



HOKKAIDO UNIVERSITY

Title	Evaluating the Relationships between the Postural Adaptation of Patients with Profound Cerebral Palsy and the Configuration of the Seating Buggy's Seating Support Surface
Author(s)	Hatta, Tatsuo; Nishimura, Shigeo; Inoue, Kaoru et al.
Citation	Journal of physiological anthropology and applied human science, 26(2), 217-224 https://doi.org/10.2114/jpa2.26.217
Issue Date	2007-03
Doc URL	https://hdl.handle.net/2115/43833
Rights	日本生理人類学会. 本文データは学協会の許諾に基づきCiNiiから複製したものである
Type	journal article
File Information	JPA26-2_217-224.pdf



Evaluating the Relationships between the Postural Adaptation of Patients with Profound Cerebral Palsy and the Configuration of the Seating Buggy's Seating Support Surface

Tatsuo Hatta¹⁾, Shigeo Nishimura²⁾, Kaoru Inoue¹⁾, Masanori Yamanaka¹⁾, Makoto Maki¹⁾,
 Norikazu Kobayashi³⁾, Hirotohi Kishigami¹⁾ and Masahiko Sato⁴⁾

1) *Department of Health Sciences, Hokkaido University School of Medicine*

2) *Division of Rehabilitation Engineering Counseling Office, Hokkaido Government*

3) *Faculty of Health Sciences, Tokyo Metropolitan University*

4) *Nagasaki Junior College*

Abstract We are currently investigating the physiological polymorphism of wheelchair users with profound cerebral palsy and the properties of the Seating Buggy (developed by S. Nishimura, 1998) to clarify important and general elements of wheelchairs for widespread use. Cerebral palsy is a diagnostic term used to describe a group of motor syndromes resulting from disorders in early brain development. Recently, it has been shown that the Seating Buggy produces functional head-neck alignments and active control of sitting balance for people with profound cerebral palsy. The Seating Buggy is a wheelchair for the profoundly disabled and features a wide adjustment range from heights of 120 cm to 175 cm. Its seating support surface is comprised of a sling-seat. To examine the relationships between the postural adaptation of patients with profound cerebral palsy and the configuration of the Seating Buggy's seating, we assessed the postural alignment of the Seating Buggy's user and then measured the configuration of its resulting seating support surface with a three dimensional scanning system. Twenty-one subjects were used for the purposes of this investigation in their everyday environment. Postural adaptation and wheelchair fitting in the Seating Buggy were assessed from the viewpoint of the Active Balanced Seating by a seating expert. The subjects fell into two categories, as follows: 11 for appropriate or nearly appropriate fitting, and 10 for ill-fitting. The depth of thoracic support and the forward distance of lumbar support for those who claimed that it was ill-fitting were significantly reduced compared with that of those who claimed that the Seating Buggy offered an appropriate or nearly appropriate fitting. It was suggested that the properly adjusted depth of thoracic support and distance of the lumbar support were related to the resulting satisfactory head-neck alignment and sitting balance of the patients with profound cerebral palsy. *J Physiol Anthropol* 26(2): 217-224,

2007 <http://www.jstage.jst.go.jp/browse/jpa2>

[DOI: 10.2114/jpa2.26.217]

Keywords: seating buggy, active balanced seating, wheelchair seating, cerebral palsy, three dimensional scanning system

Introduction

Populations are not homogeneous as a whole, but rather contain numerous sub-groups of people with different backgrounds. In other words, human populations can be divided into numerous sub-groups according to physiological characteristics. The existence of a physiological sub-group is defined as "physiological polymorphism." Sometimes, there are small groups that are far from the average of the population, and several pathological patients constitute such small groups. The physiological functions of those in a small pathological group like this are different from the average for the majority group. Physiological polymorphism can even be applied to industrial design. Moreover, it is possible to target a physiological polymorphism through industrial design (Inoue et al., 2006). It is said that to better understand health and disease, scientists must study rare diseases affecting smaller portions of the population as readily as those for which research and treatment can result in benefits to a greater number of people (Rados, 2003). We are currently investigating the physiological polymorphism of wheelchair users with cerebral palsy and the properties of the Seating Buggy (developed by S. Nishimura, 1998) to clarify important and general elements of wheelchairs for widespread use (Inoue et al., 2006).

The overall reported prevalence of children with cerebral

palsy is 2–4 per 1000 children. Cerebral palsy is the term for a range of non-progressive syndromes of posture and motor impairment that results from an insult to the developing central nervous system (Koman et al., 2004). People with cerebral palsy who have not developed trunk control have difficulty eating, speaking, moving about, and executing regular activities associated with daily living (Barks, 2004). Patients with cerebral palsy are often prescribed special seating systems for use in their wheelchairs for the purposes of improving posture and to help prevent the development of long-term deformity. The objectives of special seating systems for patients with severe cerebral palsy are generally to promote functions and maximize the comfort of the patients while in their wheelchairs (Neilson et al., 2001).

