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Effects of General Principles of Person Transfer Techniques on Low Back Joint Extension Moment

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Abstract: The purpose of this study was to examine the effects of general principles of person transfer techniques specifically on the low back joint extension moment. These effects were examined by the following measurable quantitative parameters: 1) trunk bending angle, 2) knee flexion angle, 3) distance between the centers of gravity (COGs) of the caregiver and patient, representing the distance between the caregiver and patient, and 4) the vertical component of the ground reaction force representing the amount of the weight-bearing load on the caregiver's low back during transfers with and without assistive devices. Twenty students each took the role of caregiver, and one healthy adult simulated a patient. The participants performed three different transfer tasks: without any assistive device, with the patient wearing a low back belt, and with the caregiver using a transfer board. We found that the distance between the COGs and the vertical component of the ground reaction force, but not the trunk bending and knee flexion angles, were the variables that affected the low back joint extension moment. Our results suggest that the general principle of decreasing the distance between COGs is most effective for decreasing the low back joint extension moment during transfers under all conditions.

Key words: Patient transfer, Low back belt, Transfer board, Low back moment, Motion analysis

Introduction

In recent years, the number of elderly people has markedly increased in Japan, as well as the number requiring nursing care. This increase in the patient population has increased the number of patient handling tasks undertaken by caregivers working in nursing homes or providing private home care, which in turn has led to an increase in physical strain among these workers. One patient handling task that caregivers frequently perform, the transfer of a patient to and from a wheelchair, imposes considerable demands on the caregivers during their daily activities and has become the main cause of low back pain (LBP) because of large low back load[1]. Although countermeasure maneuvers involving usage of assistive devices which are transfer board, low back belt and mechanical hoist have been developed based on clinical experience to prevent LBP caused by the transfers, LBP is a common and serious problem among caregivers[2–4]. The prevalence rate of LBP is as high as 70% among caregivers in Japan[4].

Recent research on person transfer techniques using biomechanical methods has been directed toward objectively analyzing the effects of transfer maneuvers on low back load[5–10]. Previous studies have reported that the low back compression force in most patient handling tasks exceeds 3400N, the safety limit recommended by the National Institute for Occupational Safety and Health (NIOSH)[11]. Marrass *et al*. measured dynamic low back compression force using a musculoskeletal model and reported that low back compression force exceeded 5500N while transferring a patient to and from a wheelchair[12].

Schibye *et al*. compared changes in low back compression force before and after caregivers were taught the following common general principles and reported a reduction in low back compression force after instruction: using push/pull instead of lifting procedures; using flexion of the knee joints and avoiding flexion of the back; and positioning the caregiver as close to the patient as possible[13]. These general principles are

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commonly used in the clinical setting in Japan, and the effects of using some of these general principles on reducing low back load during manual material handling have been reported[14, 15]. However, to date, no biomechanical studies have reported the effects of these principles specifically on the low back joint extension moment during person transfers, and it remains unclear whether these principles are, in fact, effective for reducing low back load.

The individual effects of these principles on low back load should be identified in order to determine objectively the most effective principles for clinicians and others to follow when transferring a patient from a wheelchair, an activity which involves large low back load to clinicians. Therefore, the objectives of this study were two-fold. First, we examined the effects of these general principles as a guide for person transfer techniques, which can be described by measurable quantitative parameters, on the low back joint extension moment during transfers. Second, assuming that different parameters might affect low back load during transfers with assistive devices, we examined the effects of these general principles on the low back joint extension moment during transfers with the low back belt and transfer board, which are the most commonly used assistive devices in clinical settings.

Participants and Methods

Study participants

Twenty male students (mean age, 22 ± 1.6 yr; mean height, 174.8 ± 4.5 cm; mean weight, 64.4 ± 7.6 kg) from the Department of Physical Therapy at the International University of Health and Welfare took the role of caregiver, and one healthy male non-student (age, 30 yr; height, 173 cm; weight, 62 kg) whose physical proportions approximated those of the Japanese standard simulated a patient in this study. Thus, all participants acting as caregivers were students, not clinicians; however, they had acquired experience in transferring patients during clinical training. Informed consent was obtained from all participants before undertaking the experiments. The experiment was conducted with strong regard for the participants' safety.

