Usability Evaluation of Electric Adjustable Bed during Back-Support Elevation Using Motion Analysis Method

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Abstract
Recently, the number of bedridden patients has increased because of the rapid growth in the aging population worldwide, and most of them have lived on an electric adjustable bed (EAB). Caring for these patients on an EAB is easier and more comfortable than on the floor or a manual adjustable bed. However, the use of an EAB has a negative effect on the slip length and the dorsal and abdomen loads on the patients. Therefore, the aim of this research was to evaluate the usability elements by elevation of the EAB’s back support using a motion analysis.
In this study, an experiment with 10 subjects (5 men, 5 women, 29.9 ± 2.28 years, 165.8 ± 8.26 cm, 64.2 ± 11.7 kg; mean ± SD) was carried out. The relative motions of the EAB and subjects were captured by a motion analysis system using a customized marker set (EAB: 24 markers, subject: 16 markers, U.E.T.C.).
The results of this study show that the slip length and the dorsal and abdomen loads increased as the back support of the EAB was further elevated, and the slip length and dorsal load were not restored when the elevation angle was returned to 0°.
A trend toward decrease in changing rate of dorsal load while increase of abdomen load were observed when the back support was elevated from Sections II-1 and II-2 (head-of-bed elevation from 30° to 60°).
It would be expected that development of new care technology and care service would be possible with the results and methods of this study.

Keywords: Head-of-bed elevation, Dorsal load, Abdomen load, Slip length, Electric adjustable bed, Bedridden patient

Introduction
Bedridden patients who spend most of their time in beds experience different loads on their body parts according to bed movement, which lead to pressure ulcers and ventilator-associated pneumonia [1-3]. Accordingly, various studies have been conducted to examine the body-pressure distribution according to bed movement [4], to develop the optimal pattern [5-8], and to propose a desirable motion angle [9]. Particularly, during head-of-bed (HOB) elevation, the pressure on the back moves onto the pelvis as the body slips downward, thereby generating high loads on the sacrum and heels; for this reason, this pressure is regarded as a cause of pressure ulcers in these parts [10]. Numerous studies have investigated the optimal angle during HOB elevation, and these previous studies have proposed the following desirable angles: 45° [11-13] and between 30° and 45° [14-20] to prevent pressure ulcers through pressure dispersion. Moreover, previous studies have also proposed various solutions to disperse the contact pressure when the body pressure changes (force movement) during HOB elevation [5-8, 21], and such analyses of the contact pressure were mainly performed for the sacrum and heels. However, other than pressure ulcers in the sacrum and heel regions, HOB elevation also generates problems such as a shearing force due to the body slipping on a mattress and dorsal or abdomen loads due to a decreasing angle. Such pressure has been considered to cause digestive disorders and dysphagia.
To solve this problem, a study was performed on the development of various electric adjustable beds (EABs) that have a folding structure and define care motion [22], the contact pressure regarding the dorsal loads during HOB elevation was examined. However, although such pressure is generated by bed movement and slipping of the body, few studies have examined the degrees of the dorsal and abdomen loads by analyzing the interaction between the bed and the body during HOB elevation. Hence, this study determined a correlation between body markers by analyzing the interaction between the bed and the body during HOB elevation and analyzed variation in the slip length of the body as well as the degrees of dorsal and abdomen loads to identify problems and causes in terms of the interaction between the bed and the body and solve problems generated by HOB elevation.

Method
Subjects: Ten subjects consisting of five males and five females (29.9 ± 2.28 years, 165.8 ± 8.26 cm, 64.2 ± 11.7 kg, and BMI: 23.2 ± 3.0 4 kg/m²; mean ± SD) participated in an experiment on analyzing motions according to the HOB elevation. Only subjects who satisfied the following conditions were selected for the experiment: the capability of assuming a typical supine position, the absence of skin problems because sensors need to be attached, the understanding of and conformity with the instructions provided by an experimenter, the understanding of experimental details and procedures, and agreement with the conditions of
the experiment.

**Measuring Data:** The functional angles of a back-support plate of the EAB, which are applied to those who spend their time in bed, were selected, and motion capture of each angle was performed by changing the angle as follows: $0^\circ \rightarrow 10^\circ \rightarrow 15^\circ \rightarrow 20^\circ \rightarrow 30^\circ \rightarrow 45^\circ \rightarrow 60^\circ \rightarrow 80^\circ \rightarrow 0^\circ$ (Fig. 1). To apply an exact angle in the experiment, a measurement was performed within an error range of $\pm 0.1^\circ$ by attaching an electric goniometer to the frame of the EAB.

