Original Article

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Biomechanical analysis of the low back load on healthcare workers due to diaper changing

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Abstract

This study was performed to analyze the low back load of healthcare workers due to diaper changing and to compare the influences of bed height and working posture. Thirteen nurses or care workers participated in this study. The low back loads at 2 bed heights and working postures were evaluated through three-dimensional motion analysis and electromyographic analysis. The results were as follows.

1. In comparison to the work at a bed height of 50 cm, that at a bed height of 60 cm resulted about decreases of 7.1% in %MVC of biceps brachii muscles ($P<0.01$), 19.5% in trunk flexion angle ($P<0.001$), 9.1% in compression force of L5/S1 ($P<0.001$), and 3.8% in % of maximum torque of L5/S1 ($P<0.01$). Analysis of these parameters showed that the low back load decreased in the following order: bed height 50 cm > bed height 60 cm.
2. At both bed heights, %MVC of the trapezius muscle ($P<0.05$) and %MVC of biceps brachii muscles ($P<0.001$) differed among different steps in the task. %MVC of biceps brachii muscles was higher during the step “Pull up trousers” than during the steps “Open diaper”, “Exchange diapers”, and “Close diaper” ($P<0.05$). These observations indicate the low back load increased during the step.
3. Regardless of the subject's height that trunk flexion angle ($P<0.001$) decreased the low back load in the order: bed height 50 cm > bed height 60 cm. On the other hand, trunk flexion angle ($P<0.001$) decreased the low back load in the order: bed height 50 cm > knee on the bed > bed height 60 cm.
4. Unsteadiness of the care receiver was significantly lower during the task with one knee placed on the bed than under any other set of conditions ($P<0.05$).

The results of this study suggest that it is advisable to avoid excessive accumulation of load through repetition and to consider measures of reducing the load, such as adjustment of bed height and placing one knee on the bed while working.

Key words

diaper changing, healthcare workers, low back load, biomechanical analysis, general linear model

Introduction

With the recent rapid aging of the population, the prevalence of low back pain among healthcare workers for the elderly is very high (about 50-80%)[1,2]. The Guidelines on Prevention of Occupational Low Back Pain (Ministry of Health and Welfare, 1994) are measures for preventing low back pain among nurses and care workers. These guidelines impose limitations on the amount of weight to be lifted by one person. There have been a number of reports emphasizing that utilizing the knowledge of body mechanics is useful for preventing low back pain[3]. There have been reports regarding the relations of compression forces of L5/S1 and

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trunk flexion angle to weight transfer or changing position. These studies employed biomechanical analyses[4] and examined the effects of assistance methods[5,6] and auxiliary devices[7] in their examinations of ways to reduce low back pain among healthcare workers.

Diaper changing has been shown to be one of the major factors responsible for the low back load in healthcare workers at care facilities for the aged[8]. According to one report, each care staff member has to change about 20 to 50 diapers per day[9]. To date, however, few studies have evaluated the physical effects of diaper changing on healthcare workers.

Previously, we demonstrated that the basic working postures assumed by healthcare workers while changing diapers are "anterior flexion with the knees slightly bent" and "anterior flexion with one knee placed on the bed"[10]. We also showed that healthcare workers keep their low back inclined forward at an average angle of 70° for a period of about 3 min while the diaper is being changed with the patient lying on a bed at a height of 45 cm above the floor[11]. However, as diaper changing involves twisting and loading the back, analysis of this work in terms of body angle only is of limited value for evaluating low back load.

Therefore, we recently began to focus on biomechanical analysis. The low back load related to the physical responses to external loads or force, and working postures. The evaluation of the low back load included motion analysis, electromyography, and biomechanical analysis. Biomechanical analysis estimated the torque around the joints and the compression applied to the joints[12]. The low back load decreased as any evaluation becomes small. This approach should allow quantitative evaluation of the low back load, which has conventionally been evaluated only subjectively.

Analyzing the process of diaper changing in terms of the low back load on healthcare workers may lead to the development of an evidence-based optimal diaper changing technique that reduces the low back load.

The present study was performed to analyze the low back load of diaper changing and to assess the influence of bed height and working posture during this process.

Methods

1. Study design

This was a semi-experimental study designed to test hypotheses.

2. Subjects

Thirteen nurses or care workers employed at universities or care-providing companies or facilities gave their informed consent to participation in this study. Inclusion criteria were: (1) having performed diaper changing as a member of a nursing or caregiving staff, and (2) having no health problems or musculoskeletal disorders at the time of enrollment in the study.

3. Outline of the experiment

1) Data collection period

August 21, 2006 through August 24, 2006

2) Representative model to simulate an elderly individual requiring assistance with diaper changing

The model simulating an elderly individual requiring assistance with diaper changing (hereafter called "the care receiver") was a graduate nursing student who consented to participation in this study. The student was a healthy adult female with a height of 156 cm and a body weight of 57.5kg. The student avoided spontaneous motion during the test to simulate a bed-ridden elderly subject.