Custom-molded seats tend to be the seat of choice for wheelchair users who have a gross spinal deformity and a severely impaired sitting ability. Custom-molded seats are known to improve the sitting posture of individuals with cerebral palsy better than standard seats. However, there are several issues to consider regarding the high costs involved, the amount of time it takes to make an appropriate seat, and the special techniques that are required of individuals to adjust their body shape and requirements for postural support.

The Seating Buggy is a ready-made wheelchair (supplied by Nissin Medical Industries) for individuals with a profound disability who have a low level of sitting ability and are unable to maintain their own sitting position. It was designed using a new concept for the physiological sub-type of a smaller pathological group. About 200–300 Seating Buggies are prescribed every year, mainly in Hokkaido Prefecture.

Recently, it has been shown that the best adjusted Seating Buggy produces functional head-neck alignments and active control of sitting balance for people with profound cerebral palsy in a clinical setting (Nishimura et al., 2006). However, there is a lack of research-based evidence to indicate how the seating support surface should be configured to best manage the functional body alignments of patients with cerebral palsy. To examine the relationships between the postural adaptation of patients with profound cerebral palsy and the configuration of the Seating Buggy's seating, we assessed the postural alignment and sitting balance of the Seating Buggy's user and then measured the configuration of its resulting seating support surface in an ecological situation. The configuration of the resulting complicated seating support surface is still known as the most difficult part of wheelchair seating to evaluate. Because of this, efforts to measure the seating surface using a three-dimensional scanning system were investigated. The research questions were as follows: What features are observed in the resulting seating support surface within the Seating Buggy using a 3-D scanning system? What factors of the configuration of the seating support surface contribute to postural adaptation and wheelchair fitting for the cerebral palsy group?

Methods

1. Subjects

This study received approval from the ethics committee of the Hokkaido University Graduate School of Medicine, Japan. Study subjects were selected from among patients who had been provided with the Seating Buggy from the seating clinic at the Hokkaido Government's rehabilitation counseling office. The selection criterion was that the subject was adolescent or adult, with profound cerebral palsy. A further selection criterion was that the subject could participate without experiencing discomfort or anxiety in an experimental situation. Most participants were unable to give written consent because of physical or cognitive impairment. We did, however, obtain written informed consent from those with custody of the participant, or a responsible person from the participant's institution who discussed the testing protocol with them and together agreed to participate in this study.

Twenty one subjects with profound cerebral palsy from an institution for the profoundly disabled or a ward for the profoundly disabled of a hospital in Hokkaido aged from 17 to 54 (mean of 37.6) were used for the purpose of this investigation in their everyday environment.

Twelve of the participants were men and nine were women. Heights ranged from 108 to 158 cm (mean of 147.3) and weight from 25 to 43 kg (mean of 33.3). Most subjects were of low to average body height and body weight. Our overall experience shows that all subjects in this study had a body build which was reasonably common in the Seating Buggy user group. Sixteen out of the 21 patients had scoliosis (mean of Cobb angles: 55.6 degrees), and two of the 21 patients had kyphosis. Mental retardation was present in all patients, and was usually severe. All subjects were dependent on others for the personal daily activities of living. They had no independent mobility, and suffered severe fine motor problems. Limitation in range of motion, balance, strength, or cognitive function limited the ability of the subjects to achieve and sustain the body positions required for sitting. All subjects were sitting as clinically prescribed in the Seating Buggy at the time of undergoing a 3-D analysis of the seating support surface. The average period on the Seating Buggy was 5.3 years. Sixteen of them were everyday users (mean of 5.5 hours/day); five others were occasional users.

2. Instrumentation

In this study, measuring the complicated 3-D curve surface of the deformed seating support surface of the Seating Buggy is important. The TRiDY (JFE-Techno-Research) is a non-contact 3-D measurement system that uses multi-pattern projection with a data projector. The measurement principle is based on the combination of two types of space code method, the switched binary stripe pattern projection and the scanned multi-slit pattern projection. The system is equipped with a data-projector connected to a personal computer in order to project two types of pattern to a physical object with the

identical optical axis. The TRiDY projects binary stripe patterns and multi-slits onto a subject surface, and produces a high resolution (at plus/minus 1.1 mm) image in 1.7 seconds for computer graphics applications. The wide scope model of TRiDY has a field of scope of 520 mm×690 mm, wide enough for a wheelchair seating support surface. Comprised of only a 12 kg detection head and a notebook PC, the system is compact and easy to carry. The TRiDY was selected for the study because of its high portability of data collection in an ecological setting.

RapidForm2006 (INUS Technology) is a comprehensive suite of tools designed to convert real solid data from 3-D scanning devices into accurate data for a variety of applications. The scanning of the Seating Buggy was performed using the 3-D scanner TRiDY. TRiDY converts the real seating support surface of the Seating Buggy into usable digital models. Scanned data is displayed with a view tool and stored in a hard disk. Data is then exported in DXF formats and imported into the RapidForm2006. An accurate 3-D model of the Seating Buggy's individual seating support surface was constructed by data processing.