Experimental conditions

The participants performed three different transfer tasks in randomized order (Fig. 1): (1) without any assistive devices (WD), (2) with the patient wearing a low back belt (LBB; MTS Support, GSI, Norway) on the upper part of the pelvis, and (3) with caregivers using a 59.5×32.5-cm transfer board (TB; MTS Board, GSI). The transfer board was employed by inserting it under the simulated patient's buttocks at an angle of 45 degrees and forming a bridge from the wheelchair to the bed. Then, the caregiver slid the patient's buttocks over the transfer board. We chose to use the low back belt and transfer board as these are the most commonly used assistive devices in the clinical setting. We chose not to use a hoist or mechanical lift because such devices completely alter the task, making the actual lift no longer dependent of the caregiver although their use is a means of decreasing load. Also, a previous study reported that the peak low back joint extension moment occurred while placing and removing a sling seat rather than while transferring the patient[16].

Experimental setup

A 3D motion analysis system consisting of 12 infrared cameras (VICON612, VICON, UK) and four force

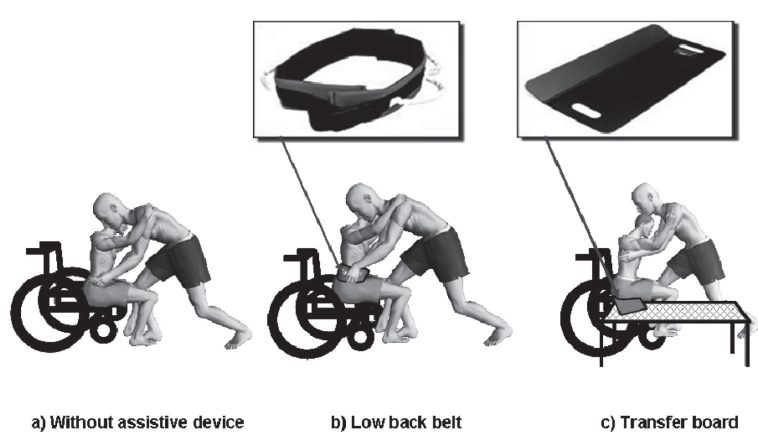

Fig. 1. Experimental conditions.
The participants performed three different transfer tasks: a) without any assistive devices (WD), b) with the patient wearing a low back belt on the upper part of the pelvis (LBB), and c) with the caregiver using a transfer board (TB).

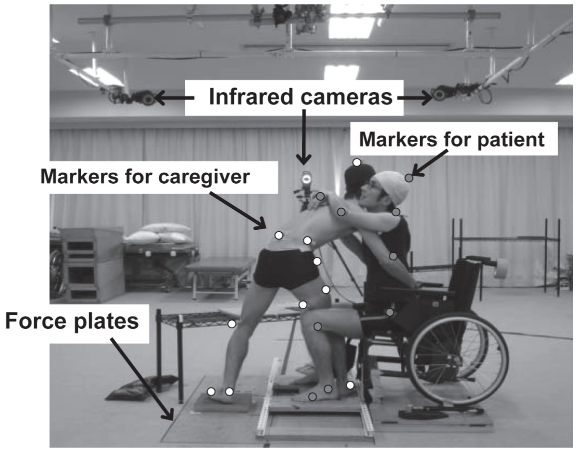

Fig. 2. Experimental setup.
Marker displacements and ground reaction forces were measured when the caregiver transferred the patient from a wheelchair to a simulated bed.