3) Diaper changing

In this study, the process of diaper changing consisted of 5 steps: (a) pulling down the care receiver's trousers, (b) unfastening the old diaper, (c) exchanging the old diaper for a new one, (d) fastening the new diaper, and (e) pulling up the trousers. Prior to the test, the subjects received explanations and were trained so that they would change the diaper in an approximately consistent manner. Each subject stood at the side of the bed that was closer to the care receiver's right hand. During the process, a taped-type paper diaper was used, together with a pad (Unicharm). The

Table 1. Three diaper changing tasks.

Task	Working posture	Bed height
(1) Bed height 50 cm	Both feet in contact with the floor 	50 cm
(2) Bed height 60 cm		60 cm
(3) Knee on the bed	One knee placed occasionally on the bed 	50 cm

temperature and relative humidity of the room were kept at 25.8 ± 0.3℃ and 61 ± 1.8%, respectively.

4) Work conditions

Changing of the diaper was performed under three sets of conditions (Table 1): (1) working with both feet in contact with the floor[10] at a bed height of 50 cm (the height of the beds often used at care facilities for the aged[13]); (2) working with both feet in contact with the floor at a bed height of 60 cm (the height of the bed usually used in hospitals[14]); and (3) working with one knee occasionally placed on the bed[10] at a bed height of 50 cm. The height of the bed was defined as the distance between the floor and the upper edge of the mattress. The mattress was 83 cm in breadth. The care receiver lay on the center of the bed.

Each subject changed diapers under each set of conditions, selected at random in an alternating fashion, with rest intervals of about 5 min.

4. Measurements (Figure 1)

1) Three-dimensional motion analysis

During the process, the posture of each subject was analyzed by checking the locations of 16 marker points located on the subject (head and neck, and both shoulders, elbows, hands, hips, knees, feet, and toes) using 4 video cameras. The load exerted during the task was measured using two force plates (Anima, Japan) and a six-component force sensor (Nitta, Japan). The value of each parameter, from which the body weight of the subject was subtracted, was totaled to yield the force applied to each subject. The frame and mattress of the bed (Quma Aura Series KQ903®, Paramount Bed, Japan) were partially modified

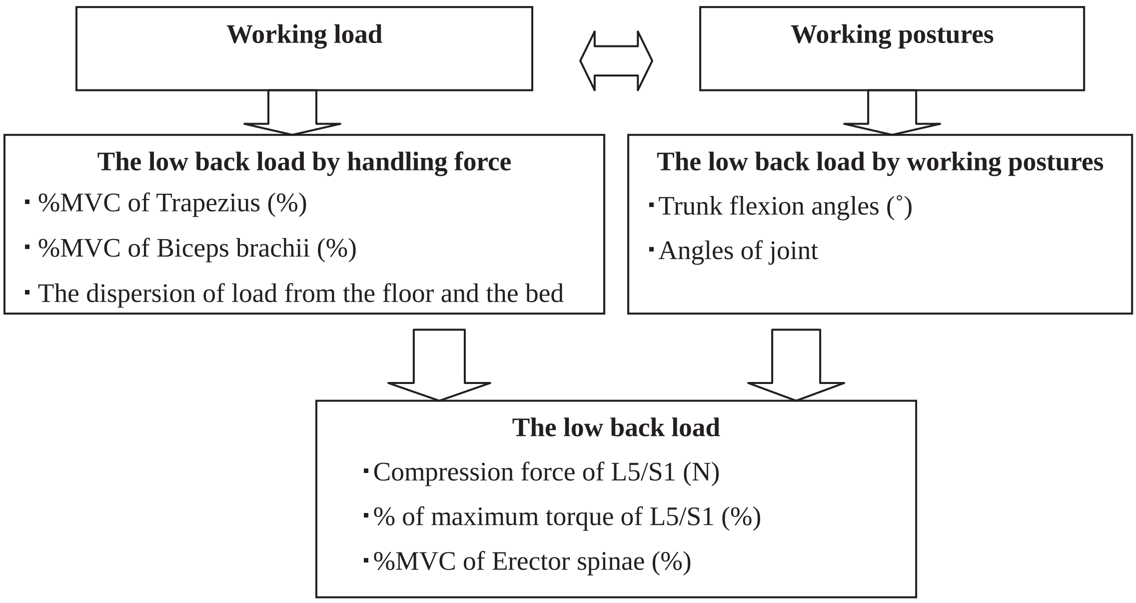

Figure1. Related chart of the low back load during diaper changing and measurements

Table 2. 12 and 6 motion views in the 5-step diaper changing task.