3. Materials

The Seating Buggy is a wheelchair for people with severe cerebral palsy who were never able to reach the milestone of independent sitting, or have lost the ability to sit independently (Fig. 1). The weight of the Seating Buggy is 16.5 kg, with a rear-wheel diameter of 14 inches and a caster diameter of 5 inches. The upper border of the backrest is 80 cm above the intersection of the backrest and the seat base, which is 38 cm in width. The adjustable depth of the seat base frame pipe is 27 cm to 42 cm. The Seating Buggy features a wide adjustment range from heights of 120 cm to 175 cm.

The seating support surface of the backrest used for thoracic support and the seat base is comprised of a sling-seat. The sling-seat consists of 3 parts and has hook and loop fastener strips underneath to secure it to the frame pipe for a wide adjustable range in depth. The sling-seat of the Seating Buggy was adjusted freely to the patient's body shape in the clinical setting. At the same time, the applied patient's body weight on the sling-seat left an impression of the patient's body shape in the seating support surface. Complicated deformation of the body produces a characteristic impression in the seating surface. The flexibility and resistibility characteristic of the sling-seat does not disturb the movement of the patient, while it provides stability to the patient's body.

A sling-seat belt as a lumbar support adjustable in height and depth was mounted to the backrest pipe for providing support to the posterior part of the pelvis. An adjustable polyurethane foam pad was mounted to the seat base pipe for providing support to the posterior part of the ischial tuberosity. These lumbar support and posterior ischial tuberosity supports are underneath the sling-seat. Various interface materials, such as polyurethane foam pads, lap belts, and seat cushions, are currently in clinical use.

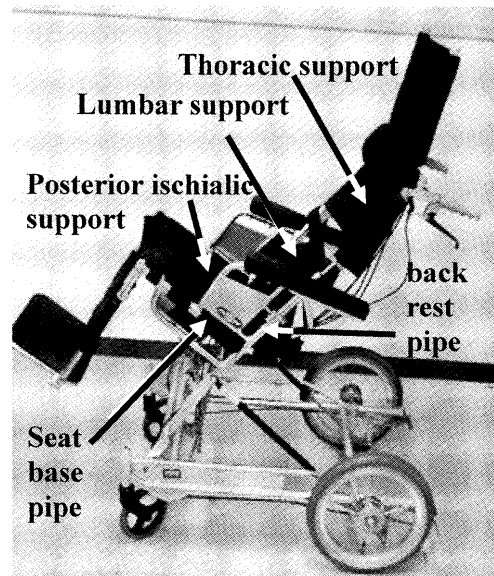


Fig. 1 Seating Buggy

The Seating Buggy is a wheelchair for the profoundly disabled featuring a wide adjustment range for heights from 120 cm to 175 cm. Its seating support surface is comprised of a sling-seat. The Seating Buggy comes equipped with wide adjustable tilting and elevating systems, thus allowing immobile users to achieve different positions.

The Seating Buggy is equipped with wide adjustable tilting and elevating systems that allow an immobile user to achieve different positions. The maximum inclination for forward tilting is 40 degrees for the perpendicular line, and for backward tilting is 80 degrees. The range of elevation is 12 cm to 60 cm. Inclination or/and elevation of the seat is adjusted to the individual's ability to sit balanced, accommodating postural requirements for activities relating to daily living.

Adaptive seating is defined here as matching the proper alignment of an individual's head-neck and sitting balance whilst functioning as the wheelchair seating support surface. We propose to refer to it as "Active Balanced Seating". In Active Balanced Seating, the alignment of the head and neck takes precedence over that of the pelvis, which is contrary to conventional seating concepts. Individuals with severe sitting disabilities can sit in a well-balanced posture with proper head-neck alignment in the appropriately adjusted Seating Buggy.

4. Protocol

Each subject and his/her individual caregiver agreed to the study protocol after an explanation of the procedure and the instrumentation. The first session with the participants involved the collection of physical data and background information. The resting posture of the subject was recorded with a hand-held digital video camera and a digital still camera. The shape and material type of the existing insert were recorded, as well as an examination of the characteristics of the individual's Seating Buggy.

In the second session, postural adaptation and the wheelchair fitting of each subject was assessed from the

viewpoint of the Active Balanced Seating by a seating expert with more than thirty years of experience as a rehabilitation engineer while the subject was seated in his/her Seating Buggy. The criterion of the assessment of adaptation was the patient's individual head-neck alignment and the resulting ability to maintain active control of head balance. The configuration of the seating support surface was excluded from the assessment. The seating expert used skilled observational techniques to assess the physiological functioning of the head-neck alignment of the subject. Subjects were divided into three categories: appropriate fitting, nearly appropriate fitting, and ill-fitting.

