Simulation of the Effect of Gravity, the Human body, and a Wheelchair on Active Balance Seating

Atsushi Tsukada[a], Shigeo Nishimura[b], and Tatsuo Hatta[c]

[a]Department of Mechanical Engineering, Meijo University, Japan (tsukada@meijo-u.ac.jp),

[b]Hokkaido Prefecture, Japan (dragon522jp2001@ybb.ne.jp)

[c]Faculty of Health Sciences, Hokkaido University, Japan (thatta@hs.hokudai.ac.jp)

1. Can the problem really be solved? We have doubts about the three supporting points.

In Japan, seating is conventionally performed without defining "What is a good posture?" According to results of success in paraplegic patients, seating has followed a uniform sequence starting from pelvic positioning, followed by arranging the upper body toward the lumbar region and head. For large three-dimensional posture deformations, the trunk is supported by three points (Fig. 1).

However, the effects of this seating practice have not been observed in many severely disabled users. In particular, do the three supporting points, developed under the theory of a spinal brace for a standing position, present difficulties when applied for seating? We have doubts about the three supporting points.

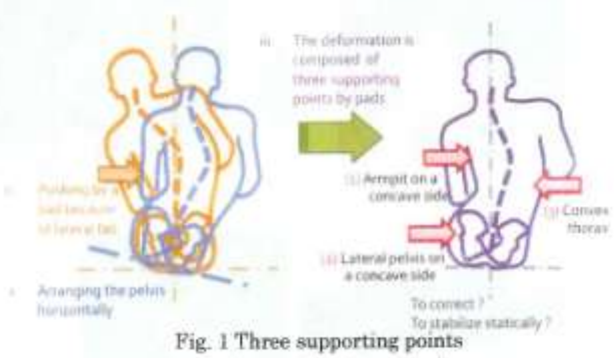


Fig. 1 Three supporting points (conventional practice)

2. Wheelchair designed physical movements—starting point for Active Balance Seating (ABS)

For a long time, S. Nishimura et al. have tried to find solutions for problems that conventional mainstream wheelchair seating practices could not address. We have performed experiments with cerebral palsy (CP) and muscular dystrophy patients, because setting the parameters according to the human body and wheelchair are more complicated and difficult in these patients. Furthermore, seating studies on the relationship among the individual, wheelchair, and other environmental factors have been carried out.

- Active Wheelchair

  The Active Wheelchair was developed for active CP patients in 1983–1986. There are two types of Active Wheelchairs. One is a foot-drive type (FWC: Figs. 2-4: 1983) and the other is a manual drive-type (AWC: Figs. 5 and 6: 1986). These novel wheelchairs were designed to perform cyclic motion and return the patient to an original posture without collapsing.

Fig. 2 The active FWC (1983)

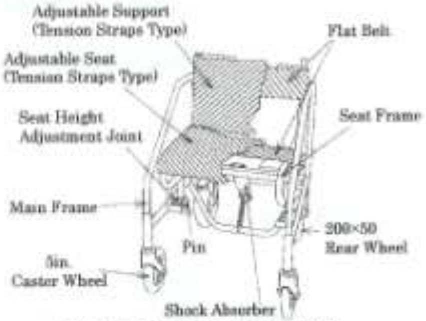


Fig. 3 Schematic of the FWC

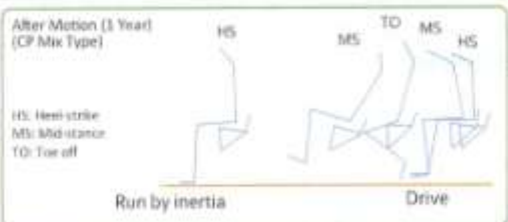


Fig. 4 Stick picture of the FWC movement

Motion using an AWC

Motion using a conventional manual wheelchair

Fig. 6 Motion using the AWC (upper) and conventional wheelchair (lower)

Fig. 5 The AWC (1986)

- Seating buggy

The Seating buggy (STB) was developed for CP patients with severe impairments (Figs. 7-11; 1993). The novelty included creation of a pelvic support system with independent equipment on the other seating parts such as a back support sheet. The pelvic support system is intended to arrange the pelvic posture in a position to provide good control of the head and neck. Furthermore, the pelvic support system has automatic fitting and self-centre functions, even if the user moves on the seat.