Step	Motion	Bed height 50/60 cm n=13	Knee on the bed n=11
a. Pull down trousers	Erect knee	○	
	Changing position (Push)	○	○
	Pull down trousers (inner part)	○	○
	Changing position (Pull)	○	
	Pull down trousers (outer part)	○	
b. Open diaper	Unfasten tape (outer part)	○	
	Front of diaper pulled down	○	
c. Exchange diapers	Changing position (push)	○	○
	Changing position (pull→supine)	○	○
	Changing position (pull→lateral)	○	
	Hold old diaper	○	
	Throw away old diaper	○	
	Adjust new diaper position (outer part)	○	
d. Close diaper	Front of diaper pulled upward	○	
	Fasten with tape (inner part)	○	
e. Pull up trousers	Changing position (push)	○	○
	Pull up trousers(inner part)	○	○
	Changing position (pull)	○	
	Pull up trousers(outer part)	○	
	Return the knee to normal position	○	

○: motions were subjected for analysis

because the force plates were designed to measure the dispersion of load from the floor and the six-component force sensor was designed to measure the dispersion of load from knees placed on the bed frame and the bed[15].

These data were subjected to three-dimensional motion analysis using a work load analysis program (CMAS, Seo). Motions that may cause the low back load were extracted from the video images and subjected to analysis. 12 motion views were selected for analysis for each of conditions (1) and (2) mentioned above. For condition (3), 6 motion views of 11 subjects (excluding 2 subjects who timed the placement of their knee on the bed inappropriately) were selected for analysis (Table 2). The extracted image frames were converted manually into digital information for calculation of trunk flexion angles, compression forces of L5/S1, and percentage of maximum torque of L5/S1[12,16].

2) Electromyography

Electromyography was performed at 6 sites (right and left erector spinae muscles, trapezius muscles, and biceps brachii muscles). Two types of electrode, *i.e.*, Disposable Electrodes F-150S and D (Nihon Kohden, Japan), were attached to specified points selected with reference to the standard points chosen and with body size taken into account[17]. Measurements were performed using bipolar induction. The signals were amplified with an EMG amplifier and sampled into a personal computer at a frequency of 500 Hz. The percentage of maximal voluntary contraction (%MVC)[17] was calculated for the 0.5-s period before and that after the frame extracted from the three-dimensional motion analysis.

3) Blood pressure, pulse, and required time to change a diaper

Blood pressure and pulse were measured before and after the task, using an automated digital hemodynamometer (HEM-632 Fuzzy®, Omron, Japan). The time required to change diapers was calculated from the video image.

4) Subjective assessment by the subject and the care receiver

The load on the shoulder, brachii, and low back perceived after the task was evaluated subjectively by each subject on a five-point Likert scale (ranking from: 1 = absent to 5 = very strong). The care receiver also subjectively assessed the degree of unsteadinesss experienced during diaper exchange.

5. Statistical analysis

As low back load arising from diaper changing is considered to be continuous in nature, we calculated the %MVC for each muscle, trunk flexion angle, compression force of L5/S1, and % of maximum torque of L5/S1 for the entire process and for each step of the process of the frame extracted from the three-dimensional motion analysis, and compared the mean of each parameter among different sets of working conditions.

The differences depending on bed height were subjected to paired *t*-test after confirming the normality of the distribution with the Shapiro-Wilk *W*-test.

One-way ANOVA was employed for inter-step comparisons. If a significant difference was noted, the parameter was then subjected to multiple comparisons using the Tukey-Kramer HSD test.

A general linear model was used to evaluate the effects of working conditions and subject's height. When it was confirmed that there was no interaction effect between working conditions and subject's height using a model involving interactions, the test was carried out using on interaction-free model.

One-way ANOVA was used for comparisons of blood pressure, pulse, and time required for the task among the 3 sets of working conditions. The Kruskal-Wallis test was employed to compare the subjective assessments of the subjects and the care receiver.

Statistical analysis was performed using JMP6®, SPSS ver.13.0 for Windows® and $P<0.05$ was regarded as statistically significant.

6. Ethical considerations

This study was approved in advance by the Kanazawa University Medical Ethics Committee. Each subject was informed regarding the objectives, methods, and ethical measures of the study and consented in writing to participation in the study. To protect the privacy of the individual subjects, the experimental data were rendered anonymous and then stored with a key for identification. Each subject decided to participate in the study at her own discretion. Due care was taken about possible physical stress arising from the experiment.

Results

1. Subject outlines

All subjects were female, with a mean age of 32.2 ± 5.4 years, mean height of 159.5 ± 5.0 cm, mean body weight of 52.6 ± 6.7 kg, and mean number of years of experience of 8.2 ± 5.0.

