

# Using Seating Techniques as a Preventative Measure against Lower Limb Edema —The Effect of Combining Tilt Angle and Reclining Mechanisms on Wheelchairs

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**Abstract.** [Purpose] The purpose of this study was to evaluate the effects of wheel chair tilt systems on lower limb hemodynamic states and their relationship to mechanical factors using near-infrared spectroscopy and a pressure distribution measuring system. [Subjects] Twelve healthy adult volunteers participated in this study. [Methods] We measured the lower limb hemodynamic states and pressure distribution experienced in a wheelchair in four tilt-conditions: reclining by five degrees, ten degrees, twenty degrees and full tilt-reclining. [Results] The results show a significant decrease in Deoxy-Hb was induced in the full-tilt reclining position. Furthermore, in comparison with the other sitting positions, full-tilt reclining produced a decrease in contact area, especially in the posterior femoral region. [Conclusion] These results suggest wheelchairs that combine tilt and reclining capabilities can, by altering the sitting position and thus improving lower limb hemodynamic states, prevent venous edema in wheelchair users who cannot perform active muscular pumping.

**Key words:** Tilt reclining, Venous return, Seating

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## INTRODUCTION

In recent years the increasing number of wheelchair-bound elderly in hospitals and welfare institutions has become a pressing concern. Studies suggest that some residents spend over 10 hours a day in their wheelchairs<sup>1)</sup> and that the duration of sitting and occurrence of edema are positively

related<sup>2)</sup>. It is believed that extending the duration of sitting induces the accumulation of blood in the lower limb veins, a factor contributing to venous edema. Venous edema is a condition caused by venous pressure and venous stasis that results in inhibited venous return<sup>3)</sup>. Treatment for this condition generally involves active movement and leg elevation. However, due to illness or disability

many elderly wheelchair users cannot move themselves and there is a tendency for venous edema to occur in their lower limbs.

In our previous study<sup>4)</sup> on the relationship between wheelchairs with tilt capabilities and lower limb elevation function, we measured lower limb hemodynamic states. Those results showed a significant increase in venous return when the tilt angle was 30 degrees, confirming tilt angle as a method for preventing blood accumulation, and the efficacy of this seating based method was quantitatively verified. However, that study only compared the basic sitting position with 30 degree tilt; it did not measure the effects of full-tilt reclining or intermediate positions.

Generally tilt capable wheelchairs used in hospital and welfare institutions can be adjusted between -11 and +55 degrees of tilt. It should be noted that tilt can be achieved not only by using a specifically constructed tilt mechanism, but also by adjusting other components of the wheelchair such as the size of the casters and wheels. Based on the physical condition of the user, a combination of tilt and reclining mechanisms are often used.

Although the relative positions of the heart and lower limbs have been shown to significantly increase venous return, the degree to which other factors may influence venous return is still unclear. As other studies show<sup>5)</sup>, if we look at the relationships between hemodynamic states and mechanical factors we see that subcutaneous hemodynamic states and external pressure on the limbs are negatively related. However, although we conducted a review of the existing literature on this topic, research relating to the physiological and mechanical evaluation of tilt-enabled wheelchairs was not found.

Therefore, we decided to conduct experiments to evaluate the effects of varying tilt angles and full-tilt reclining on lower limb hemodynamic states and their relationship with mechanical factors by using near-infrared spectroscopy (NIRS) and a pressure distribution measuring system.

## SUBJECTS AND METHODS

Twelve healthy adult males (age  $23.8 \pm 5.3$ , height  $169.9 \pm 4.3$  cm, weight  $62.4 \pm 4.4$  kg) participated in this study. Before commencing this study, all participants received a written explanation of the aims and nature of the research and signed

consent forms indicating they understood these aims and voluntarily agreed to take part in the study.

In order to minimize the effect of tight fitting garments on lower limb hemodynamic states, participants were instructed to wear loose fitting short-sleeved T-shirts and shorts. In order to keep the pelvis close to the backrest during measurement, participants placed their buttocks as far back in the chair as possible. The subjects were instructed to lightly rest their upper limbs close to their thighs and to rest their head against the headrest whilst looking ahead at a comfortable angle. They were further instructed not to move their limbs or trunk during measurement.