In addition, the STB seating was designed to be arranged in a short time, because standard Japanese delivery service is not possible in Hokkaido, where the STB was developed. Hokkaido is the northernmost island and largest prefecture in Japan. Hokkaido is very similar to Ireland (Fig. 12).

Fig. 7 Target user

Fig. 8 The STB (1993)

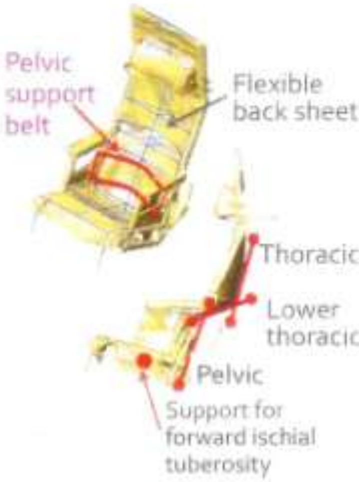


Fig. 11 Common formation

Fig. 9 Pelvic support system (independent equipment)

Fig. 10 Support for the forward ischial tuberosity (independent equipment)

Fig. 12 Similarity between Hokkaido and Ireland

3. Definition of Active Balance Seating (ABS)—thorax-supporting model, for example.

What is good posture? Active Balance Seating (ABS) was constructed as a result of what many disabled users have taught and showed us. ABS clearly defined "good posture" and is the common methodology regardless of the type of disability and its severity (S. Nishimura, 2002). The major characteristics are as follows:

I. Applying a minimum energy condition (Fig. 13b) to each disability.
II. The head and neck are indicators of good posture.
III. Making effective use of gravity.

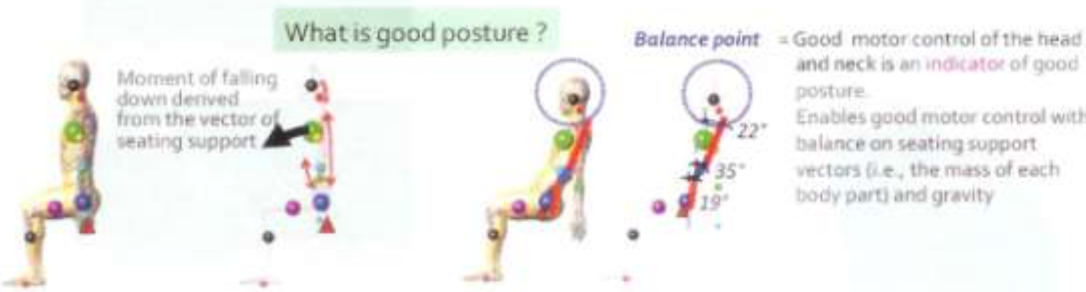


Fig. 13a 90-90° posture. This posture is necessary for user effort.

Fig. 13b Minimum energy posture

To be established these I – III, novelty was defined "principal support" and "ancillary support".

- **Principal support** (Figs. 14 and 15)
  - Simplification of muscular activity.
  - Simple configuration for easy motor control.
  - Support around the origin of the following:
    - Trapezius muscle
    - Erector spinae muscles
    - Hamstring muscles

- **Ancillary Support** (Fig. 15)
  - Non-invasive and flexible support.
  - Decompression on the seat.
  - No interference with breathing (respiratory motion).

Fig. 14 Principal supports (●) correspond to the patient's caregiver's arms when carrying the patient.

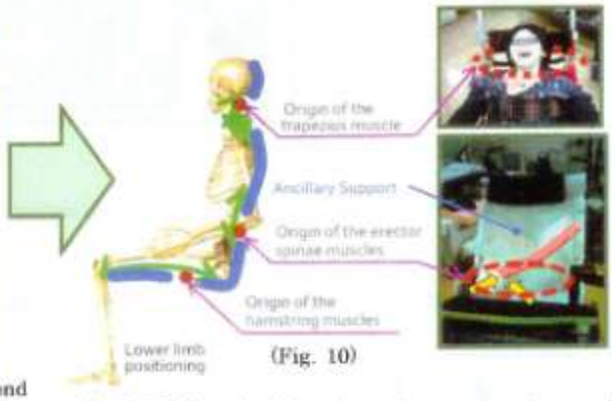


Fig. 15 ABS methodology (e.g., thorax-supporting model)

The moment of falling down can be minimized. Through slight adjustments to the balance support, the fall is set in a better direction so that it acts as a body extension. Therefore, the user can physically move with support from the seat. Furthermore, the user can individually perform cyclic motion and return to an original posture without collapsing. Doing so draws better functionality, even in cases with asymmetric posture such as scoliosis. These settings of the ABS theory promote posture arrangement over time (Fig. 16).

