The effect of a newly developed wheelchair with thoracic and pelvic support on cervical movement and muscle activity in healthy elderly women

Noriko Sawada[1], MS
Tatsuo Hatta[2]*, PhD
Hirotoshi Kishigami[2], PhD
Maiko Shimizu[1]
Taichi Yoda[1]
Hiroshi Goda[1]

[1] Graduate School of Health Sciences, Hokkaido University
Kita-12, Nishi-5, Kita-ku, Sapporo 060-0812, Japan
[2]Faculty of Health Sciences, Hokkaido University
Kita-12, Nishi-5, Kita-ku, Sapporo 060-0812, Japan

***Corresponding author:**
Tatsuo Hatta
Faculty of Health Sciences, Hokkaido University
Kita-12, Nishi-5, Kita-ku, Sapporo 060-0812, Japan
Tel: +81-01-706-3335
Email: thatta@hs.hokudai.ac.jp

Word count: 2330/2500 words

Abstract

Background: As the population ages, the number of elderly individuals using a wheelchair is increasing. A standard wheelchair with a vertical backrest (S-WC) pushes on a kyphotic spine and exacerbates forward head posture. Forward head posture limits cervical movement. We used a new wheelchair (N-WC) that does not exacerbate thoracic kyphosis. The N-WC does not have a flat backrest, but has a support belt for the thorax and pelvis. The purpose of this study was to compare head-neck angle, cervical range of motion, and cervical muscle activity in the N-WC and the S-WC in healthy elderly women.

Methods: We measured head-neck alignment, trunk tilt angle, cervical muscle activity, and pressure distribution on the backrest. Data from 17 subjects were analyzed.

Results: Head-neck angle was close to neutral in the N-WC. The trunk was tilted further back and the area over which pressure was distributed on the backrest was expanded in the N-WC. Cervical range of motion and cervical muscle activity during neck extension were significantly greater in the N-WC than in the S-WC, but during neck flexion there was no significant difference between the wheelchairs.

Conclusion: In the N-WC, head-neck alignment was close to the neutral posture because the wheelchair support belt accommodated kyphosis and did not push the spine forward, so cervical muscle activity may be reduced when at rest. These results suggest that the N-WC prevented forward head posture and improved cervical movement and muscle activity.

Key words: wheelchair, aged, forward head posture, head-neck alignment, cervical muscle, electromyography.

As the population ages, the number of elderly individuals using a wheelchair is growing, and it is expected to continue to increase in the future. Wheelchair use affects work performance and social participation, and is an important tool for disabled people to improve their quality of life.

It is necessary to consider the effects of age-related changes in posture on sitting posture in a wheelchair. Several studies have reported a need for pelvic support during wheelchair use [1-4], but few studies have focused on the effect of thoracic kyphosis on sitting posture in a wheelchair in elderly individuals. When sitting in a wheelchair, the thoracic spine is in contact with the surface of the backrest and thoracic kyphosis affects the force exerted on the backrest. A standard wheelchair (S-WC) has a vertical and flat backrest that does not fit the rounded form of the thoracic spine. Because the flexibility of the spine decreases with age [5], the spine is pushed forward by the horizontal force exerted by the backrest. This may increase forward head posture (FHP). FHP is one of the most common postural problems in elderly individuals and results in the head being positioned anterior to the trunk [6, 7]. Cervical range of motion (ROM) is limited by FHP [8-10], and this reduces the postural activity of the cervical neck muscles [11, 12].

In this study we used a newly developed wheelchair (N-WC) that has been designed to accommodate the spine shape that is common to elderly individuals, including spine deformations and reduced flexibility. The purpose of this study was to determine if head-neck alignment, cervical muscle activity, and cervical ROM differed between the N-WC and the S-WC. Subjects were healthy elderly women who exhibited a mild kyphosis and could safely perform the experiment.

Material and Methods

The S-WC and N-WC

The S-WC was the Nissin NA-400 (Nissin Medical Industries Co., Ltd., Kitanagoya, Japan). This wheelchair is shown in Figure 1(a). It is similar to the N-WC, but it has a vertical, flat backrest. The majority of wheelchairs in use have this type of structure.