A customized marker set was utilized to analyze the slip length, dorsal load, and abdomen load of the body. Among the 40 markers, 16 markers [Head (2 ea), Shoulder (2 ea), Clavicle (1 ea), Sternum (1 ea), Iliac crest (2 ea), ASIS (2 ea), GT (2 ea), Knee (2 ea), and Ankle (2 ea)] were attached to the bodies of the subjects, and as a result, six virtual markers [Chead (center of head), Csho (center of shoulder), Cpel (center of iliac), Cgt (center of greater trochanters), Ckne (center of knee), and Cank (center of ankle)] were generated (Fig. 2-1). Twenty-four markers were attached to the EAB [top of mattress (8 ea), bottom of mattress (6 ea), frame of EAB (10 ea)] (Fig. 2-2).

**Data Analysis:**

- **Slip Length:** The slip lengths of the head (Chead), shoulder (Csho), and pelvis (Cpel) were measured on the basis of the dUMAT marker attached to the upper mattress of the EAB, and the slip lengths of the knee (Ckne) and ankle (Cank) were measured on the basis of the dLMAT marker (Fig. 3). An initial value was set as zero, and the distance variation was defined as the slip length.
- **Dorsal Load:** The dorsal loads were analyzed on the basis of the changes in the length ($L_{dsl}$) of a dorsal region that was defined to be from the virtual marker of Csho, which indicates the center of both shoulders, to that of Cpel, which indicates the center of both iliac markers. The analytic results showed that the dorsal loads increased as $L_{dsl}$ decreased and that the dorsal loads decreased as $L_{dsl}$ increased (Fig. 4).

The abdomen loads were analyzed on the basis of the...
angle between the spine and the pelvis. Through this analysis, it was found that increasing the angle of the back-support plate of the EAB led to tilting of the pelvis and that the abdomen loads increased as the angle ($\theta_{adl} = \angle C_{sho}C_{pel}C_{gt}$) between the spine ($C_{pel}C_{gt}$) and the pelvis ($C_{pel}C_{gt}$) decreased (Fig. 4).

Analysis of Dorsal and Abdomen load

![Diagram](Image)

Figure 4. Analysis of the dorsal and abdomen loads

Results

Table 1. Results for the variation in the slip length (units: mm)

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<td>14.98</td>
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<tr>
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<tr>
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<td>50.23</td>
<td>51.35</td>
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<tr>
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<td>22.26</td>
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<td>96.31</td>
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<td>109.24</td>
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<td>-29.80</td>
<td>-20.90</td>
<td>30.43</td>
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Results for the Slip Length: As the angle of the back-support plate of the EAB increased, the distances from the upper part (dUMAT) of the mattress to the head (Chead), shoulders (Csho), and pelvis (Cpel) decreased, thereby increasing the distance variation. On the other hand, when the back-support plate descended to the initial angle of $0°$, the distance decreased compared to the initial state, thereby leading to a distance variation that was less than zero. The distances from the upper mattress to the head (dUMAT – Chead), shoulder (dUMAT – Csho), and pelvis were 24 mm, 28.9 mm, and 20.8 mm, respectively, thereby decreasing the distance variation and indicating movement to the feet. Moreover, the distances from the lower part (dLMAT) of the mattress to the knee (Ckne) and ankle (Cank) decreased, thereby increasing the distance variation; when the back-support plate of the EAB descended to the initial angle of $0°$, the distance decreased compared to the initial distance, thereby leading to a distance variation greater than zero. The distances from the lower part of the mattress to the knee (dLMAT – Ckne) and ankle (dLMAT – Cank) were found to be 30 mm and 28.2 mm, respectively, thereby indicating movement to the feet (Table 1).

Results for the Dorsal Load: In Section I in Fig. 5, $L_{dsl}$ was 453.2 ± 33.6 mm at the initial angle of $0°$, and this distance tended to constantly decrease during HOB elevation. In Section II in Fig. 5, $L_{dsl}$ constantly decreased until
Section II-2 while exhibiting a gradual decrease in Section II-3. Ldsl reached a minimum value of 395.2 ± 26.8 mm at an angle of 80° and then increased to 445.2 ± 29.2 mm at the initial angle of 0° in Section III. However, this distance was lower by approximately 9 mm compared to that before the angle of the back-support plate increased. This distance difference occurred owing to the dorsal loads, which were not removed by the resistance to the shear force during the descent after HOB elevation (Fig. 5).