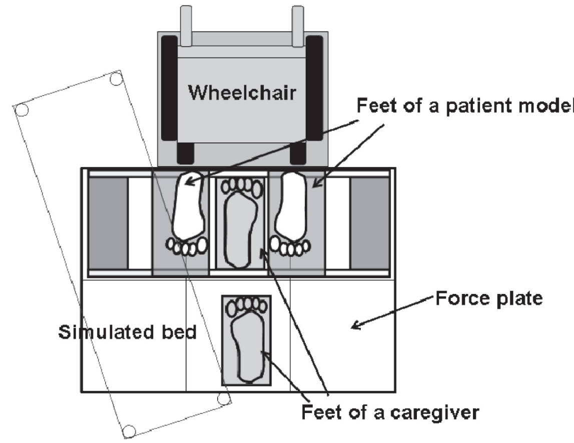

Fig. 3. Use of force plates in experimental setup.
This setup (Katsuhira *et al.*, 2008) made it possible to obtain the ground reaction force for both the caregiver and the patient.

plates (AMTI, USA) was used to record kinematic and kinetic data at a sampling frequency of 120 Hz (Fig. 2). The recorded data were low-pass filtered with a second-order recursive Butterworth filter with a cut-off frequency of 6 Hz according to the technique reported by Winter[17].

A total of 15 reflective markers were attached to the following positions on the caregivers and the simulated patient: the top of the head, and bilaterally on the acromion process, lateral epicondyle, ulnar styloid process, acetabulum, knee, ankle, and the fifth metacarpophalangeal joint. Moreover, an additional 10 reflective markers were attached to the following positions only on the caregivers: on both midtemporal points, midpoint between the acromion process and lateral epicondyle, anterior superior iliac spine, iliac crest, midpoint between the acetabulum and knee, anterior and posterior aspects of the thigh, and the point between the fourth and fifth lumbar vertebra, in order to locate spinal segments. These markers were interpolated using techniques reported in our previous study when marker data were missing[18]. This method made it possible to obtain kinematic data not only for the caregiver but also for the patient.

Transfer was performed between a standard type wheelchair that had removable arm- and footrests (REVO, etac, Sweden) and a simulated bed, which had black wire frames to maximize the camera view. This setup for transfers simulated real clinical settings as closely as possible. The angle between the wheelchair and the bed was 30 degrees, and the height of the bed was the same as the height of the wheelchair seat at 45 cm, which is the seat height of the Japan Industrial Standard wheelchair. A special platform was laid over the force plate for the patient's feet to stand on. The caregiver's feet were positioned on two separate boards (270 mm × 270 mm) (Fig. 3). The positions of the caregiver's feet were arbitrarily fixed, but they could be moved on the boards without restriction. This setup made it possible to obtain not only ground reaction forces for the caregiver but also for the patient, and to calculate the low back joint extension moment of the caregiver. The ground reaction force for the patient was used to monitor loads on the caregiver in order to limit differences in the amount of assistance provided by the patients during different trials. Caregivers were assigned an orientation of transfer: lifting and rotating the patient to the left with the right foot placed between the patient's feet. We assumed normal functioning of the patient's upper extremities, and the patient was instructed to maintain his legs in as relaxed a position as possible during the trials. Caregivers were supervised in the use of assistive devices; they practiced each task at least five times and repeated the tasks until they became accustomed to doing them. A 20-min rest period was given before starting the test trials.

This experimental setup has been used in a previous study[18].

Calculation methods for kinematic and kinetic parameters

The point between the 4th and 5th lumbar vertebrae (L4/L5) was defined as the center of rotation of the low back joint in this study on the basis of evidence that 85–95% of all disc herniations occur with relatively equal frequency at L4/L5 and L5/S1[19]. The low back joint extension moment was calculated as reported previously[18]. An eight-link segmental model was developed to calculate the low back joint extension moment in which we used inverse dynamics and referred to the calculation methods of Skotte *et al*[9]. Anthropometric parameters for mass, center of mass, and moment of inertia for each segment were obtained from reports by Winter *et al.*[17] and Okada *et al*[20]. The lengths of the foot, shank, thigh, and pelvis, and the anteroposterior diameter of the pelvis were measured from the markers attached to each segment.

To reduce the risks for LBP during transfers, it is recommended that caregivers use flexion of the knee joints and avoid flexion of the back, move closer to the patient, and use push/pull instead of lifting procedures as much as possible. We selected the following parameters to describe these general principles by measurable quantitative parameters: trunk bending angle, distance between COGs of the caregiver and patient, and the vertical component of the ground reaction force applied to the caregivers. The trunk bending angle and knee flexion angle were calculated by the Eulerian method using coordinate systems as determined by markers at the point midway between the acromion process and L4/L5 on the trunk, and at the point midway between the anterior superior iliac spine and the iliac crest on the pelvis. The COGs of the caregivers and the patient were calculated using the coordinate value of the attached markers on each participant, and then the distance in the horizontal plane between the COGs of both participants was calculated. Anthropometric parameters necessary for the calculation of the COG were obtained from reports by Winter[17] and Okada *et al*[20].