[Insert Figure 1 here]

The N-WC was the ZAOU wheelchair (Nissin NA-501, Nissin Medical Industries Co., Ltd.), which has been commercially available since 2011. This wheelchair is shown in Figure 1(b). The N-WC was created using the seating theory proposed by Nishimura [13]. The N-WC was created with the goal of minimizing the activity of antigravity muscles when the user is in a sitting posture with adequate head-neck alignment. Adequate head-neck alignment makes movement easier and requires less muscle activity by minimizing the cervical moment arm. In the N-WC, the center of gravity is positioned differently relative to the thoracic and pelvic regions.

The N-WC includes one pelvic support belt and two thoracic support belts, shown in Figure 1(c). The pelvic support belt has a hook and Velcro loop fastener and can be set at one of several pelvic angles. The upper end of the pelvic support belt was set to support the iliac crest, and the back was set to support L4-L5. Thus, the pelvic support belt was set to support the pelvis from the side and the back, and was set to support a pelvic angle of 15–19°.

The thoracic support cross belt was set to support the lower thorax and the thoracic support straight belt was set to support the upper thorax, as is standard. The intersection of the cross belt was positioned approximately 1 inch above the pelvic support belt. The lower thoracic support angle was set to 30–35°. The function of the thoracic straight belt was to provide relaxation and not to inhibit movement. The height of the thoracic straight support was set so that the patient could sit and relax comfortably, and the tension in the belt prevented the frame of the wheelchair pressing into the spine or the armpits.

Participants

Nineteen healthy elderly women over the age of 65 years participated in this study. Participants were recruited though the Sapporo Silver Human Resources Center. Potential participants were screened and included in the study if they could be safely transferred into a wheelchair. Participants were excluded if they had scoliosis or any disability that affected cervical ROM, the maintenance of sitting posture, or prevented them from sitting safely in a wheelchair. This study was approved by the Hokkaido University Health Sciences Research Institute Ethics Committee and informed consent was obtained from each participant.

Postural Measurement

Rand markers were placed over the left lateral orbital margin, tragus, lateral condyle, and C7 spinous process. A skin reference marker was placed on the skirt of the wheelchair at the projected location of the left trochanter. The location of each marker was recorded and automatically digitized using DARTFISH software (Dartfish Co., Ltd., Lausanne, Switzerland). Head angle was defined as the angle between the vertical and the line through the tragus and the lateral orbital margin, and neck angle was defined as the angle between the vertical and the line through the C7 spinous process and the tragus [8,14-16]. Trunk tilt angle was defined as the angle between the vertical and the line joining the trochanter and C7.

Electromyography (EMG)

EMG was measured from the cervical erector spinae muscle (CES) and the sternocleidomastoid muscle (SCM) using surface electrodes (Biometrics Ltd., Newport, UK). EMG signals were digitally recorded using an A/D converter board with a 16-bit dynamic resolution and a sampling frequency of 1 kHz and were filtered using a Butterworth filter at 20–500 Hz.

The root mean square EMG amplitude (RMS) was calculated at rest and during flexion or extension of the neck. RMS was normalized to the resting RMS [16-19]. The standard is to normalize EMG to the value recorded during a maximum voluntary contraction. However, these measurements are laborious and depend on the participant’s ability to perform maximal contractions. Maximal voluntary contractions are particularly difficult for elderly individuals, especially maximal contractions of the cervical muscles [18,19]. Limited thoracic flexibility prevents many elderly individuals from performing true maximal voluntary contractions of the cervical muscles in a prone position [5,19]. Therefore, in this study, we did not normalize EMG to maximal voluntary contractions.

Pressure Distribution

The distribution of pressure on the backrest of the wheelchair was measured using force-sensing arrays (Vista Medical Ltd., Winnipeg, Canada) in a 43 × 43 cm flexible pressure mat and the measured pressure range was 0–200 mmHg. The mat was placed on the center of the backrest and pressure was measured for approximately 30 s after the sitting posture had stabilized. The area over which active pressure sensors were distributed was defined as the sensing area. Sensing area, average pressure, and the location of the center of pressure were determined for each participant in each wheelchair.

Procedure

Participants sat on the wheelchair so that their buttocks were in contact with the back of the seat surface and they leaned fully against the backrest. They placed their hands on their thighs and flexed their knees at 90°. The wheelchair footrests were removed, and if the soles of the feet did not contact the ground, the gap was compensated using boards. The line of vision was fixed horizontally.

