2014 5th IEEE RAS & EMBS International Conference on
Biomedical Robotics and Biomechatronics (BioRob)
August 12-15, 2014. São Paulo, Brazil

Adjustable sheet for intelligent seating system*

Takehito Kikuchi, *Member, IEEE*, Ken'ichi Anzai

***Abstract*— A proper seating is important as an aid for cerebral palsy patients, and has good influence on patients' physical conditions and mentalities. Deformity of spine causes gaps between their backs and backrests of wheel chairs. Generally, urethane cushions are used to fill up the gaps. However, this method cannot handle their dynamic motion that will happen in daily life. In the previous study, we developed the first prototype of the intelligent seating system (i-Seating 1) by using a conventional adjustable-belt type seating and some air bags on the belts. We could control the posture and pressure of users, but there is a severe limitation for real situations. In this paper, we propose to use an adjustable sheet mechanism for the wheelchair seating. The adjustable sheet mechanism is very simple and a combination of a main sheet and adjustment belts. We installed this mechanism in the conventional adjustable-belt type seating. For convenience of the adjustment, we also developed a back-shape measurement system and proposed an adjustment method on the basis of the measurement results. Finally, a validation test was conducted and evaluated. The experimental result indicated that the adjustable sheet fit to the complex back shape and controlled a good posture and even pressure for a dummy deformed backbone.**

I. Introduction

Seating is a fundamental and important function of wheelchairs and other welfare devices on which users sit. Appropriate seating provides comfortable postures of upper bodies of the users [1]. For examples, patients suffering from severe cerebral palsy tend to have severely deformed backbones by muscle hypertonia (Fig.1) and it is impossible to sit on a wheelchair only with a normal backrest [2].

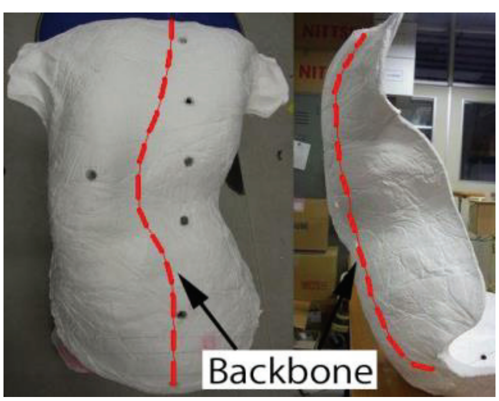

Figure 1. Gypsum mold of a back of a cerebral palsy patient

*Resrach supported by Fluid Power Technology Promotion Foundation.
Takehito Kikuchi is with the Faculty of Engineering, Oita University, 700 Dannoharu, Oita 870-1192 Japan (corresponding author to provide phone & fax: +81-97-554-7771; e-mail: t-kikuchi@oita-u.ac.jp).
Ken'ichi Anzai was with the Graduate School of Science and Engineering, Yamagata University, 4-3-16 Jonan, Yonezawa 992-8510 Japan.

Generally they require custom-made backrests made of poly-urethane cushion or other additional support parts on the backrest to keep adequate postures, prevent bedsores, advancements of breathing, circulatory, eating, communication functions, and so on. However, conventional custom-made backrests do not have a function to vary its shape to keep fitting on backs of patients who change postures based on growth or depending on the dynamic motions in daily life. In addition, the complicated back shapes of severe cerebral palsy patients disturb the even back pressure distribution [2].

The objective of this study is to develop a new seating system that concurrently allows to

1) support their comfortable postures of upper bodies for good eating, breathing, communication and so on, and

2) make even distribution of pressure on their backs for less bedsores.

Conventional seating systems can be classified into mainly two types, the modular type and the non-modular type. In addition, each the types can be categorized into three types listed below.

a) Mold type: This type is generally made of thermo-plastics or poly-urethane. The shape is manually cut or automatically machined on the basis of the three dimensional data of the gypsum model of users like Fig.1. This type mostly fits the individual's back than other types. However, it usually takes much time to make a suitable shape for individuals.

b) Adjustable-belt type: The seating of this type consists of some separated fabric bands with hook and loop fasteners (Left of Fig.2). The length of each band is adjustable. User can adjust its length depending on the convex and concave of their backs. However, it is impossible to fit the complex deformation only with the total length of the bands. Then, generally optional cushions are used to fill the gap between the bands and the user's back (Right of Fig.2).