The third session involved the actual data-set acquisition. Following the assessment, the subject was lifted out of his/her seat to a bed with the help of his/her caregiver. The Seating Buggy's adjusted sling seat for the individual does not tend to return to its original shape once it is transformed by the body weight. The impression made from the body remained on the seating support surface. The front or oblique view of the seating support surface of the Seating Buggy was scanned by the TRiDY. The TRiDY was fixed on the trestle with wheels varied at an angle by an experimenter during scanning. The seating support surface of the Seating Buggy was roughly divided into twelve parts. Each part was scanned sequentially within 1.7 seconds. A generous amount of scanning was performed because the TRiDY could not discern the folding or shading parts around the corners of some interface materials. Scanned data was confirmed on the display and stored in a hard disk. The stored data was exported in DXF formats and imported into the RapidForm2006. An exact 3-D model of the Seating Buggy's seating support surface was constructed from twelve amounts of scanned data, processed by the RapidForm2006. Some small missing parts emerged due to certain disadvantages in the 3-D scanning. However, data was not patched and smoothed out because this process could further increase errors.

5. Measurement

In the first session, the 3-D graphic model of the seating support surface was displayed within the application of the RapidForm2006. The overall configuration of the 3-D model was examined from various angles for feature analysis. The thoracic support, the lumbar support, and the posterior ischial tuberosity support of the Seating Buggy were defined in the 3-D graphic model. The seating support surface was adjusted for the deformation of the patient's body shape. Various adjusted seating support surfaces were observed from person to person. The characteristic of the seating support surface in the middle area differed from the lateral area within the coronal plane. Kyphosis or scoliosis is known as the usual second condition for patients with profound cerebral palsy (Majd et al., 1997). We adopted the middle area of the seating support surface as an indicator of kyphosis, and the left or right lateral area of the seating support surface as convex curvature of scoliosis of the patient with cerebral palsy for analysis.

In the second session, according to general observation, we displayed the front view of the 3-D graphic model of the seating support surface symmetrically on the coronal plane. We depicted a perpendicular line in the middle or the lateral quarter of the 3-D model. The traced contour of the seating support surface was highlighted and observed from different angles. The side view of the 3-D graphic model of the seating support surface was selected for measurement within the sagittal plane.

In the third session, we defined the measuring points of the seating support surface according to the following procedure (Fig. 2). It was primarily the backrest pipe and seat base pipe of the Seating Buggy that were confirmed. We defined the intersecting point of the backrest pipe and seat base pipe as the reference point of the platform just as we would with a standard wheelchair. 1) Line A: the frame line of the backrest pipe was moved in parallel to the innermost point for thoracic support. 2) Line B: the frame line of the backrest pipe was moved in parallel to the innermost point for lumbar support. 3) Line C: the frame line of the backrest pipe was moved in parallel to the front point of lumbar support. 4) Line D: the frame line of the seat base pipe was moved in parallel to the highest point of the anterior part of the seat base. 5) Line E: the frame line of the seat base pipe was moved in parallel to the lowest point of the posterior part of the seating base. 6) Reference point of sitting: we defined this as the intersecting point of Lines C and E. The reference point for sitting in the Seating Buggy was not defined as the reference point for the platforms like a standard wheelchair. The individual reference point of sitting varied according to the intersection of individually defined Lines C and E.

The fourth session involved the actual data-set measurement. The side view of the 3-D graphic of the Seating Buggy was printed out and measurements made of the depth of the thoracic support (vertical distance from Line A to Line B), the lumbar support (vertical distance from Line B to Line C) and the posterior ischial tuberosity support (vertical distance from Line D to Line E). The measurements of the depth of thoracic support, the lumbar support, and the posterior ischial tuberosity support represent the characteristics of the seating support surface itself. The distances from the reference point of the platform to the reference point of sitting were also measured. The distance of the lumbar support (vertical distance from the backrest pipe to Line C) and the posterior ischial support (vertical distance from the seat base pipe to Line E) were confined here as the distances from the reference point of the platform to the reference point of sitting. The measurements of the distance of the lumbar support and the posterior ischial support were the relative position of the seating support surface associated with the platform of the Seating Buggy.

To examine the differences in the configuration of the seating support surface between the determined categories, we compared the average values. The discriminating factor from the data was the only determined category.