2. Low back load in all steps of diaper changing compared between two bed heights (Table 3)

%MVC of erector spinae muscles was significantly (35.5%) higher at a bed height of 60 cm than 50 cm ($P<0.01$). %MVC of biceps brachii muscles was significantly (7.1%) lower and % of maximum

Table 3. Summary of biomechanical analysis for 2 bed heights (n=13).

	Bed height 50 cm	Bed height 60 cm		Change rate[1)]
	Mean ± SD	Mean ± SD	P value	%
%MVC of Erector spinae (%)	17.2 ± 6.7	23.3 ± 6.3	0.0017**	35.5
%MVC of Trapezius (%)	13.1 ± 3.1	12.8 ± 3.6	0.69	−2.3
%MVC of Biceps brachii (%)	12.6 ± 1.8	11.7 ± 2.0	0.0011**	−7.1
Trunk flexion angles (°)	53.2 ± 2.8	42.8 ± 2.2	<0.001***	−19.5
Compression force (N)	1167.2 ± 153.5	1061.0 ± 147.6	<0.001***	−9.1
% of maximum torque (%)	18.6 ± 1.2	17.9 ± 1.2	0.0023**	−3.8

SD: standard deviation, 1) Changing rate of mean values from bed height of 50 cm: (Mean value at bed height of 60 cm − 50 cm) / 50 cm × 100, paired *t*-test, **$P<0.01$, ***$P<0.001$

Table 4. Summary of biomechanical analysis of bed height 50 cm (n=13).

	a. Pull down trousers	b. Open diaper	c. Exchange diaper	d. Close diaper	e. Pull up trousers		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*P* value	
%MVC of Erector spinae (%)	18.4 ± 8.4	16.0 ± 8.1	15.9 ± 7.2	15.3 ± 5.3	18.8 ± 7.1	0.64	
%MVC of Trapezius (%)	10.9 ± 3.3	16.3 ± 9.5	11.1 ± 3.6	16.0 ± 3.9	15.3 ± 4.7	0.024*	
%MVC of Biceps brachii (%)	14.9 ± 3.1	12.1 ± 2.6	10.7 ± 2.4	13.0 ± 3.7	17.0 ± 3.5	<0.001***	e>b**, e>c**,e>d*, a>c**
Trunk flexion angles (°)	52.9 ± 3.6	51.6 ± 5.7	54.0 ± 3.4	54.2 ± 2.9	52.6 ± 3.5	0.45	
Compression force (N)	1194.4 ± 143.8	1212.4 ± 158.5	1145.4 ± 141.6	1115.5 ± 194.2	1168.9 ± 186.1	0.60	
% of maximum torque (%)	19.2 ± 1.4	19.3 ± 1.7	18.1 ± 1.7	18.0 ± 1.8	18.6 ± 1.3	0.15	

SD: standard deviation, one-way ANOVA, Tukey-Kramer HSD test, *$P<0.05$, **$P<0.01$, ***$P<0.001$

Table 5. Summary of biomechanical analysis of bed height 60 cm (n=13).

	a. Pull down trousers	b. Open diaper	c. Exchange diaper	d. Close diaper	e. Pull up trousers		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*P* value	
%MVC of Erector spinae (%)	23.9 ± 6.4	20.1 ± 8.4	23.1 ± 8.3	22.0 ± 5.3	24.7 ± 6.4	0.52	
%MVC of Trapezius (%)	11.2 ± 2.7	16.9 ± 9.6	10.7 ± 3.7	14.4 ± 5.2	14.9 ± 5.5	0.046*	
%MVC of Biceps brachii (%)	13.0 ± 2.5	11.9 ± 1.8	10.5 ± 3.2	10.2 ± 3.0	15.8 ± 3.6	<0.001***	e>b**, e>c**, e>d**
Trunk flexion angles (°)	40.9 ± 3.3	41.1 ± 2.9	44.8 ± 3.4	44.4 ± 2.7	42.5 ± 4.1	0.0076**	c>a*, c>b*
Compression force (N)	1077.4 ± 134.7	1082.9 ± 163.2	1052.8 ± 150.8	1035.7 ± 152.3	1055.7 ± 169.6	0.94	
% of maximum torque (%)	18.6 ± 1.5	18.0 ± 1.7	17.3 ± 1.7	17.8 ± 1.7	17.9 ± 1.5	0.40	

SD: standard deviation, one-way ANOVA, Tukey-Kramer HSD test, *$P<0.05$, **$P<0.01$, ***$P<0.001$

torque of L5/S1 was significantly (3.8%) lower at a bed height of 60 cm than 50 cm ($P<0.01$). Trunk flexion angle was significantly (19.5%) lower and compression force of L5/S1 was significantly (9.1%) lower at a bed height of 60 cm than 50 cm ($P<0.001$).