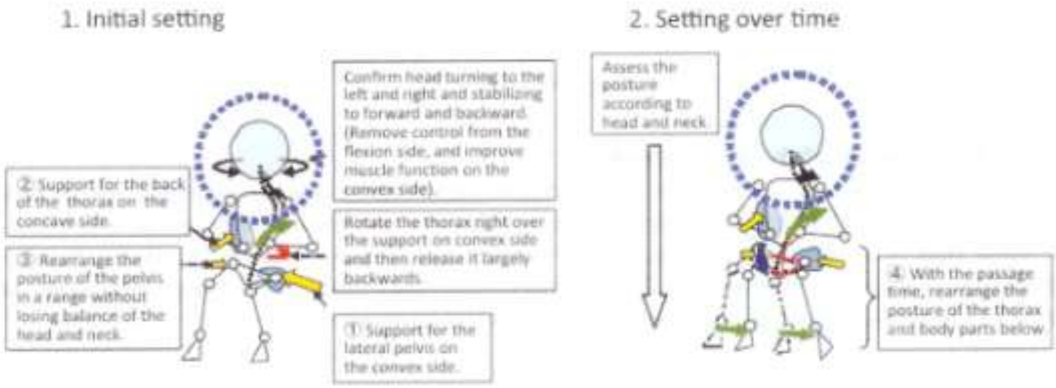


Fig. 16 Methodology of the initial and over time ABS settings

Fig. 17 Results of posture before and after usage of an ABS Wheelchair

The theory of ABS is to apply a minimum energy condition to achieve balance between gravity and the mass of each physical part, and to apply the material properties of the seat-interface while considering the characteristics of each physical region. Wheelchairs based on ABS could be used to reveal the users' potential physical abilities that are not detected with the conventional method (Fig. 17).

- Expanded ABS—Design for all (Universal Design)

ABS is a common conceptual methodology regardless of the type of disability and its degree of severity. For example, ABS can be applied to the hemiplegia (Fig. 18). Furthermore, this is true for non-disabled persons, because ABS was applied to the design of the office chair (Fig. 19).

Fig. 18 Left hemiplegia (asymmetric, slip sitting posture)

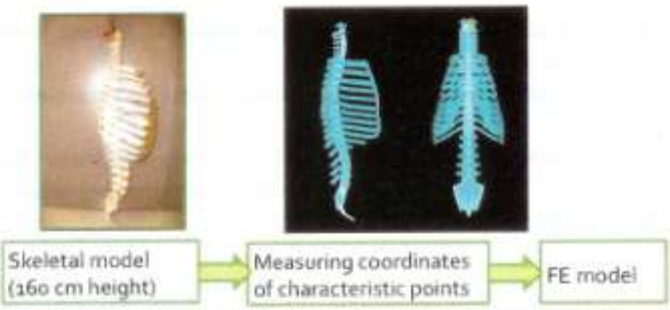
Fig. 19 Office chair with ABS

4. Biomechanical simulation of the human body

The aim of this simulation was to analyse our doubts regarding the three supporting points. A second aim was to also develop a visualisation of the biomechanical situation of gravity, the human body, and a wheelchair in ABS to counter the claim that it is difficult for seating concerned persons to understand ABS seating, because it vastly differs from conventional seating methodology. It is expected that visualisation of the biomechanical situation would have a great effect on users or seating concerned persons to better understand the essential problems.

4.1 Modelling

A three-dimensional model of the spinal column and thorax was constructed, and finite element (FE) analyses were carried out. It was assumed that a model of only the skeletal system is similar to a user with low activity of the antigravity muscles. The FE model was generated on a computer by measuring coordinates of characteristic points on a skeletal model. The spine model was composed of the vertebrae (cervical, thoracic, and lumbar), intervertebrae, sacrum, and coccyx. The thorax model was composed of the ribs, costal cartilage, and sternum. The costovertebral joints were represented to substitute the articular cartilage.



- Standing height: 160 cm • Number of elements: 15572
- Weight: 48.6 kg • Number of nodes: 23834

Fig. 20 Construction of the FE model

4.2 Load and boundary conditions

The vertebrae and intervertebral disks were entered according to the material properties of cortical and cancellous bones and those of the annulus fibrosus and nucleus pulposus, respectively. The sacrum, coccyx, and spinous process were entered as general cortical material properties, because it was assumed that the difference of properties between cortical and cancellous bones was not affected by the deformity caused by loading. A model was developed for seating and standing to confirm the difference from the action of gravity (Fig. 21). The seating model was represented by tilting 15° simply from a vertical line. The load conditions were set as the head weight and its moment distributed at each cervical vertebra.