Results for the Abdomen Load: The value of $\theta_{adl}$ was $174.0 \pm 3.8^\circ$, which is close to $180^\circ$, at the initial angle of 0°, and it tended to decrease as the back-support plate of the EAB ascended. When the angle of the back-support plate was 80°, the value of $\theta_{adl}$ was the lowest value of $137.3 \pm 10.3^\circ$; when the back-support plate descended to the initial angle of 0°, the value of $\theta_{adl}$ was $174.4 \pm 4.5^\circ$, which is similar to its initial value before elevation of the back-support plate. In addition, a variation in $\theta_{adl}$ of 7.7° was observed when the angle of the back-support plate of the EAB was adjusted between 30° and 45°, (Fig. 6).

Discussion

In this study, the negative factors generated when the the back-support plate of the EAB was elevated were analyzed, such as the slip between the EAB and the body, the dorsal loads, and the abdomen loads through a motion analysis. Slippage between the mattress and the body occurs under a contact pressure and generates a shear force at the part contacted, which leads to pressure ulcers. It was found that the body did not return to its initial location but moved in the direction towards the lower body, even though the angle of the back-support plate increased and then decreased to the initial angle. It was also observed that the distance variation between the pelvis and the lower body was the greatest when the angle of the back-support plate increased from 30° to 45° compared to the other elevation angles (Table 1).

Moreover, the lower body is pushed to the lower part of the bed owing to the electromotive force for HOB elevation on the EAB, and sliding and slippage occur while the upper body moves closer to the upper part of the mattress. However, when the upper and lower body parts move closer to the upper part of the mattress, the latter exhibits a greater distance variation than the former, thereby leading to dorsal loads. In this situation, if HOB descent occurs, the body tends to move towards the lower part of the mattress (Fig. 7).

Dorsal loads are generated by the operation mechanism shown in the steps in Fig. 7. These loads occur when the distance variation between the shoulders and the upper part of the mattress becomes greater than that between the pelvis and the upper part of the mattress. Thus, they tend to increase as the angle increases; and they exhibited a constant increase from Section I to Section II-1 (45°), whereas the increase in the load was somewhat reduced from a certain angle in Section II-2. As shown in Step 2 of Fig. 7, when HOB elevation occurred from the angle of 45° to an angle greater than 60°, where sliding and slippage were generated, the friction force and dorsal loads decreased. Moreover, the dorsal loads partially remained when the angle of the back-support plate decreased to the initial angle after HOB elevation; this result supports previous studies [22] on defining care for recuperation, which emphasized the necessity of care motions to remove dorsal loads (Figs. 5 and 7).

In contrast to the dorsal loads according to the slip length, the abdomen loads tended to be completely removed when the elevated back-support plate descended to the initial angle; the greatest increase in the load during the elevation was found between 30°
and 45° (Fig. 6).

The results of this study confirm that sliding and slippage of the body, which occur owing to EAB operation, lead to the negative factors mentioned above. On the basis of these results, it is also considered that the three negative factors can be prevented by using the EAB at an angle less than 30°, where the lower body begins slipping. Previous studies also recommended the use of the EAB at an angle less than 30° to prevent pressure ulcers in the sacrum region [11-13]. However, the previous studies quantified these negative factors through phenomenal measurement, whereas this study analyzed the reasons for the occurrence of the negative phenomena based on the mechanism of bed movement. Thus, this study is significant in that it can be effectively used to analyze the causes of the problems indicated in previous studies, which proposed a desirable angle for using the EAB during HOB elevation [11-20]. As such, this study, which examined the negative factors due to elevation of the back-support plate of the EAB through a motion analysis, supports the results of previous studies and is expected to provide the basis for developing technology that removes these negative factors. For example, the findings of this study can be applied to studies on establishing measures to eliminate negative factors by developing a mattress to prevent slippage between the mattress and the body during elevation of the back-support plate, by developing a bed-movement mechanism to remove dorsal loads, and by defining care motions.

Conclusion

This study examined the slippage between the EAB and the body, the dorsal loads, and the abdomen loads according to the elevation of the back-support plate of the EAB through a motion analysis. Previous studies used the contact pressure to derive such results, but this pressure, which is generated by bed movement, cannot intuitively show its relationship with the movement. On the contrary, the results of this study were derived through a motion analysis. Thus, it is anticipated that further studies on developing technology for improvement will be conducted more effectively by removing negative factors through an improvement in the bed movement or a mechanism based on the results of this study. In addition, because this study quantified the negative factors differently from previous studies, it is expected to serve as a guideline for developing technology or improving care motions for recuperation.

Acknowledgement

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References