%MVC of trapezius muscles did not differ significantly with bed height ($P=0.69$).

3. Low back load compared between individual steps of diaper changing at each bed height

1) Low back load at each step of diaper changing at a bed height of 50 cm (Table 4)

%MVC of trapezius muscles ($P<0.05$) and %MVC of biceps brachii muscles ($P<0.001$) differed significantly among individual steps of diaper changing. %MVC of biceps brachii muscles during the step "e. Pull up trousers" differed significantly from that during the steps "b. Open diaper" ($P<0.01$), "c. Exchange diapers" ($P<0.01$), and "d. Close diaper" ($P<0.05$), and the same parameter during the step "a. Pull down trousers" differed significantly from that during the step "c. Exchange diapers" ($P<0.01$).

In terms of %MVC of erector spinae muscles, trunk flexion angle, compression force of L5/S1, and % of maximum torque of L5/S1, there were no significant differences among individual steps of diaper changing.

2) Low back load in each step of diaper changing at a bed height of 60 cm (Table 5)

%MVC of trapezius muscles ($P<0.05$), %MVC of biceps brachii muscles ($P<0.001$), and trunk flexion angle ($P<0.01$) differed significantly among individual steps of diaper changing. %MVC of biceps brachii muscles during the step "e. Pull up trousers" differed significantly from that during the steps "b. Open diaper", "c. Exchange diapers", and "d. Close diaper" ($P<0.01$), and trunk flexion angle during the step "c. Exchange diaper" differed significantly from those during the steps "a. Pull down trousers" and "b. Open diaper" ($P<0.05$).

In terms of %MVC of erector spinae muscles, compression force of L5/S1, and % of maximum torque of L5/S1, there were no significant differences among individual steps of diaper changing.

4. Effects of bed height and subject's height on low back load at 20 motion views during diaper changing (Table 6)

%MVC of erector spinae muscles was higher at

Table 6. Summary of biomechanical analysis for 2 bed heights and subject's height at 20 motion views (n=13).

	Bed height			Subject's height	
	cm	β	*P* value	β	*P* value
%MVC of Erector spinae (%)	50	0	0.020*	0.32	0.20
	60	5.82			
%MVC of Trapezius (%)	50	0	0.94	0.03	0.84
	60	−0.10			
%MVC of Biceps brachii (%)	50	0	0.17	0.22	0.0030**
	60	−0.88			
Trunk flexion angles (°)	50	0	<0.001***	0.07	0.51
	60	−10.16			
Compression force (N)	50	0	0.079	−6.99	0.26
	60	−106.31			
% of maximum torque (%)	50	0	0.10	−0.05	0.28
	60	−0.77			

β : regression coefficient, GLM, **P*<0.05, ***P*<0.01, ****P*<0.001

Table 7. Summary of biomechanical analysis for 3 tasks and subject's height at 6 motion views (n=11).

	3 Tasks			Subject's height	
	Tasks	β	*P* value	β	*P* value
%MVC of Erector spinae (%)	50 cm[1)]	0	0.021*	0.93	<0.001***
	60 cm[2)]	6.63			
	Knee on[3)]	2.02			
%MVC of Trapezius (%)	50 cm	0	0.79	0.17	0.17
	60 cm	−0.73			
	Knee on	−0.87			
%MVC of Biceps brachii (%)	50 cm	0	0.74	0.68	<0.001***
	60 cm	−0.06			
	Knee on	−0.79			
Trunk flexion angles (°)	50 cm	0	<0.001***	0.38	0.011*
	60 cm	−12.39			
	Knee on	−6.31			
Compression force (N)	50 cm	0	0.18	−0.05	0.99
	60 cm	−121.37			
	Knee on	−17.54			
% of maximum torque (%)	50 cm	0	0.41	0.15	0.82
	60 cm	−0.64			
	Knee on	0.37			

β : regression coefficient, 1) Bed height 50 cm, 2) Bed height 60 cm, 3) Knee on the bed,
GLM, **P*<0.05, ****P*<0.001

a bed height of 60 cm than 50 cm ($\beta=5.82$, $P<0.05$), while trunk flexion angle was lower at a bed height of 60 cm than at 50 cm ($\beta=-10.16$, $P<0.001$). Thus, bed height strongly affected %MVC of erector spinae muscles and trunk flexion angle. Compression force of L5/S1 ($\beta=-106.31$, $P=0.079$) and % of maximum torque of L5/S1 ($\beta=-0.77$, $P=0.10$) tended to be lower at a bed height of 60 cm than 50 cm.

%MVC of biceps brachii muscles was strongly affected by the subject's height, and it became higher as the subject's height increased ($\beta=0.22$, $P<0.01$).