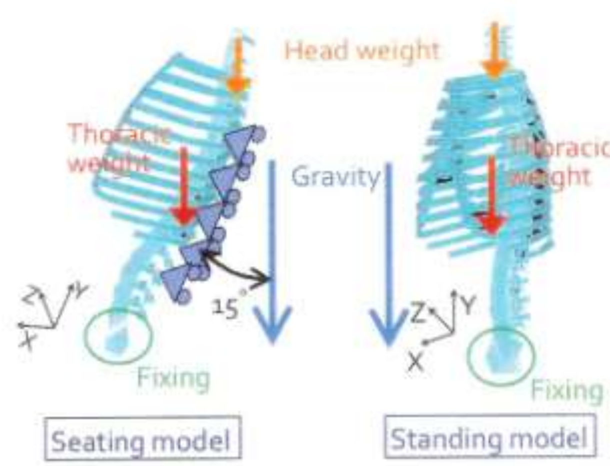


Fig. 21 The loads and boundary conditions of each model

Table 1 Material properties

	Young's modulus [MPa]	Poisson's ratio	Modulus of transverse elasticity [MPa]	Density [kg/m³]
Cortical bone	(x) 700 (y) 1000 (z) 700	(xy) 0.315 (xz) 0.45 (yz) 0.315	(xy) 241 (xz) 241 (yz) 241	1800
Cancellous bone	(x) 140 (y) 200 (z) 140	(xy) 0.315 (xz) 0.45 (yz) 0.315	(xy) 48.3 (xz) 48.3 (yz) 48.3	860
Annulus fibrosus	13.3	0.4		1065
Nucleus pulposus	0.1	0.49		1000
Costal bone	5000	0.3		1800
Costal cartilage	500	0.3		1800
Costovertebral joint	1.1	0.3		1000

4.3 Results

The following figures show the simulation results between standing and seating. Application of displacement and equivalent stress (Figs. 22 and 23) visually confirmed that the biomechanical situations change considerably owing to differences in the action of gravity in the standing and seating models.

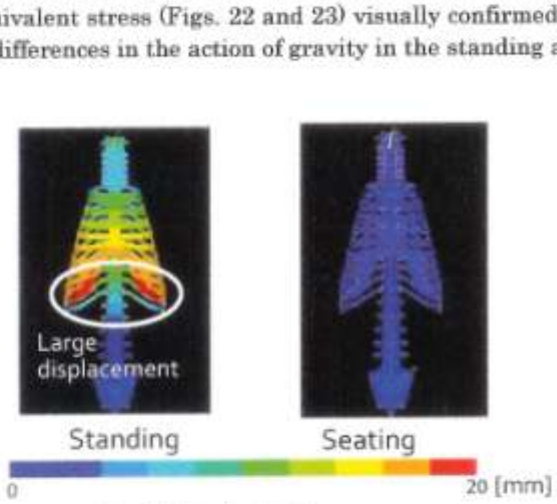


Fig. 22 Displacement

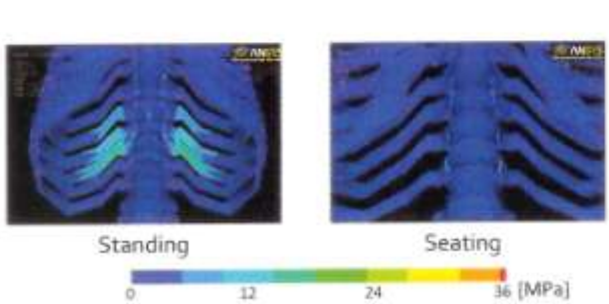


Fig. 23 Equivalent stress

5. Conclusion

In this study, it was necessary to conduct a biomechanical simulation of seating based on the differences between ABS and conventional seating schemes.

We developed a model that can be used for visualising the biomechanical interactions of the human skeletal system when assuming wheelchair seating.

In the future, in studies using this model, it will be important to include nonlinear characteristics of body parts and implement time-dependent analysis. Development of ABS and conventional wheelchair models to analyse the biomechanical situation while seating will also be needed.

Acknowledgment

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