Figure 2. Conventional seating for wheelchair: adjustable belt type seating (left) and tailor-made cushion (right)

c) Others: For example, Trail et al.[3] developed the Matrix Seating System [4] that has a matrix structure of many degrees of freedom with ball-joints and clamp-units. By fastening and releasing each joint, user can make 3 dimensional shapes of the matrix. However due to the many numbers of the adjustment points, it takes so much time to fit it for individuals.

As mentioned above, the requirements for the good seating system are not only the basic performance (adjustability of the posture and pressure), but also the easiness of the adjustment.

To solve this problem, we have developed the intelligent seating system (i-Seating). The first prototype of the i-Seating (i-Seating 1, Fig.3) was a combination of the adjustable-belt type, mentioned above, and some separated air bags (Fig.4). As shown in Fig.4, the air bag fills the gap due to the complex deformation of the back and support the force on the concave parts. The air pressure was controlled to make comfortable posture and pressure for users [5]. However, the controllable spatial resolution highly depending on the size of the air bag, and there was a severe limitation for the real situations.

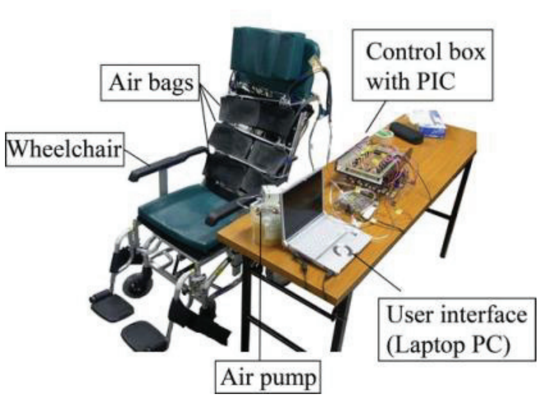

Figure 3. Prototype of i-Seating 1 system [5]

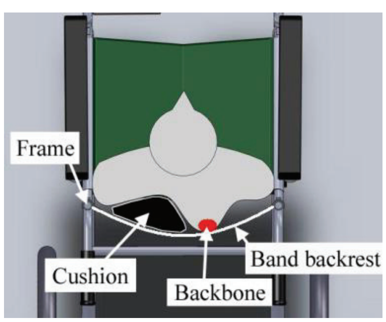

Figure 4. Mechanism of i-Seating1 [5]

In this paper, we propose to use an adjustable sheet mechanism for the wheelchair seating. The adjustable sheet mechanism is very simple and a combination of a main sheet and adjustment belts. We installed this mechanism in the conventional adjustable-belt type seating. For convenience of the adjustment, we also developed a back-shape measurement system and proposed an adjustment method on the basis of the measurement results. Finally, a validation test was conducted and evaluated.

II. Adjustable sheet

A. Basic idea of adjustable sheet

In the previous version of the i-Seating system [5], we used the combination of the adjustable belt and air bags (Fig.4). However, the size of the air bags is a limitation of the controllable spatial resolution. Matrix Seating System [4] used a large number of the ball joints. But its adjustment is very complex. As a material for the seating system, we required a flexible, transformable, tough, continuous and simple one.

To cover such multiple requirements, we propose a simple mechanism of the adjustable sheet (Fig.5). The adjustable sheet consists of a main sheet and a few adjustable belts. The main sheet is a material that is flexible for bending, but tough for stretch. The adjustable belt is fixed on its both edges with arbitrary points of the main sheet. The length of the belt is adjustable. The belt is also flexible for bending, and tough for stretch.

We can easily make an arch of the main sheet by fixing the both edges of the adjustable belts and adjust its length. The concave portions of the back (1 of Fig.5) can be supported with the arches of the main sheets. The convex portion (2 of Fig.5) of the back naturally covered with the flexion of the main sheet.

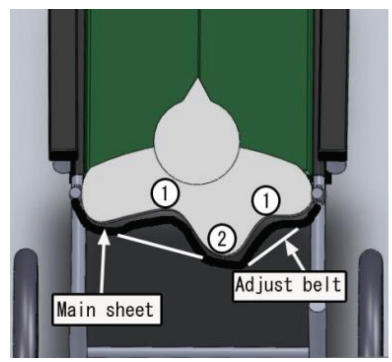

Figure 5. Mechanism of i-Seating 2

B. Feasibility of main sheet

The main sheet of the adjustable sheet must be flexible for bending and tough for stretch. We chose a polypropylene (PP) sheet (thickness: 0.75 mm, yield stress 30 MPa, and bending elastic modulus: 1 GPa) as a material of the main sheet because of its flexibility and low cost.