5. Effects of working conditions and subject's height on low back load at 6 motion views during diaper changing (Table 7)

Trunk flexion angle decreased significantly ($P<0.001$) in the order bed height 50 cm > knee on the bed > bed height 60 cm ($P<0.01$) (Figure 2). On the other hand, %MVC of erector spinae muscles increased significantly ($P<0.05$). Thus, the low back load during diaper changing was affected by working conditions.

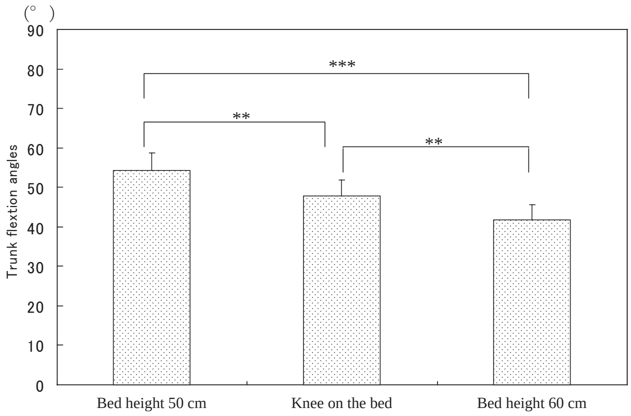

Figure 2. Trunk flexion angles for 3 diaper changing tasks.
Tukey-Kramer HSD test, $^{**}P<0.01$, $^{***}P<0.001$

%MVC of erector spinae muscles ($\beta=0.93$, $P<0.001$), %MVC of biceps brachii muscles ($\beta=0.68$, $P<0.001$), and trunk flexion angle ($\beta=0.38$, $P<0.05$) became higher as the subject's height increased, thus indicating influence of subject's height on these parameters.

6. Blood pressure, pulse, and time required for the task compared among different working conditions (Table 8)

There were no significant differences in blood pressure, pulse, and time required for the task depending on the working conditions.

7. Subjective assessment by the subject and the care receiver depending on the working conditions (Table 9)

Unsteadiness of the care receiver was lowest during the task with one knee placed on the bed, differing significantly from that during the task under the two other sets of working conditions ($P<0.05$).

The subjective assessment regarding stress on the brachii, shoulder, or low back of the subject did not differ significantly depending on the working conditions.

Discussion

The major findings of the present study that diaper changing causes constant low load on healthcare wokers' low back. Considerations were based on the effects of bed height and working posture.

1. Relationship between bed height (2 heights tested) and low back load while changing diapers as assessed by biomechanical analysis

%MVC of biceps brachii muscles, trunk flexion angle, compression force of L5/S1, and % of maximum torque of L5/S1 were lower when the bed height was 60 cm than 50 cm, indicating a difference in low back load depending on bed

Table 8. Blood pressure, pulse and time required for 3 diaper changing tasks (n=13).

	Bed height 50 cm	Knee on the bed	Bed height 60 cm	
	Mean±SD	Mean±SD	Mean±SD	P value
Systolic pressure (mmHg)	123.5±12.2	124.3±16.1	127.8±14.5	0.71
Diastolic pressure (mmHg)	78.5±4.9	76.8±6.6	82.7±12.1	0.20
Pulse (time/min)	90.5±17.9	90.8±19.0	89.2±18.2	0.97
Required time (s)	164.5±24.7	170.0±30.9	169.9±26.8	0.84

SD: standard deviation, one-way ANOVA

Table 9. Subjective assessment by the subject and the care receiver for 3 diaper changing tasks (n=13)

	Bed height 50 cm	Knee on the bed	Bed height 60 cm	
	Mean±SD	Mean±SD	Mean±SD	P value
Subject				
Brachii	1.8±0.7	1.8±0.7	1.7±0.6	0.85
Shoulder	1.4±0.7	1.5±0.8	1.6±0.9	0.81
Low back	2.5±1.2	2.2±1.1	2.4±1.3	0.91
Care receiver				
Unsteadiness	1.9±0.5	1.3±0.5	1.5±0.7	0.017*

SD: standard deviation, Kruskal-Wallis test, $^{*}P<0.05$

height (Table 3). The increase observed in the %MVC of erector spinae muscles at a bed height of 60 cm than 50 cm seems to reflect the influence of flexion relaxation (the phenomenon that an electromyogram cannot be recorded when the joint is bent excessively, *e.g.*, during excessive anterior flexion)[18]. The trunk flexion angle was 53.2±2.8° at a bed height of 50 cm. Combining this result with the previous report that flexion relaxation is absorbed when trunk flexion angle is 60 degrees or more[19]. These results suggest that the power of the dorsal muscles cannot be exerted satisfactorily at a bed height of 50 cm. %MVC of erector spinae muscles was 23.3±6.3% at a bed height of 60 cm. Combining this result with the previous report that endurable time in a stress position decreases sharply when %MVC is over 20%[20]. By the way, it is desirable to determine the endurable time for continuation of this type of task. Therefore, it is thought that there is a limit in %MVC of erector spinae muscles assumption the index of the low back load.