Participants performed three neck extension trials followed by three neck flexion trials. In each trial, participants maintained a relaxed sitting posture for 5 s (Phase 1). They then extended or flexed their neck to the end of the ROM (end-ROM) over 5 s (Phase 2), stayed in the end position for 5 s (Phase 3), and returned to the starting position over 5 s (Phase 4). The order of wheelchair use was randomly assigned.

Resting head angle and resting neck angle were defined as the average angle in Phase 1. Flexion head angle and flexion neck angle were defined as the average angle in Phase 3 of the flexion trials. Extension head angle and extension neck angle were defined as the average angle in Phase 3 of the neck extension trials. All measures were averaged over the three trials.

Participants practiced the movement repeatedly to ensure that the trunk did not compensate for cervical movement.

Analysis

Resting head angle, resting neck angle, and normalized RMS for CES and SCM were compared between two wheelchairs. The sensing area, the mean pressure in the sensing area, and the location of the center of pressure were compared between the two wheelchairs. All comparisons were made using the Wilcoxon signed rank test and were considered significant at $p < .05$. All analyses were performed using IBM SPSS statistics version 22.0 (Armonk, NY, USA). Data are expressed as mean ± standard deviation.

Results

A total of 19 subjects participated in this study. In the first two subjects there was interference between EMG and force-sensing arrays. For subsequent subjects we changed the arrangement of the equipment to prevent interference. Therefore, data without interference were available for 17 subjects. Data from 17 participants were included in the analysis. The age, height, and weight of the participants were 69.9 ± 3.49 years, 150.7 ± 4.77 cm, and 53.8 ± 8.07 kg, respectively.

[Insert Table 1 here]

Resting head angle, resting neck angle, and trunk tilt angle are shown in Table 1. Resting head angle and resting neck angle were smaller in the N-WC than in the S-WC (p = .039 and .001, respectively; Table 1). Head and neck angle were close to the neutral position in the N-WC. Trunk tilt angle was greater in the N-WC than in the S-WC ($p < .001$; Table 1), indicating that the trunk was tilted further backward in the N-WC (Fig. 2).

[Insert Figure 2 here]

The area of the backrest over which pressure was distributed (sensing area) was 446.83 ± 130.23

cm^2 in the S-WC and 698.55 ± 209.13 cm^2 in N-WC. This area was significantly larger in the N-WC than in the S-WC. The average pressure in the sensing area was 6.91 ± 2.08 mmHg in the N-WC and 7.75 ± 2.61 mmHg in the S-WC, and was not significantly different between the two wheelchairs. The center of pressure had a similar horizontal location in the two wheelchairs, but was 4.72 ± 3.83 cm lower in the N-WC than in the S-WC ($p = .003$).

In Phase 3 of the neck extension trials, the head and neck extension angles were smaller in the N-WC than in the S-WC ($p = .015$ and .001, respectively) and the normalized RMS of CES was higher in the N-WC than in the S-WC ($p = .006$). However, there was no significant difference in the normalized RMS of SCM. In Phase 3 of the neck flexion trials, head and neck flexion angles and CES and SCM were similar in the two wheelchairs.

Discussion

The purpose of this study was to compare head-neck alignment, neck movement, and neck muscle activity when sitting in the N-WC compared to the S-WC. Head and neck angle at rest were lower in the N-WC than in the S-WC. Head-neck alignment was close to neutral in the N-WC, whereas the head was positioned anteriorly the trunk in the S-WC. FHP increases with age [20,21] and is higher in elderly than in young individuals [20-23]. FHP causes the posterior neck muscles to shorten, increases the load on the joints and ligaments, and weakens the muscles [6,24]. Eliminating FHP reduces the load on the neck. FHP is also associated with neck pain [8,25-27], and eliminating FHP may help to prevent neck pain.