Firstly, we hypothesized that the body weight of the user (W [kgf]) is 60 kgf, and 60% (R = 0.6) of the whole weight is the weight of the upper body. The tilt angle of the back seat (θ [deg]) is 60 degree. The total length (L [m]) and width (B [m]) of a sheet is 0.36 m, and 0.05 m, respectively. In addition, total number of the sheet (N) is 7. These values are referred from the commercially available adjustable-belt type seat (Fig.2).

By these conditions, the average pressure (P [Pa]) which is applied on the main sheet is

$$P = \frac{W \times g \times R \times \cos\theta}{L \times B \times N} \cong 1.40\text{kPa}. \quad (1)$$

We assumed that the external force is evenly applied on the sheet. Thus, the uniformly-distributed load (p [N/m]) will be as follows.

$$p = P \times B \cong 70.1 N/m \quad (2)$$

Here, we focus on the bending at the convex portion as a severely deformed part. The curvature of the convex portion is assumed 50 mm (diameter is 100 mm) according to the comments of some occupational therapists. Therefore, the condition for the material calculation on this part will be the pure bending. Provided that the convex shape is completely circle (a half circle), the maximum deformation on the middle of the pure bending becomes 0.05 m.

According to the material calculation, if the thickness of the sheet (h) is bigger than 0.76 mm, the sheet does not enough flex to fit the concave portion. In this case, the thickness of the PP sheet is 0.75 mm. Thus the flexibility of the sheet is adaptable.

Additionally, in the case of the thickness of 0.75mm, the minimum curvature radius of the deformation becomes 39 mm in which the sheet does not generate permanent deformation, because we assumed that the curvature of this case is bigger than 50 mm. Therefore, the prepared PP sheet is enough tough for the back support.

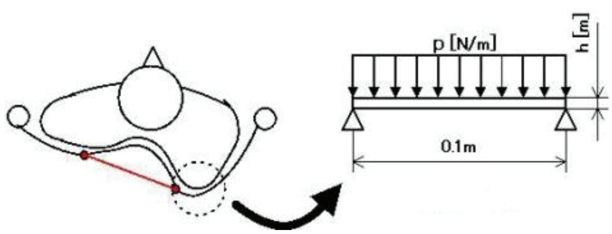

Figure 6. Condition for material calculation

C. Tension of adjustment belt

To evaluate the tension of the adjustment belt in the practical condition, we conducted a simple test as shown in Fig.7. We made an arch whose chord length was 0.1 m by pulling a wire whose one edge was fixed on the edge of the main sheet and another edge was fixed on the force sensor. A part of the gypsum model that is a part of the concave of the back was put on the arch and a lord of 14 N was applied on the gypsum model. The value of the lord was calculated from the same assumption mentioned in the section II-B.

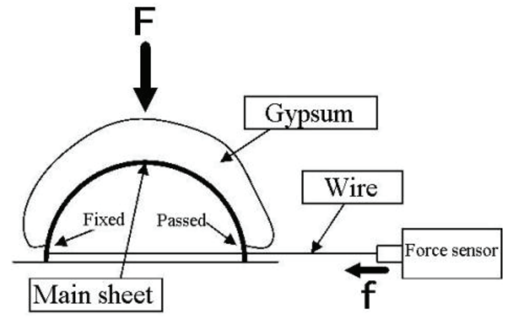

Figure 7. Test method for force measurement of adjust belt

As results, the tension of the wire was 0.8 N with the variation of the chord length of 0.58 mm. According to these result, the assumed tension that applied on the adjustment belt is inconsiderable.

D. Prototype of adjustable sheet

To evaluate the performance of the adjustable sheet on the seating system, we prototyped it by using a PP sheet and an adjustment belt (Fig.8, and 9). The PP sheet was cut by a width of 50 mm. We punched some holes aligned toward the longer direction of the sheet. We put some small hooks on these holes for fixing the adjustment belt. Seven adjustable sheets were installed on the side frames of the seat of an wheelchair as shown in Fig.10

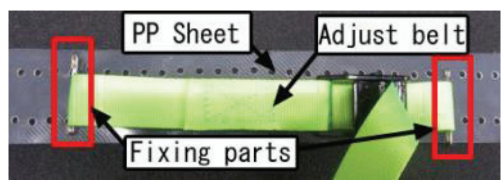

Figure 8. A prototype of adjustable sheet


Figure 9. Making arch with the adjustment belt

Figure 10. Prototype of i-Seating 2

III. Measurement system for back shape and adjustment method

A. Back shape measurement

In order to use the adjustable sheets as materials of the seating system, we should know the total length of the main sheets before users sit on the wheelchair. In addition, if we can know the fixing points of the adjustment belts, it must be useful. From this reason, we developed a measurement system for the back shape of the users and an adjustment method with the information of it.