At a bed height of 50 cm, the compression force of L5/S1 was found to be about 1200 N, which is about 1/3 of the known minimal level (3400 N) involving a high risk of low back pain[21]. In previous studies in the field of nursing, great sudden load, exceeding the level of risk, was observed when repositioning the care receiver in a wheelchair[5,6], when only one person transferred the patient between bed and wheelchair[7], and during the process of sling removal with the patient seated in a wheelchair[22]. Diaper changing was found to cause a more continuous but lower low back load as compared with these other tasks.

%MVC of trapezius muscles did not differ between the 2 bed heights. The trapezius muscles are involved in adjusting the range of the subject's motion during manipulation of the diaper. It seems that the subjects adjusted the heights of their elbows instead of their shoulders to avoid load on the shoulder joint, irrespective of the height of the bed.

%MVC of trapezius muscles and biceps brachii muscles varied from step to step during the change process at both bed heights. %MVC of biceps brachii muscles was higher during the step "e. Pull up trousers" than during the steps "b. Open diaper", "c. Exchange diaper", and "d. Close diaper" at a bed height of 50 and 60 cm. These differences were attributed to the necessity of the subject to move the legs of the care receiver when pulling the trousers up. %MVC of trapezius muscles tended to be higher in step "b. Unfasten the diaper." This was probably because the diaper-unfastening step involves more frequent up and down motions of the shoulder joints among individual steps. The trunk flexion angle was greater during the step "c. Exchange the diapers" than during the steps "a. Pull down trousers" and "b. Open diaper" at a bed height of 60 cm. This was probably because the subject bent their trunk forward to come closer to the care receiver to observe the work more clearly and adjust the diaper position using delicate hand motions.

There were no differences between any two steps of the task in terms of %MVC of erector spinae muscles, compression force of L5/S1, or % of maximum torque of L5/S1 (Tables 4 and 5). As these parameters are directly associated with the low back load, the data indicate that this type of load is almost constant while changing diapers, indicating the validity of using the mean of each parameter for statistical analyses.

2. Effects of bed height and working posture and subject's height on low back load

No interactions were noted between working conditions and subject's height ($P>0.64$), supporting the view that these are both independent factors that exert additive rather than synergistic effects. The results of statistical tests with subject's height, 2 bed heights, and 3 sets of working conditions serving as factors are discussed below.

The trunk flexion angle and %MVC of erector spinae muscles were greatly affected by bed height. The compression force of L5/S1 and % of maximum torque of L5/S1 tended to decrease with higher bed position (Table 6). These observations indicate that bed height affects low back load during the task. According to one report, the range of work elevation in which the leg muscles can be effectively utilized is equivalent to 35－45% of the worker's height for changing position[23]. In future, it is desirable to determine the optimal bed height for the diaper changing task.

The %MVC of biceps brachii muscles was greatly affected by the subject's height. The strength of biceps brachii muscles is manifested better during flexion than extension. As the brachii are longer in taller subjects, they tend to remain slightly bent during the task, allowing the subjects to utilize these muscles better.

The trunk flexion angle and %MVC of erector spinae muscles were affected by the working conditions (Table 7). This can be explained as follows. When the subject placed one knee on the bed, the 6 motions used for diaper changing are primarily accomplished by changing position. Analysis of these parameters showed that low back load decreased in the following order: bed height 50 cm ＞ knee on the bed ＞ bed height 60 cm. Therefore, if it is difficult to adjust the bed height, it is advisable for the subject to place one knee on the bed to reduce the low back load.

%MVC of erector spinae muscles, %MVC of biceps brachii muscles, and trunk flexion angle were affected by the subject's height. This is because greater force, needed to change position, could be exerted by taller subjects, as bending biceps brachii muscles are easier for taller subjects. It is also possible that when the subject comes closer to the care receiver to reduce the force needed to move the care receiver with a body weight of about 60 kg, trunk flexion angle increases with the subject's height, accompanied by an increase in %MVC of the erector spinae muscles. These results suggest that changing position during diaper changing more frequently causes muscular fatigue among taller subjects.

3. Relationships between low back load and blood pressure, pulse, time required for the task, and subjective assessment by the subject and care receiver

The present study also involved evaluation of systemic load. The blood pressure, pulse, time required for the task (Table 8), and subject's subjective assessment (Table 10) did not differ depending on working conditions. From the perspective of biomechanical analysis, on the other hand, the low back load did differ depending on working conditions. These results suggest that during one single diaper change, differences in bed height or working posture are unlikely to be reflected in systemic load.