Data analysis

Three trials were recorded for each caregiver in each task. Very few participants showed variability among the three trials; however, regression and multiple regression analysis using averaged data in the three trials must include this variability. Thus, the median peak value of the low back joint extension moment in the three trials was chosen as the representative value for analysis, as were the trunk bending angle, knee flexion angle, distance between the COGs, and vertical component of the ground reaction force at the time of the peak low back joint extension moment. Averaged knee flexion angles in bilateral legs were used as the knee flexion angle in statistical analyses. The peak low back joint extension moments and vertical ground reaction forces at that time were normalized by subject weight (kg). The distance between the COGs was also normalized by subject height (mm) for the statistical analyses.

Pearson's correlation coefficient was used to quantify the correlations among the low back joint extension moment and the parameters affecting it, which were trunk bending angle, knee flexion angle, distance between the COGs, and the vertical component of the ground reaction force. Stepwise multiple regression analysis was performed to investigate the effect of these parameters on the low back joint extension moment under each condition. The peak low back joint extension moment was chosen as the dependent variable; trunk bending angle, knee flexion angle, distance between the COGs, and vertical component of the ground reaction force were chosen as the independent variables. Values of $p<0.05$ were considered significant. Statistical analyses were conducted using the software package SPSS version 12.

Results

Wave form of low back joint extension moment in time series

The averaged low back joint extension moment of all caregivers (from the time when the marker on top of the head moved 1 cm forward to the time when the marker ceased moving) with one standard deviation is shown in Fig. 4. Under all conditions, the low back joint extension moment began to increase when the caregiver moved close to the patient, and the magnitude of the low back joint extension moment reached a peak between lifting and lowering.

Peak low back joint extension moment

The mean peak values with one standard deviation for the low back joint extension moments were 3.20 ± 0.59 Nm/kg, 3.05 ± 0.55 Nm/kg, and 2.99 ± 0.51 Nm/kg under the WD, LBB, and TB conditions, respectively. The low back joint extension moment was significantly smaller during TB transfer than under the WD and LBB conditions.

Relationships between low back joint extension moment and affecting parameters

Scatter diagrams of the relationships between the low back joint extension moment and parameters that affected it are shown in Fig. 5. Significant correlation coefficients between the low back joint extension moment and both the distance between the COGs and the vertical component of the ground reaction force were observed, but not between the low back joint extension moment and the other kinematic variables (i.e., trunk and knee bending angles), under all conditions. Also, there were no significant correlations between the distance between the COGs, the vertical component of the ground reaction force, and the other kinematic variables. The highest correlation was observed between the low back joint extension moment and the distance between the COGs. Results of stepwise multiple regression analysis