We examined the characteristics of the N-WC that diminished FHP. First, we examined the effect of thoracic and pelvic support on the trunk tilt angle and the pressure on the backrest in the N-WC. Trunk tilt angle was larger in the N-WC than in the S-WC, and the area of the backrest over which pressure was distributed was larger. There was no significant difference between the two wheelchairs in the average pressure exerted in the sensing area. We consider this to reflect the fact that the pressure on the backrest was dispersed over a larger area in the N-WC. Second, we examined the effect of the N-WC on trunk tilt angle and head-neck alignment. Trunk tilt angle was greater and the trunk was tilted further backward in the N-WC than in the S-WC. The center of gravity of the trunk shifted backward and was located lower on the backrest in the N-WC than in the S-WC. Thus, the position of the head's center of gravity was directly above the trunk. This minimized the cervical moment arm, bringing the head-neck alignment closer to the neutral posture, and may eliminate FHP.

We examined differences in cervical movement. The maximal neck extension angle was lower in the N-WC than in the S-WC and the cervical ROM was larger, likely because the cervical moment arm was lower. Previous studies have reported that cervical ROM decreases as FHP increases [20,28], and that cervical ROM is lower in FHP than in a neutral posture [9,14,20]. CES activity was higher in the N-WC than in the S-WC. Previous studies have reported that neck muscle activity is lower in a neutral posture than in FHP [14,24] and that cervical muscle activity at rest is greater in elderly individuals than in young people [14,18,30]. Elderly individuals tend to have more FHP than younger individuals, and CES activity at rest may also be higher in the elderly. CES activity at rest was lower in the N-WC than in the S-WC because head-neck alignment was near the neutral posture.

The results of this study suggest that the N-WC was effective at eliminating FHP and affected cervical movement. These results need to be confirmed in elderly individuals who have noticeable muscle weakness or a high level of thoracic kyphosis. In this study, we verified the immediate effect of the N-WC. In future studies, we aim to demonstrate the effects of prolonged sitting and change over time or pain/comfort/quality of life evaluation.

Acknowledgements: No funding was received for this study.

Conflict of Interest: The authors have no conflicts of interest to declare.

References

1. Morl F, Ingo Bradl. Lumber posture and muscular activity while sitting during office work. Journal of Electromyography and Kinesiology 2013; 23:362-8

2. Horton SJ, Johnson GM, Skinner MA. Changes in head and neck posture using an office chair with and without lumber roll support. Spine 2009; 35(12): E542-8

3. Lin F, Parthasarathy S, Taylor SJ, Pucci D, Hendrix RW, Makhsous M. Effect of different sitting postures on lung capacity, expiratory flow, and lumber lordosis. Arch Phys Med Rehabil 2006; 87:504-9

4. Carcone SM, Keir PJ. Effects of backrest design on biomechanics and comfort during seated work. Appl Ergon. 2007; 38:755-64

5. Hinman MR. Comparison of thoracic kyphosis and postural stiffness in younger and older women. The Spine Journal 2004; 4:413-7

6. Nam SH, Son SM, Kwon JW, Lee NK. The intra- and inter-rater reliabilities of the forward head posture assessment of normal healthy subjects. Journal of Physical Therapy Science 2013; 25:737-9

7. Grimmer-Somers K, Milanse S, Louw Q. Measurement of cervical posture in sagittal plane. J Manipulative Physiol Ther 208; 31:509-17

8. Lau KT, Cheug KY, Chan KB, Chan MH, Chiu TT. Relationships between sagittal postures of thoracic and cervical spine, presence of neck pain, neck pain severity and disability. Manual Therapy 2010; 15:457-62

9. Walmsley RP, Kimber P, Culham E. The effect of initial head position on active cervical axial rotation range of motion in two age population. Spine (Phila Pa 1976). 1996; 21(21): 2435-42

10. Friebert IM, Roach KE, Yang SS, Dierking LD, Hart FE. Cervical range of motion and strength during resting and neutral head postures in healthy young adults. Journal of Back and Musculoskeletal Rehabilitation 1999; 12:165-78

11. Szeto GP, Straker LM, O’Sullivan PB. A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work-1: neck and shoulder muscle recruitment patterns. Manual Therapy 2005; 10(4): 270-80

12. McLean L. The effect of postural correction on muscle activation amplitudes recorded from the cervicobrachial region. Journal of Electromyography and Kinesiology 2005; 15:527-35

13. Shigeo N. Science of the wheelchair and humans. Description of thorax support model in active balance seating. The Hokkaido Journal of Occupational Therapy 2013; 30(1): 21-31 [In Japanese]