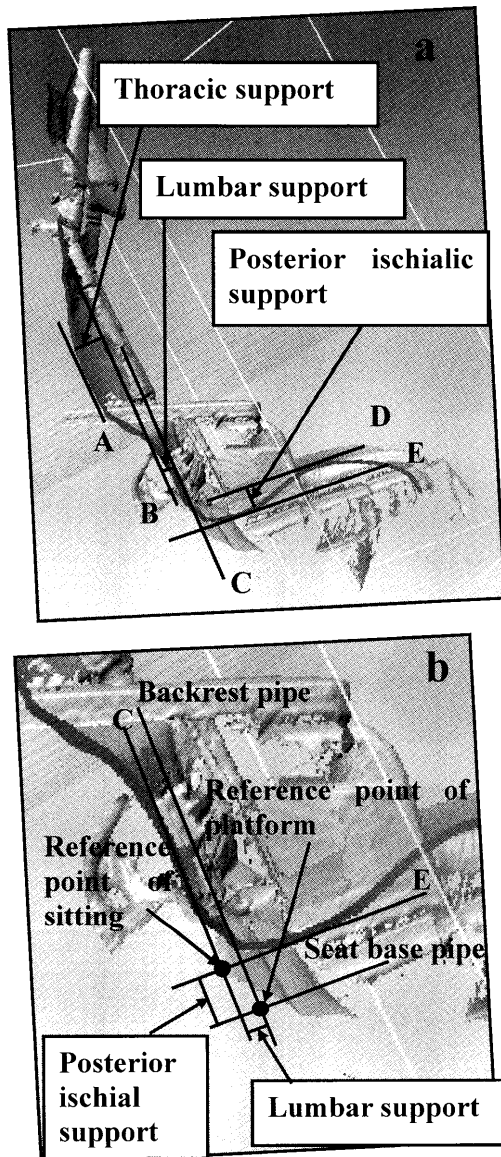


Fig. 2a, b Measurement Items

Fig. 2a The side view of the 3-D graphic of the Seating Buggy was used to measure the depth of the thoracic support (vertical distance from Line A to Line B), the lumbar support (vertical distance from Line B to Line C) and the posterior ischial tuberosity support (vertical distance from Line D to Line E).

Fig. 2b The distance of the lumbar support (vertical distance from the backrest pipe to Line C) and the posterior ischial support (vertical distance from the seat base pipe to Line E) were measured.

Results

The resulting features of the seating support surface determined using a 3-D scanning system are shown in Fig. 3. The features of the seat base of the seating support surface were found to be nearly identical. However, the features of the backrest of the seating support surface were distinct from each other. It is said that customized wheelchair inserts used for passive correction of scoliosis, stabilization of the trunk, and

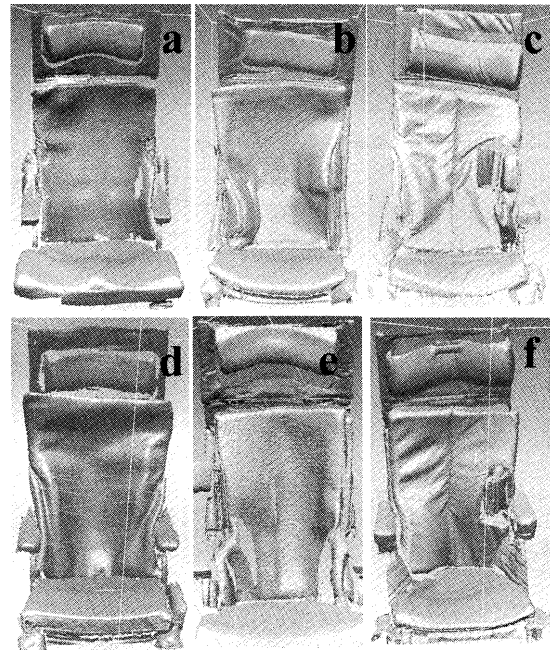


Fig. 3 Examples of the seating support surface of the Seating Buggy
Representative examples of the resulting features of the seating support surface determined using a 3-D scanning system. The upper columns of “a,” “b,” and “c” are representative examples of the AAF category, and the lower columns of “d,” “e,” and “f” are representative examples of the IF category. The user of example “a” did not have scoliosis, the user of example “b” had scoliosis measuring 44 degrees, and the user of example “c” had scoliosis measuring 90 degrees. The user of example “d” did not have scoliosis, the user of example “e” had scoliosis measuring 45 degrees, and the user of example “f” had scoliosis measuring 81 degrees.

provision of head and neck support rarely halt curve progression once the curve has exceeded 40 degrees (Koman et al., 2004). For this reason, all subjects were divided into two groups on the basis of the degree of their scoliosis as follows: 12 subjects with scoliosis measuring over 40 degrees and 9 subjects with scoliosis measuring under 40 degrees or without scoliosis. There is a significant relationship between the scoliosis (over 40 degrees) and the depth of thoracic support of the lateral area ($r=.675$, $p=.016$), and the distance of the lumbar support of the lateral area ($r=.668$, $p=.018$). The larger degrees of scoliosis correlate with the larger depth of thoracic support and the increased distance of lumbar support. Various adjusted seating support surfaces observed from person to person were set out according to the degree of the user’s scoliosis. Our discussions were thus carried out separately according to the degree of scoliosis, i.e., over 40 degrees or under 40 degrees.

Subjects fell into one of three categories as follows: 7 for appropriate fitting, 4 for nearly appropriate fitting, and 10 for ill-fitting (IF). The categories of appropriate fitting and nearly appropriate fitting were united as approximately appropriate fitting (AAF), because of the small amount of data in the category of the nearly appropriate fitting for statistical analysis. The physical characteristics of the subjects in the different

categories are presented in Table 1.