A depth sensor (Microsoft Kinect Sensor) was adopted as a reasonable measurement device. We set the coordination system of the sensor as shown in Fig.11 and measure the depth (Z direction) of a back shape toward the transverse direction (X direction) on each Y position.

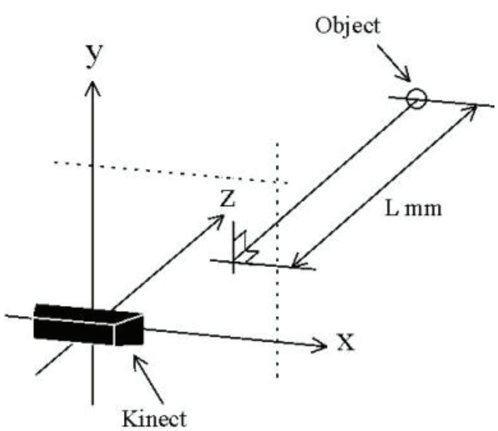

Figure 11. Position and coordination system for depth sensor

We set the Kinect sensor just behind a back so as to be parallel against it (Fig12). We defined the closest point of the back as a zero position and measured within 120 mm from it as a target surface. The back surface was evenly split in seven parts in the vertical directions and the depth data were averaged in the same zones (Fig.13). The surface length was calculated from the integration of the depth data (Fig.14). Validation tests were conducted for the measurement system with the Kinect sensor. There are about 5 % errors in the measured surface length, but the effect of the error is thought to be small.

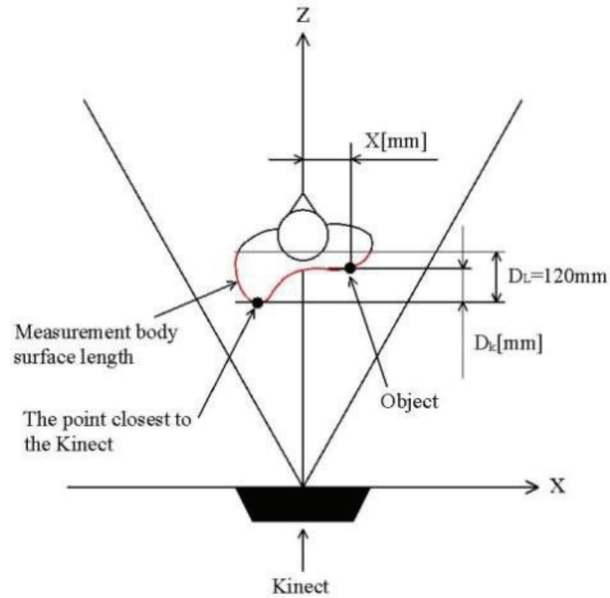

Figure 12. Measurement area of depth sensor

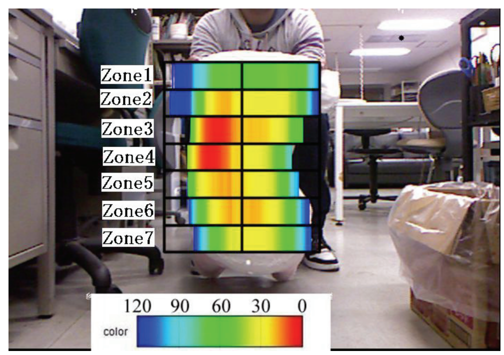

Figure 13. Measured image with depth sensor: contour map with color gradation for gypsum model