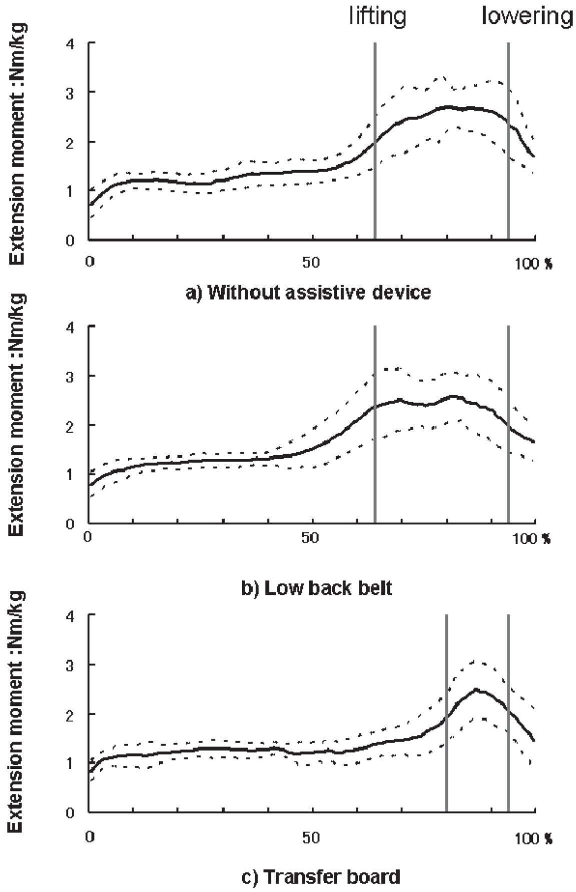

Fig. 4. Average low back joint extension moment.
Solid line and dotted line show the average low back joint extension moment and one standard deviation, respectively. Vertical axes show the low back joint extension moment. Horizontal axes show time from the starting point to the ending point of the transfers as 0 to 100%. In the WD (Fig. 4a) and LBB transfers (Fig. 4b), the first and second gray vertical lines approximate the average time at which the patient was lifted and lowered, respectively. During the TB transfer (Fig. 4c), the first and second gray vertical lines show the time needed for sliding a patient and reaching the bed. Therefore, the position of the first gray line for TB transfer is different from that for the other conditions because the TB transfer included the preparation time needed to insert the transfer board before lifting in the movement cycle. BH: body height.

in which the low back extension moment was chosen as the dependent variable, and the parameters that affected it were chosen as independent variables, are shown in Table 1. The distance between the COGs and the vertical component of the ground reaction force, but not trunk bending angle or knee flexion angle, were shown to be critical variables in the three tasks. The coefficients of determination obtained under the WD (r^2=0.799), LBB (r^2=0.987), and TB (r^2=0.998) conditions were extremely high. The significance of the effect of the distance between the COGs was larger than that of the vertical component under all conditions.

Discussion

Low back joint extension moment

The magnitude of the low back joint extension moment reached a peak at the time between lifting and lowering in all conditions. Skotte *et al*. reported that the low back extension moment is largest while lifting a patient from sitting on a bed to standing on the floor[9], which is in good agreement with the findings of the present study. They also reported that the low back extension moment is largest among the rotations about all axes while performing the same lifting movement[9], which is also in good agreement with the findings of the present study. However, in their study, the mean peak value of 184 ± 42 Nm was slightly smaller than our value of 200.5 ± 36.33 Nm. A patient who had suffered a stroke and had been instructed to cooperate in the transfer served as the patient in their study, whereas the present study used a simulated patient who was instructed not to cooperate. Therefore, the discrepancies in the extension moment were likely caused by differences in the patients and test conditions used. In addition, we found that the low back joint extension moment was significantly smaller during TB transfer than under the WD and LBB conditions. This finding is in good agreement with our previous study[18].

Effects of different techniques on low back load

The results of stepwise multiple regression analysis revealed that the distance between the COGs and the vertical component of the ground reaction force, but not trunk bending and knee flexion angles, were variables affecting the low back extension moment under all conditions. Generally, increased trunk bending angle causes an increased low back extension moment because of the extended lever arm of the joint moment, which reflects the distance from the low back joint to the COG of HAT (the head, trunk, and arm). However, we observed that the low back joint extension moment decreased during trunk bending in person transfers because the caregiver moved close to the simulated patient, decreasing the distance between them. It can also be understood that the vertical component of the ground reaction force shows the weight-bearing load directly on the caregiver, including their body weight. The weight of the patient did not change throughout the experiment; however, the vertical component of the ground reaction force was selected as a critical variable because this parameter showed not only the amount of weight-bearing load but also the accelerations applied to the caregiver. Thus, faster transfer movements caused