All mean depth and distance measures are shown in Table 2 and Table 3. The result of the two sample *t*-tests on the average values of the categories indicated that the depth of the thoracic support and the distance of the lumbar support were significantly different in patients with scoliosis measuring over 40 degrees. However, there was no difference between the two categories of patients without scoliosis and those with scoliosis measuring under 40 degrees. The depth of the thoracic support and the distance of the lumbar support for those who claimed that it was the IF was significantly reduced compared to that of those who claimed that the Seating Buggy offered AAF in patients with scoliosis measuring over 40 degrees.

Table 1 Physical characteristics of subjects

Subjects with scoliosis over 40 degrees (Mean±SD)			
	Height (cm)	Weight (kg)	Scoliosis (degree)
AAF (n=6)	147.9±5.5	31.6±6.1	74.0±26.2
IF (n=6)	147.4±17.5	34.0±5.7	70.7±11.8
Subjects with scoliosis under 40 degrees or without scoliosis (Mean±SD)			
	Height (cm)	Weight (kg)	Scoliosis (degree)]
AAF (n=5)	146.2±11.1	33.9±4.6	7±9.9
IF (n=4)	145.8±4.7	35.3±5.8	10.5±12.3

Table 2 The measurement of patients with scoliosis over 40 degrees (Mean±SD)

Middle	TS	LS	PIS	DLS	DPIS
AAF	43.6±13.3**	30.6±23.1	17.6±16.4	46.5±54.0*	12.5±29.6
IF	16.4±7.6**	14.2±11.9	28.3±5.1	-24.9±23.8*	6.8±31.9
Lateral	TS	LS	PIS	DLS	DPIS
AAF	91.2±41.0*	16.4±12.6	11.3±18.6	104.3±81.6*	37.4±47.1
IF	34.0±18.4*	16.4±18.0	18.7±13.7	12.4±43.9*	5.6±15.2

AAF: Approximately Appropriate Fitting, IF: Ill-Fitting, TS: Depth of Thoracic Support, LS: Depth of Lumbar Support, PIS: Posterior Ischial Support, DLS: Distance of Lumbar Support, DPIS: Distance of Posterior Ischial Support *: $p < 0.05$, **: $p < 0.01$

Table 3 The measurement of patients with scoliosis under 40 degrees or without scoliosis (Mean±SD)

Middle	TS	LS	PIS	DLS	DPIS
AAF	35.4±26.5	27.2±25.0	30.6±26.1	31.3±46.8	28.6±55.3
IF	35.7±3.4	30.6±6.8	37.4±20.4	27.2±36.4	28.9±26.3
Lateral	TS	LS	PIS	DLS	DPIS
AAF	79.6±23.6	17.0±8.7	21.7±26.1	93.8±54.7	46.2±48.4
IF	67.2±23.6	16.2±10.9	18.7±12.8	74.8±48.4	49.3±19.5

AAF: Approximately Appropriate Fitting, IF: Ill-Fitting, TS: Depth of Thoracic Support, LS: Depth of Lumbar Support, PIS: Posterior Ischial Support, DLS: Distance of Lumbar Support, DPIS: Distance of Posterior Ischial Support

Discussion

Adaptation of each subject was assessed by a seating expert from the viewpoint of Active Balanced Seating. The criterion of the assessment was the individual head-neck alignment and resulting ability to maintain active control of head balance. Eleven of the 21 patients who were assessed with AAF showed proper alignment and the ability to maintain active control of head-neck balance. Many of the dependent sitters could not function properly in activities relating to daily living and required medical care for respiration and eating/swallowing. It is well documented that the patient's head position influences swallowing during feeding and reduces the risk of aspiration. If the head is not stable, then the movements of jaw and tone needed for feeding will be impaired (Redstone et al., 2004). The criterion of adaptation adopted for assessment was justified for the most basic physiological functions. The well-adjusted seating support surface of the Seating Buggy may contribute to improved respiration and eating ability for patients with profound cerebral palsy.

Asymmetric spasticity and the effect of gravity are thought to be important in the development of scoliosis in patients with cerebral palsy. Severe scoliosis in those with cerebral palsy often causes additional motor dysfunction, compromised pulmonary function, and increased nursing care demands (Saito et al., 1998). Adolescents and adults with cerebral palsy are at risk from many secondary conditions that can lead to a loss of function and deterioration in the sufferer's quality of life. Scoliosis is one of the common secondary conditions that children and adults with cerebral palsy suffer from. Loss of

function is primarily related to the difficulty of adapting seating devices to give the individual a comfortable, pain-free, upright position (Murphy et al., 1995; Gajdosik and Cicirello, 2001). Most wheelchair-bound patients with scoliosis required wheelchair modification to achieve a stable sitting balance (Majd et al., 1997). Since secondary conditions in the dependent wheelchair user are quite common, providing the research-based technical protocol of the adaptive seating support for those people has a clinical justification.