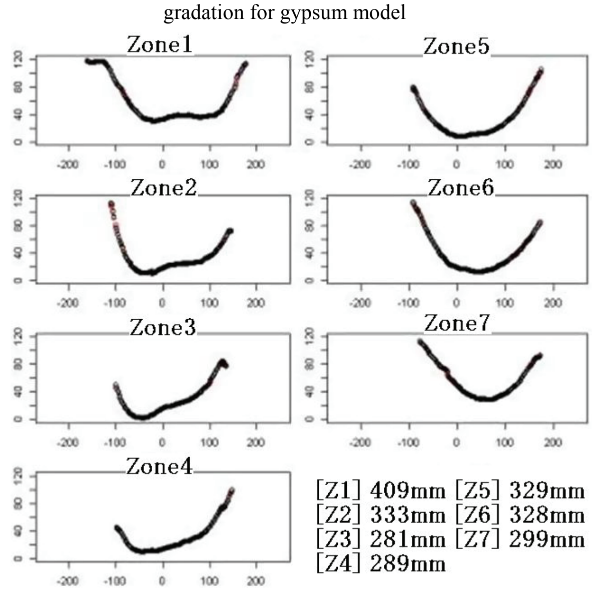

Figure 14. Result of measurements for gypsum model

B. Adjustment method

By using the surface information calculated with the measurement system, we can previously know the total length of the main sheet, and the fixing points of the adjustment belts on the sheet. The average total length of a part of the back (No.1 of Fig.15) can be calculated with the integration of the depth and transverse data of the measurement. We can manually select both edges of the concave portion of the back from the shape information of Fig.14. After the selection, the measurement system automatically calculates the surface length of the concave portion (No.2 of Fig.5), chord length of it (No.3 of Fig.5), and the length from left side to a selected point (No.4 of Fig.5). From the information we can adjust the total length of the main sheet, the length of the adjustment belt, and both fixing points for it.

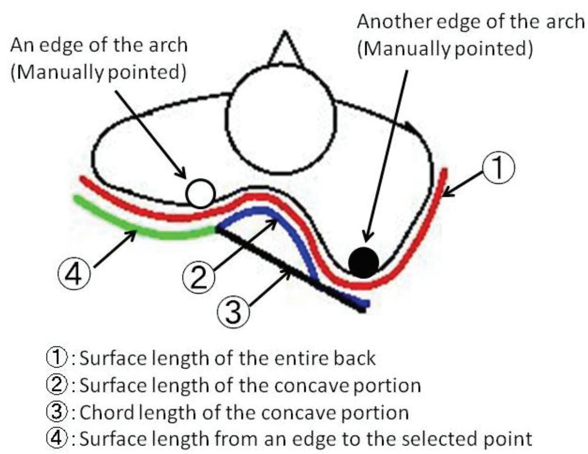

Figure 15. Each length for adjustment

IV. Validation Test for Dummy Backbone

In order to evaluate the performance of the measurement system and adjustable sheet, we conducted a validation test for a healthy person with a dummy backbone.

A. Method

As an experimental participant, a healthy young man was recruited. A flexible tube whose diameter is about 50 mm was attached on his back so as to make a complex shape as shown in Fig.16.

Figure 16. Dummy backbone

The back shape information was acquired with the measurement system as shown in Fig.17. By checking these shapes an operator selected both edge of the concave portions for each part of the back (dots in Fig.18). The total and partial lengths for adjustment were calculated from the data. The main sheets were arranged and installed in the seat of the wheelchair (left of Fig.19), and adjustment belts were installed on the estimated points with the estimated length (right of Fig.19).