During the experiment adjustable tilt-enabled wheelchairs (LAC Healthcare, Netti III) were used. Seat depth, leg support height and head support positions were all adjusted to suit the participants' physiques. Instead of the standard urethane foam cushion, a newly designed 2 cm deep urethane foam cushion with a wooden base was used.

The experimental conditions were 5-degree tilt (tilt angle 5°, back-support 95°, leg-support 30°); 10-degree tilt (tilt angle 10°, back-support 95°, leg-support 30°); 20-degree tilt (tilt angle 20°, back-support 95°, leg-support 30°) and full-tilt reclining (tilt angle 20°, back-support 120°, leg-support 30°).

In order to maintain body posture under each condition the most suitable angle for the backrest is between 95 and 105 degrees<sup>6)</sup>. For the wheelchairs used in this experiment the most suitable footrest angle in the full-tilt reclining position was between 20 and 30 degrees<sup>7)</sup>. In this research the differences between each configuration were based on the lowest discernable angle of change as reported in other studies<sup>8)</sup>.

In order to measure hemodynamic states in the lower limbs an NIRS tissue blood oxygenation monitor (Omegawave Co., BOM-L1TR, Japan) was used. NIRS uses hemoglobin's reaction to near infrared light to non-invasively calculate the density of oxygenated hemoglobin (Oxy-Hb) and deoxygenated hemoglobin (Deoxy-Hb) in the blood<sup>9)</sup>. Thus, on the left lateral posterior surface of the lower thigh a stabilized probe was placed on the gastrocnemius muscle. Measurements were taken in a semi-orbicular tissue compartment at a depth of 0–20 mm. From these results the total hemoglobin (Total-Hb), Oxy-Hb and Deoxy-Hb levels were calculated.

Hemodynamic states were first measured at a sampling frequency of 1 Hz for five minutes whilst

the subject was in the basic sitting position (seat angle 2°, back-support 95°, leg-support 30°). The average value for Total-Hb, Oxy-Hb and Deoxy-Hb during the last 30 seconds of this experiment was taken as the baseline values. Thereafter, we measured the hemodynamic states under the four conditions of tilt and recline, leaving 1 minute's rest between each measurement. The average value for the last 30 seconds of each condition was calculated and, from the average value, the value (percent) relative to the baseline measurements were calculated.

In order to measure seat pressure a pressure distribution measuring system (NITTA Co., CONFORmat, Japan) was used. The mat size was 471 × 471 mm, the resolution was 32 × 32 points and the pressure measurement range was 0–35 kpa. The sensor mat was placed between the subject and the wheelchair seat. Pressure measurements (sampling rate 1 Hz) were taken simultaneously with the measurements for the hemodynamic states under the four conditions, however values for the first 30 seconds of each sitting were used. The average values for the last 3 seconds of the initial 30 seconds were used to generate the data for the contact area. Furthermore, images recorded during the experiment were converted into isobaric pressure maps and qualitative analysis was performed.

Statistical analysis was performed using one-way analysis of variance (ANOVA) to evaluate the rate of change of the hemodynamic states and the pressure in the contact area under the four conditions. When a significant difference was recognized, a multiple comparison test was performed using the Bonferroni test method. The level of significance was set at  $p < 0.05$ . Data was analyzed using SPSS 14.0 statistics software.

## RESULTS

Under the 4 conditions, significant differences were identified in Deoxy-Hb levels. The multiple comparison results for the three tilt positions and the full-tilt reclining position show a marked decrease in Deoxy-Hb occurred in the full-tilt position: 5-degree tilt,  $102.6 \pm 17.4\%$ ; 10-degree tilt,  $102.8 \pm 13.9\%$ ; 20-degree tilt,  $98.4 \pm 14.1\%$  and full-tilt reclining,  $88.3 \pm 15.1\%$ . However, as can be seen in Table 1, no significant changes were identified for Oxy-Hb and Total-Hb levels.