Sixteen of the 21 patients have scoliosis (mean of 55.6) and two of them have kyphosis. Deformities of the spine are the most prominent physiological feature of people with profound cerebral palsy. Twelve of the 16 patients had scoliosis measuring over 40 degrees. There is a significant relationship between scoliosis (over 40 degrees) and the depth of thoracic support or the distance of lumbar support of the lateral area. Larger degrees of scoliosis correlate with larger depth of thoracic support or increased distance of lumbar support. The mean of Cobb angles was 72.3 degrees in the 12 patients with scoliosis measuring over 40 degrees. Six of the 12 patients assessed with AAF had a mean of Cobb angles of 74.2 degrees. The depth of thoracic support and distance of lumbar support of the seating support surface of the Seating Buggy features a wide adjustment range from scoliosis ranging from zero degrees to over 70 degrees.

For wheelchair users, balancing sufficient trunk support with adequate trunk mobility has important functional and medical consequences (Sprigle et al., 2003). A functional requirement is that the sitting position is used in everyday life and does not impair balance, spasticity, or respiration (Bolin et al., 2000). The seating support surface of the Seating Buggy did not apply forced correction of the lateral curvature of spine or the deformed chest like the three point forces with lateral pads. It is said that deformities of the spine have been extremely difficult to manage with braces because the curves are often quite rigid (Majd et al., 1997). Also, it is said that customized wheelchair inserts used for passive correction of scoliosis, stabilization of the trunk, and provision of head and neck support rarely halt curve progression once the curve has exceeded 40 degrees (Koman et al., 2004). The seating support surface of the Seating Buggy was made using adjustable sling-seats. The sling-seat's flexibility and resistibility characteristics do not disturb the movement of a patient, while also providing stability to the trunk and pelvis. The seating support surface of the Seating Buggy should be adjusted to sustain the weight of the body from underneath, depending on the patient's deformity of spine.

This study showed significant differences for the seating support surface of the Seating Buggy between the AAF and the IF. The values between the middle area and the lateral area are not a different pattern, hence we will discuss them with no distinction. Children with cerebral palsy sat with a more reclined pelvis and a more collapsed trunk (Van Der Heide et al., 2005). Without trunk control, the paraspinal extensors and abdominal muscles cannot provide balanced co-contraction to

hold the trunk upright. Gravity pulls downward, resulting in the collapse of the trunk into scoliosis or rotoscoliosis (Barks, 2004). The depth of the thoracic support of the IF decreased significantly compared with that of the AAF. The relationship between the depth of the thoracic support and the head-neck alignment of the patients is the first issue to discuss. The depth of thoracic support reflects the shape of lateral curvature or/and backward curvature of the spine of the subject.

The more planar thoracic support of the IF does not have sufficient depth for supporting the curved upper trunk. Additionally, the planar thoracic support of the IF pushes the lateral curvature or/and the backward curvature of the spine forward. Patients of the IF may tend to struggle to flex forward or lean to one side. As a result, a forward or laterally inclined upper trunk of the IF can no longer establish itself as a stable base for the head-neck position.

On the other hand, it was speculated that the trunk of the AAF was supported well along its curvature of the spine or chest by the deeper-lying adjusted thoracic support. Deeper thoracic support forms anchorage of the chest wall from the underneath. A well-supported upper trunk establishes a stable basis for the proper head and neck position. The proper alignment of head-neck and sitting balance observed in the AAF were the result of the basis of a stable upper trunk.

The distance of the lumbar support of the AAF increased significantly compared with that of the IF. The distance of the lumbar support reflects directly the relative position of the lumbar support relevant to the backrest pipe. The increased distance of the lumbar support in the AAF indicated that the lumbar support was elucidated forward. The relationship between the lumbar support and the head-neck alignment is the second issue to discuss.

Sitting causes the pelvis to rotate backwards and the lumbar lordosis to reduce (Harrison et al., 2000). Some deficiencies reported with the standard wheelchair are that it promotes a posterior pelvic tilt, scoliotic posture, or kyphotic posture (Gavin-Dreschnack, 2004). The function of the lumbar support with the posterior part of the seat base tilted is to increase the lordosis of the lumbar spine (Lin et al., 2006). Lumbar support has the lowest disc pressures and lowest electromyography recordings from spinal muscles (Harrison et al., 1999). Elucidated lumbar support of the AAF may prevent backward inclination of the pelvis and lumbar spine. Because of the decreased backward inclination of the pelvis and lumbar spine, a stable base for the appropriate alignment of the trunk may establish itself. It was speculated that the proper head-neck alignment of the AAF was followed by the appropriate alignment of the trunk. Head-neck alignment is influenced by trunk alignment, which depends upon the stability of the pelvis.

In the Active Balanced Seating within the Seating Buggy, primarily the thoracic support should be adjusted sufficiently in depth to provide appropriate support to the patient's lateral or backward curvature of the spine and chest wall from underneath. Secondly, the lumbar support should be adjusted

to prevent the backward inclination of the patient's pelvis with or without the depth of the posterior ischial tuberosity support.