14. Hsiao LP, Cho CY. The effect of aging on muscle activation and postural control pattern for young and older computer users. Appl Ergon 2012; 43:926-32

15. Yang JF, Cho CY. Comparison of posture and muscle control pattern between meal and female computer users with musculoskeletal symptoms. Appl Ergon 2012; 43:785-91

16. Straker L, Burgess-Limerick R, Pollock C, Murray K, Netto K, Coleman J, et al. The impact of computer display height and desk designs on 3D posture during information technology work by young adults. Journal of Electromyography and Kinesiology 2008; 18(2):336-49

17. Gomes M, Reis JG, Neves TM, Neves TM, Petrella M, Aberu D. Impact of aging on balance and pattern of muscle activation in elderly women from different age group. International Journal of Gerontology 2013; 7:106-11

18. Laughton A, Slavin M, Katdare K, Nolan L, Bean JF, Kerrigan DC, et al. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. Gait and Posture 2003; 18:101-8

19. Soderberg GL, Knutson LM. A guide for use and interpretation of kinesiologic electromyographic data. Phys Ther 2000; 80:485-98

20. Quek J, Pua YH, Clark RA, Bryant AL. Effect of thoracic kyphosis and forward head posture on cervical range of motion in older adults. Manual Therapy 2013; 18:65-71

21. Nemmers TM, Miller JW, Hartman MD. Variability of the forward head posture in healthy community-dwelling older women. Journal of Geriatric Physical Therapy 2009; 32:10-4

22. Kuo YL, Tully EA, Galea MP. Video analysis of sagittal spinal posture in healthy young and older adults. J Manipulative Physiol Ther 2009; March/April:210-5

23. Boyle J, Milne N, Singer KP. Influence of age on cervicothoracic spinal curvature: An ex vivo radiographic survey. Clinical Biomechanics 2002; 17:361-7

24. Caneiro JP, O’Sullivan P, Burnett A, Barach A, O’Neil D,Tveit O, et al. The influence of different sitting postures on head/neck posture and muscle activity. Manual Therapy 2010; 15:54-60

25. Yip CH, Chiu TT, Poon AT, Poon TK. The relationship between head posture and severity and disability of patterns with neck pain. Manual Therapy 2008; 13:148-54

26. Stezo G.P, Straker L, Raine S. A field comparison of neck and shoulder postures in symptomatic and asymptomatic office workers. Appl Ergon 2002; 33(1): 75-84

27. Chiu TW, Lam TH, Hedley AJ. Correlation between physical impairments, pain, disability and patient satisfaction in patients with chronic neck pain. Arch Phys Med Rehabil 2005; 86(3): 534-40

28. Burgess-Limerick R, Plooy A, Ankrum DR. The effect of imposed and self-selected computer monitor height on posture and gaze angle. Clinical Biomechanics 1998; 13:584-92

29. Laursen B, Jensen BR, Ratkevicus A. Performance and muscle activity during computer mouse tasks in young and elderly adults. Euro J Appl Physiol 2001; 84(4): 527-35

30. Kobara K, Eguchi A, Watanabe S, Shinkoda K. The influence of distance between the backrest of a chair and the position of the pelvis on maximum pressure on the iscium and estimate share force. Disabil Rehabil Assist Technol 2008; 3(5): 285-91

Figure legends

Figure 1. The two wheelchairs. Illustrations of the standard wheelchair (a) and the new wheelchair (b) from the side, illustrating the structure of the backrest. Both the seat and the backrest planes were 400 × 400 mm. The seat angle was 2.9° for both wheelchairs. Photograph (c) of the new wheelchair showing the structure of the thoracic and pelvic support.

Figure 2. Sitting posture in the two wheelchairs. Photograph showing sitting posture in (a) the S-WC and (b) the N-WC. It is evident that there is forward head posture in the S-WC, but that head-neck alignment was close to neutral in the N-WC. The trunk was tilted in the N-WC.