**Table 1.** Hemodynamic State Results for Sitting Positions

	Oxy-Hb	Deoxy-Hb	Total-Hb
5-degree tilt	$98.8 \pm 7.4$	$102.6 \pm 17.4$	$99.8 \pm 10.3$
10-degree tilt	$100.6 \pm 5.9$	$102.8 \pm 13.9$	$101.2 \pm 8.4$
20-degree tilt	$102.9 \pm 6.9$	$98.4 \pm 14.1$	$101 \pm 8.9$
Full-tilt reclining	$102.6 \pm 6.6$	$88.3 \pm 15.1^*$	$97.2 \pm 9.3$

percentage: %, n=12, \* $p < 0.05$ .

**Table 2.** Contact Area Results for Sitting Positions

	Contact Area
5-degree tilt	$855.1 \pm 92.5$
10-degree tilt	$870.9 \pm 107.1$
20-degree tilt	$841.9 \pm 84.7$
Full-tilt reclining	$672.8 \pm 100.5^*$

percentage: %, n=12, \* $p < 0.05$ .

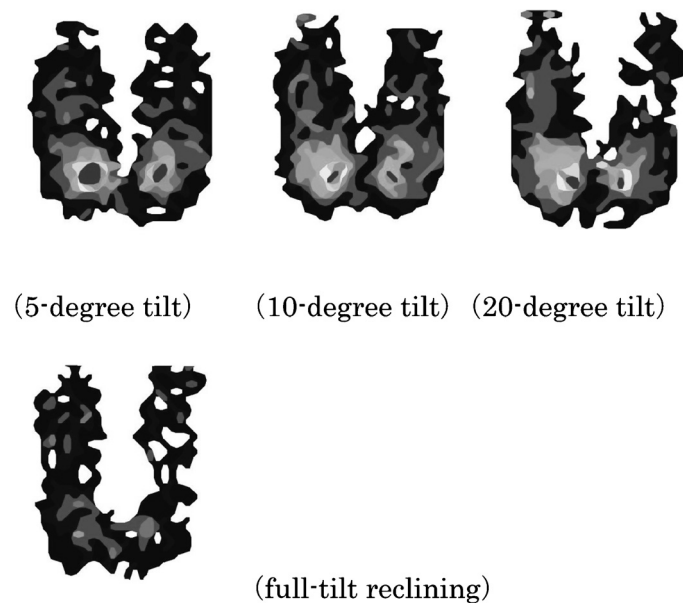
The size of contact area across the 4 conditions also showed significant differences. As can be seen in Table 2, the multiple comparison results for the three tilt positions and the full-tilt reclining position, show a marked decrease in contact area occurred in the full-tilt position: 5-degree tilt,  $855.1 \pm 92.5 \text{ cm}^2$ ; 10-degree tilt,  $870.9 \pm 107.1 \text{ cm}^2$ ; 20-degree tilt,  $841.9 \pm 84.7 \text{ cm}^2$  and full-tilt reclining,  $672.8 \pm 100.5 \text{ cm}^2$ .

Figure 1 shows the pressure distribution measurement results for the typical values of contact area experienced under each test condition in an isobaric pressure map. When the three tilt positions were compared with the full-tilt reclining position, the results showed reduced overall contact area for all subjects in the full-tilt position, especially in the size of the contact area of the posterior femoral region.

## DISCUSSION

Tilt mechanisms are mechanisms that allow a user to tilt the seat and back-support forwards or backwards in unison. Using tilt mechanisms to prevent falls or to disperse overall pressure levels is a method widely practiced in care environments, however the relationship between tilt mechanisms and blood flow stasis is not well understood<sup>10</sup>.