In this context, individuals with severe sitting disabilities of the AAF can sit in a well-balanced posture with proper neck-head alignment in the Seating Buggy.

Due to the complexities of sitting problems in patients with profound cerebral palsy based on physiological issues, the standard solution for the majority group is not applicable. Preliminary results confirmed that the Seating Buggy investigated in this study is an appropriate wheelchair for this small physiological sub-group.

Results from the measuring system indicated that a 3-D scanning method is a noninvasive procedure that can be used to evaluate wheelchairs for those with profound disabilities. In this study, we measured the physiological function of posture indirectly through wheelchair interface. Further study is required to directly measure this physiological function. Results of the measurement of the seating support surface varied, indicating the need for a future study with a larger number of subjects.

Acknowledgements This work was supported by a grant from the Ministry of Education, Culture, Sports, Science and Technology (project 17370091). We thank Mr. Toshihiko Miura, Mr. Itsuki Nagato, and Mr. Naohide Takaya for their kind help in data collection.

References

- Barks L (2004) Therapeutic positioning, wheelchair seating, and pulmonary function of children with cerebral palsy; A research synthesis. *Rehabil Nurs* 29: 146–153
- Bolin I, Bodin P, Kreuter M (2000) Sitting position—posture and performance in C5–C6 tetraplegia. *Spinal Cord* 38: 425–434
- Gajdosik CG, Cicirello N (2001) Secondary conditions of the musculoskeletal system in adolescents and adults with cerebral palsy. *Phys Occup Ther Pediatr* 21: 49–68
- Gavin-Dreschnack D (2004) Effects of wheelchair posture on patient safety. *Rehabil Nurs* 29: 221–226
- Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ (1999) Sitting biomechanics part I: review of the literature. *J Manipulative Physiol Ther* 22: 594–609.
- Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ (2000) Sitting biomechanics, part II: optimal car driver's seat and optimal driver's spinal model. *J Manipulative Physiol Ther* 23: 37–47
- Inoue K, Hatta T, Nishimura S (2006) An approach to wheelchair design by using the physiological polymorphism of users with cerebral palsy. The 8th International Congress of Physiological Anthropology Abstracts Book, 3
- Koman LA, Smith BP, Shilt JS (2004) Cerebral palsy. *Lancet* 363: 1619–1631
- Lin F, Parthasarathy S, Taylor SJ, Pucci D, Hendrix RW, Makhous M (2006) Effect of different sitting postures on lung capacity, expiratory flow, and lumbar lordosis. *Arch Phys Med Rehabil* 87: 504–509.
- Majd ME, Muldowny, DS, Holt RT (1997) Natural History of Scoliosis in the Institutionalized Adult Cerebral Palsy Population. *Spine* 22: 1461–1466
- Murphy KP, Molnar GE, Lankasky K (1995) Medical and functional status of adults with cerebral palsy. *Dev Med Child Neurol* 37: 1075–1084
- Neilson AR, Bardsley GI, Rowley DI, Hogg J, Malek M, Morrison GC, Kirkwood CA (2001) Measuring the effects of seating on people with profound and multiple disabilities—A Preliminary study. *J Rehabil Res Dev* 38: 201–214
- Nishimura S, Hatta T, Inoue K, Yamanaka M, Maki M, Kobayashi N, Kishigami H, Sato M (2006) Development of the Seating Buggy and Active Balanced Seating-Standard and adjustment range for the seating-system for severely handicapped patients. *Japanese Journal of Physiological Anthropology* 11 Supp 1: 88 [*In Japanese*]
- Rados C (2003) Orphan products: Hope for people with rare diseases. *FDA Consumer* 11: 10–15
- Redstone F, West JE (2004) The Importance of Postural Control for Feeding. *Pediatr Nurs* 30: 97–100
- Saito N, Ebara S, Ohotsuka K, Kumeta H, Takaoka K (1998) Natural history of scoliosis in spastic cerebral palsy. *Lancet* 351: 1687–1692
- Sprigle S, Wootten M, Sawacha Z, Thielman G (2003) Relationships among cushion type, backrest height, seated posture, and reach of wheelchair users with spinal cord injury. *J Spinal Cord Med* 26: 236–243
- Van Der Heide JC, Fock JM, Otten B, Stremmelaar E, Hadders-Algra M (2005) Kinematic characteristics of postural control during reaching in preterm children with cerebral palsy. *Pediatr Res* 58: 586–593

This article was presented at the 8th International Congress of Physiological Anthropology, 2006 (ICPA 2006), in Kamakura, Japan.

Received: September 30, 2006

Accepted January 9, 2007

Correspondence to: Tatsuo Hatta, Department of Health Sciences, Hokkaido University School of Medicine, Kita 12, Nishi 5, Kita-ku, Sapporo, 060–0812 Japan

Phone: +81-(0)11-706-3335

Fax: +81-(0)11-706-4916

e-mail: thatta@cme.hokudai.ac.jp