The care receiver reported significantly less frequent unsteadiness when the subject placed one knee on the bed during the task (Table 9). This was probably because the care receiver felt safer with the subject in this posture, as if held in the subject's arms. This suggests that placing one knee on the bed is useful for reducing the unsteadiness of the care receiver during changing position.

4. Methods of changing diapers recommended to alleviate low back load

1) Proposals for nursing practice

The results of the present study demonstrated quantitatively that diaper changing causes constant low load on healthcare workers' low back, and that this load may be reduced by adjusting the bed height and placing one knee on the bed during the task. The results suggest that repetition of the task, which results in the accumulation of excessive load, should be avoided to prevent low back pain among healthcare workers.

With regard to adult diaper changing, previous reports have shown that load on the healthcare worker may be increased in the presence of contractures or cognitive disorders on the part of the care receiver[13]. Similaly it has been reported that load arising from support while transferring to a wheelchair can be reduced if support is provided by two caregivers working together[24]. It seems desirable to repeat this form of study under more difficult conditions for healthcare workers and to confirm the effects of having pairs of caregivers working together in terms of reducing the load arising from this type of task.

2) Limitations of this study and open questions for the future

One limitation of this study was that the sample size was small due to physical and time restrictions, which resulted in an inability to draw conclusions from some analyses that did not produce clearly statistically significant results. Another limitation was that although the present study analyzed low back load through evaluation of the mean value of each parameter, no well-defined indicator of continuous but low load was available, leaving many questions unresolved concerning optimal methods of evaluating cumulative load. Further studies should be carried out based on the results reported here.

Conclusions

The present study was performed to analyze the low back load of healthcare workers arising from diaper changing and to compare the influence of bed height and working posture. Thirteen nurses or care workers participated in this study. The low back load under 3 sets of working conditions was analyzed through three-dimensional motion analysis, evaluation of electromyograms, and subjective assessment. The following results were obtained.

1. In comparison to the work at a bed height of 50 cm, that at a bed height of 60 cm resulted about decreases of 7.1% in %MVC of biceps brachii muscles, 19.5% in trunk flexion angle, 9.1% in compression force of L5/S1, and 3.8% in % of maximum torque of L5/S1.
2. At both bed heights, %MVC of the trapezius muscle and %MVC of biceps brachii muscles differed among different steps in the task. %MVC of biceps brachii muscles was higher during the step “Pull up trousers” than during the steps “Open diaper”, “Exchange diapers”, and “Close diaper”.
3. Bed height was shown to strongly affect trunk flexion angle. %MVC of biceps brachii muscles was strongly affected by the subject’s height.
4. Trunk flexion angle was shown to be affected working conditions, and trunk flexion angle decreased in the order: bed height 50 cm ＞ knee on the bed ＞ bed height 60 cm. %MVC of biceps brachii muscles and trunk flexion angle were affected by the subject’s height.

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おむつ交換作業におけるケアスタッフの腰部負担に関する生体力学的評価

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要　　旨

本研究は、おむつ交換におけるケアスタッフの腰部負担を明らかにすることを目的とした。被験者は、研究協力の得られた看護・介護職13名である。３次元動作解析と筋電図解析を用い、２種類のベッドの高さと作業姿勢による腰部負担への影響を検討した結果、以下の知見を得た。

1. おむつ交換全工程では、ベッドの高さ50㎝に比べ60㎝で、上腕二頭筋%MVCが7.1%（$P<0.01$）、体幹前傾角が19.5%（$P<0.001$）、椎間板圧縮力が9.1%（$P<0.001$）、腰部最大トルク比が3.8%減少（$P<0.01$）し、腰部負担の軽減が示された。

2. おむつ交換各工程では、僧帽筋%MVC（$P<0.05$）、上腕二頭筋%MVC（$P<0.001$）に工程間の差を認めた。上腕二頭筋%MVCは、「e ズボンを上げる」が「b おむつを開く」、「c おむつを換える」、「d おむつを閉じる」に比べ高く（$P<0.05$）、腰部負担増加に影響した。

3. おむつ交換全工程において、体幹前傾角（$P<0.001$）は、身長差に関わらずベッドの高さ50㎝に比べ60㎝で腰部負担の減少を認めた（$P<0.01$）。一方、膝乗せ時の６動作において、体幹前傾角（$P<0.001$）は、身長差に関わらずベッド50㎝、膝乗せ姿勢、ベッド60㎝の順に腰部負担の軽減を認めた（$P<0.01$）。

以上より、おむつ交換時の腰部負担軽減には、ベッドの高さ調節や膝乗せ姿勢の活用が効果的であり、繰り返しによる累積的負担を避ける必要性が示唆された。