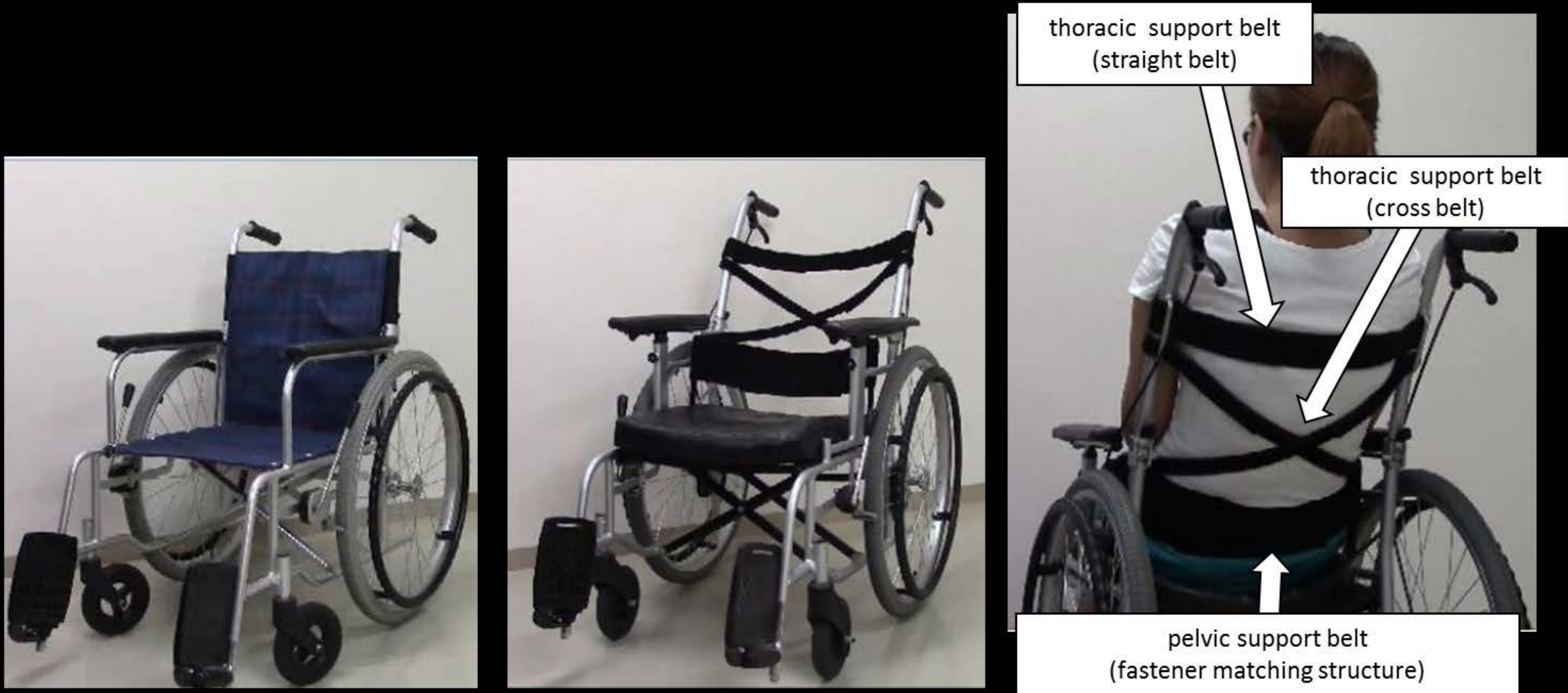
thoracic support belt
(straight belt)
thoracic support belt
(cross belt)
pelvic support belt
(fastener matching structure)

Table 1. Head, neck, and trunk tilt angle.

		S-WC	N-WC	p value
Head angle (°)	rest	63.9 ± 7.21	62.0 ± 7.65	.039*
	extent	20.8 ± 11.71	16.1 ± 14.73	.015*
	flex	100.6 ± 12.45	96.7 ± 11.31	.162^{ns}
Neck angle (°)	rest	38.3 ± 4.46	33.7 ± 4.99	.001*
	extent	15.5 ± 11.73	8.8 ± 11.83	.001*
	flex	56.5 ± 10.13	53.9 ± 9.27	.438^{ns}
Trunk tilt angle (°)		23.1 ± 2.47	30.9 ± 2.52	.000*

S-WC, standard wheelchair; N-WC, new wheelchair.

Data are mean ± SD. ***** $p < .05$ ns ; no significant