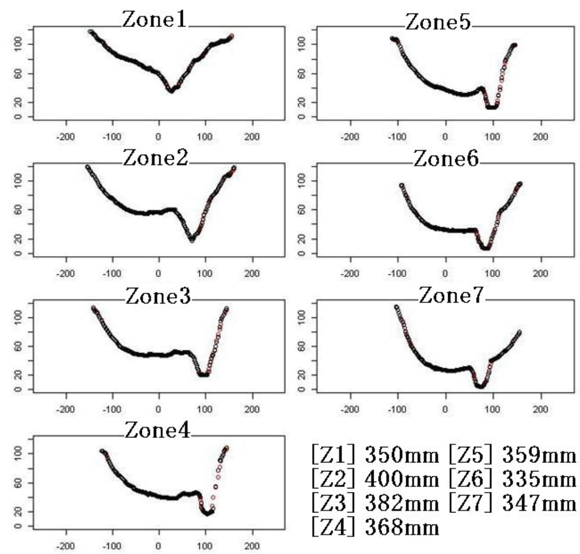

Figure 17. Surface information of dummy backbone

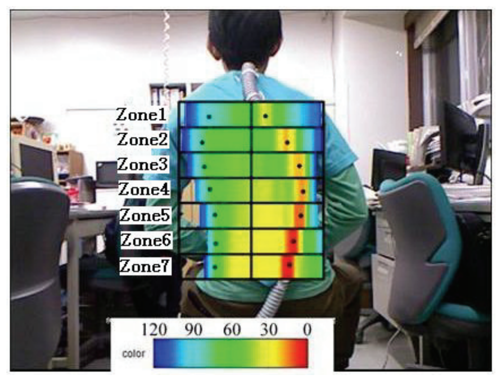

Figure 18. Measurement result for dummy backbone

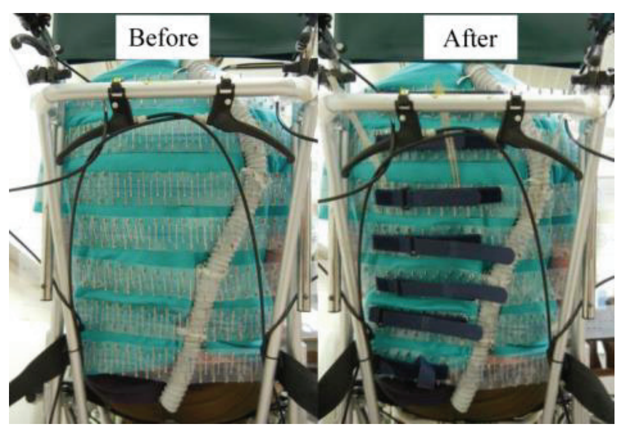

Figure 19. Appearance before / after adjustment

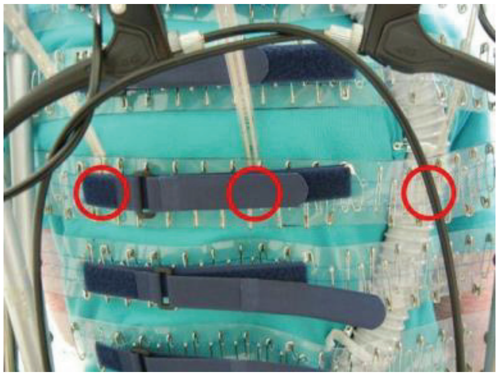

Figure 20. Positions of force sensors

Three flexible force sensors (Nitta, FlexiForce) were inserted between the back and main sheet installed at the third line from the top. These sensors were located at the left side, the middle of the concave portion, and the middle of the convex.

B. Result

Figure 21 shows rotational angles of shoulder lines before and after the adjustment. The angle was decreased with the adjustment of the adjustable sheets. After the adjustment, the angle was approximately zero. Although an extraneous substance existed on his back, the participant can comfortably sit on the seat.

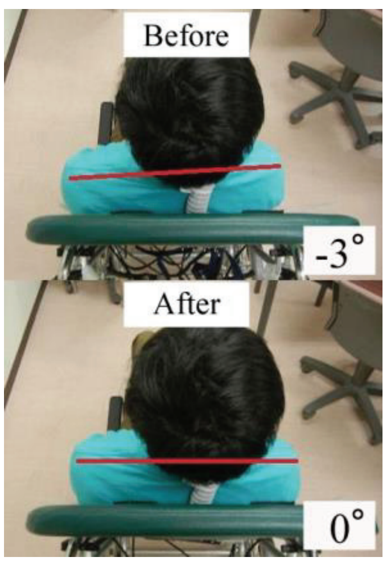

Figure 21. Rotational angle of shoulder before / after adjustment

The outputs of the flexible force sensor were summarized in Table I. The force distribution was uneven before the adjustment. There existed high pressure on the convex parts of the back despite there did not exist any pressure on the concave portion. On the other hand, the force distribution was averaged and the maximum force was reduced after the adjustment. The maximum difference of the force was reduced by 12 % of the initial values. The force just on the dummy backbone was reduced by 45 % of the initial values.

TABLE I. FORCE ON THE BACK BEFORE / AFTER ADJUSTMENT

Unit: N	Before	After
Left side	3.01	1.16
Concavity	0.00	1.26
Salient	3.47	1.56
Max. difference	3.47	0.40

C. Discussion

According to the experimental result, the adjustable sheet and proposed adjustment method performed to control the comfortable posture of the user and averaged the pressure distribution on the back. The dummy backbone made very extreme convex and concave on the back, but back shapes of real patients has more smooth deformations. Thus, this system has sufficient potential for use as a seating system for real patients.

V. CONCLUSION

In this paper, we proposed a new version of the i-Seating system. We prototyped an adjustable sheet for the seating and implemented it on the back support. The depth-sensor based measurement was utilized to recognize the shape of users' backs and decide the fixing points of the adjustment band. Experimental results show significant reduction of the pressure on the back of the dummy deformation of the spine.

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