Among the elderly, the incidence of edema in the lower limb and leg<sup>11</sup>, which occurs for a variety of reasons, is remarkable. In particular those elderly who are wheelchair-bound experience a high level of



**Fig. 1.** Isobaric Pressure Map of Contact Area

risk. Furthermore, it is believed that this risk is positively correlated with the length of time they must spend in the wheelchair. The structure of wheelchairs and the associated effect on the posture of the user has been identified as a contributory factor in the development of deep-vein thrombosis (DVT), of which edema is one of the main symptoms<sup>12</sup>.

The use of foot-support elevating mechanisms to raise the legs and combat lower limb venous edema in wheelchair users who have a decreased level of muscle pump caused by paralysis or pain, has become widely practiced. However, raising the legs, that is to say extending the knee joint in patients whose hamstrings cannot be fully extended, may lead to slipping around in the chair. Therefore, in our previous study we brought attention to the fact that tilt mechanisms can be used as a method to raise the lower limbs, and further reported that a 30-degree tilt angle resulted in significant increase in venous return.

In our present study we researched the effects of differing tilt-angle configurations and full-tilt reclining positions on venous return. Moreover, in order to determine the relationship between venous return and mechanical causes we measured and tested pressure distribution on the seating surface.

The results show that in comparison to the 5-, 10- and 20-degree tilt positions, Deoxy-Hb showed a significant decrease in the full-tilt reclining position. However, changes in Oxy-Hb and Total-

Hb levels were not observed. Given that a significant decrease in Deoxy-Hb is indicative of an increase in venous return<sup>13</sup>, these results show that although tilt configured between 5 and 20 degrees did not significantly influence the levels of venous return in the lower limbs, full-tilt reclining had a large affect on this process. Combining the results of this study and our previous study, it becomes clear that if a tilt mechanism is used in isolation, it is necessary to configure the tilt to 30 degrees, however if both the tilt and reclining mechanisms are combined, it is possible to increase venous return at 20 degrees of tilt.

The results for the size of contact area show that only a significant decrease was seen in the full-tilt reclining position and that this decrease was particularly noticeable in the posterior femoral region. Contact area was considered as a parameter not in terms of the level of pressure, but whether there was contact or not. It is thought that the contact area decreases in the full-tilt reclining position as a result of the weight being shifted from the sitting surface towards the head and back-support<sup>14</sup>. Regarding the relationship between hemodynamics and pressure, it has been reported that pressure exerted on the posterior femoral region impedes blood flow<sup>15</sup>. Furthermore, reducing pressure on the posterior femoral region is an important factor in reducing resistance to venous return<sup>16</sup>. In the full-tilt reclining position the

contact area in the posterior femoral region is decreased, and thus the force of compression on the popliteal vein and great saphenous veins running through the connective tissue between the skin and fascia around the femur is decreased<sup>17)</sup>. Therefore, a decrease in the contact area may also affect lower limb hemodynamics.

Given the evidence presented above, it can be argued that full-tilt reclining lowers the position of the heart relative to the limbs<sup>4)</sup> and, through reducing the amount of contact area in the posterior femoral region and other such causes of resistance, increases the amount of venous return.

It is important to prevent edema because it induces tissue contracture and adhesion in the surrounding tissue. However, due to the growing time restrictions on hospital and welfare institution staff there is a limit to the amount of therapeutic massage that can be performed in order to minimize the incidence of edema<sup>18)</sup>. When viewed from the context of seating based therapy, using adjustable wheelchairs that can both tilt and recline would enable the prevention of venous edema in patients who do not possess the ability to move their limbs by themselves. Furthermore, as this method does not require specialized medical equipment or installation it can easily be incorporated in a daily program of care.

This research has shown that in order to increase venous return using a tilt and recline method requires a tilt of at least 20 degrees. This research has further shown not only the importance of the relative positioning of the heart and limbs on venous return, but also how pressure exerted on the posterior femoral region influences venous return. Given that this data was obtained using healthy subjects, it is still necessary to carry out further research using actual wheelchair users in order to fully verify that full-tilt reclining is a viable method of increasing venous return and thus reduces the incidence of edema in long-term wheelchair users. However, these initial results are encouraging.

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