)the subject places his head and trunk against the long backrest, (b)the subject doesn't places his head and trunk against the long backrest, (c)the pressure curves of the subject in (a) (The pressure curves in right ischial tuberosity (red)，left ischial tuberosity (pink) and ischium-coccyx areas (blue) as the tilt angles change continuously.), (d)the pressure curves of the subject in (b) (The pressure curves in right ischial tuberosity (red)，left ischial tuberosity

(pink) and ischium-coccyx areas (white) as the tilt angles change continuously.)

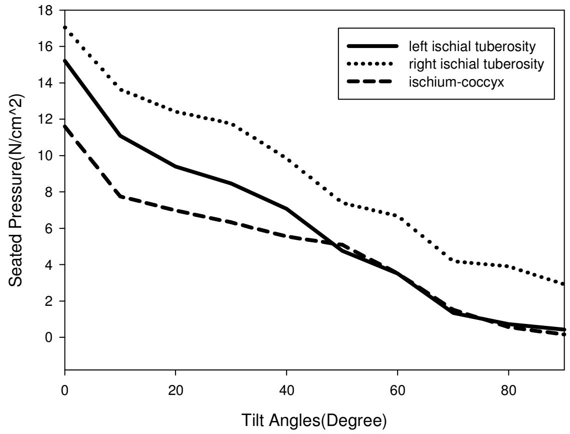

Fig. 7. The seated pressure curves on ischial tuberosities and ischium-coccyx areas v.s. tilt angles of **non-senior subjects**.

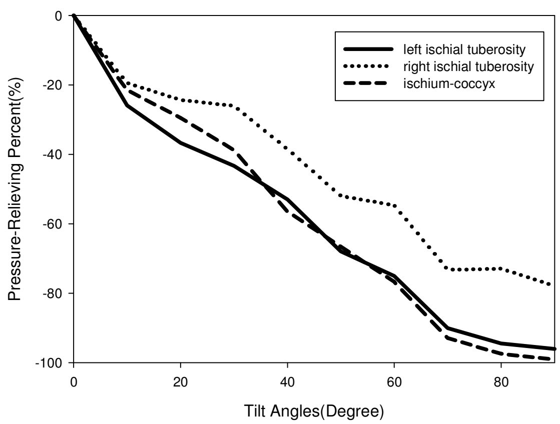

Fig. 8. The pressure-relieving percent curves on ischial tuberosities and ischium-coccyx areas v.s. tilt angles of **non-senior subjects**.

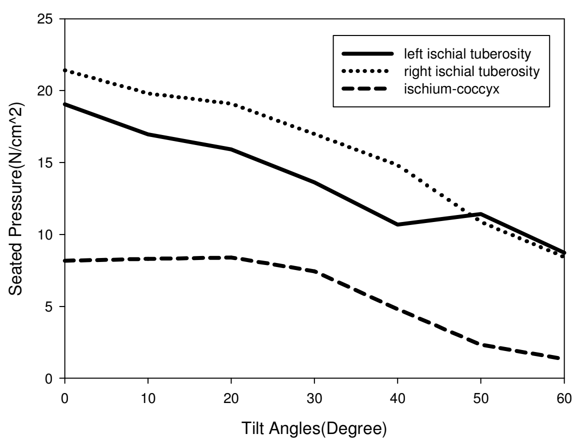

Fig. 9. The seated pressure curves on ischial tuberosities and ischium-coccyx areas v.s. tilt angles of **senior subjects**.

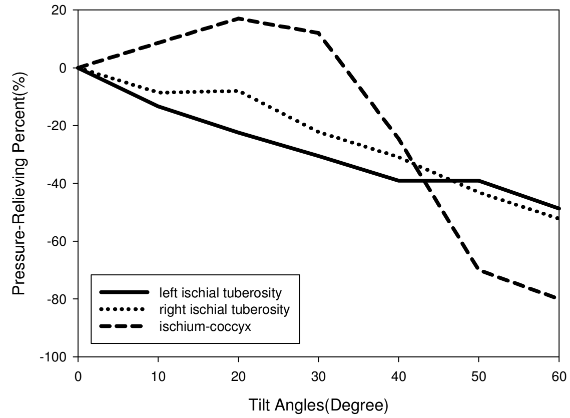

Fig. 10. The pressure-relieving percent curves in ischial tuberosities and ischium-coccyx areas v.s. tilt angles of **senior subjects**.