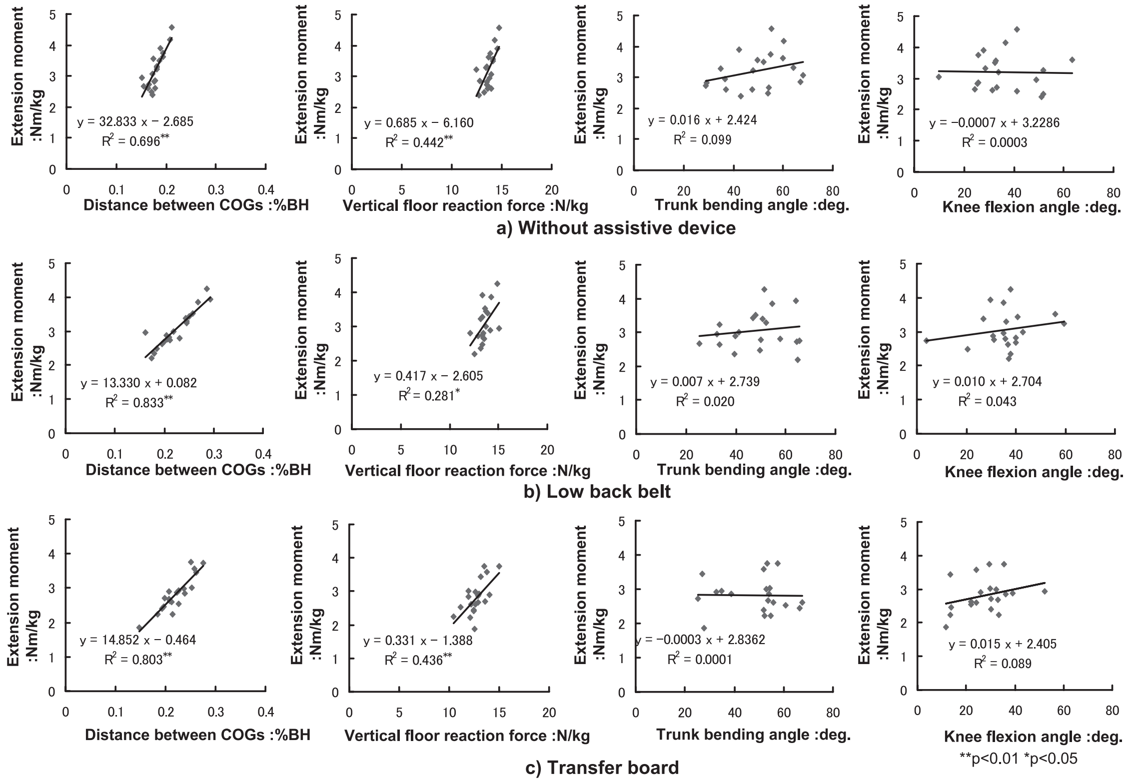

Fig. 5. Scatter diagrams of relationships between the low back joint extension moment and the parameters distance between the COGs, vertical component of the ground reaction force, trunk bending angle, and knee flexion angle.

Table 1. Result of stepwise regression analysis

	Adjusted r^2	β	p
a) Without assistive device			
(1) Distance between COGs	0.799*	0.675	<0.001
(2) Vertical ground reaction force		0.387	<0.01
b) Low back belt			
(1) Distance between COGs	0.987*	0.851	<0.001
(2) Vertical ground reaction force		0.397	<0.001
c) Transfer board			
(1) Distance between COGs	0.998*	0.777	<0.001
(2) Vertical ground reaction force		0.458	<0.001

Adjusted r^2 represents determination coefficient. β represents standardized partial regression coefficient.
*p<0.001.

larger acceleration, which provoked larger ground reaction forces. Accordingly, the vertical component of the ground reaction force and the distance between the COGs, but not the trunk bending angle, could be a factor in low back load.

In addition, there were no significant correlations between the distance between the COGs, the vertical component of the ground reaction force, and the other kinematic variables. Kingma *et al.*[21] and van Dieën *et al.*[22] reported that bending the knees rather than the back during lifting did not result in substantial reduction of low back load during manual material handling tasks. This was due to the large distance between the low back joint and the COG of the object since the knee bends with a backward shift and rotation of the pelvis. The same reason might apply to our finding that the knee flexion angle was not a parameter affecting low back load in person transfers. Moreover, the standardized partial regression coefficient of the distance between the COGs was the largest under all three of the conditions tested. Thus, the distance between the COGs was the most significant factor affecting the magnitude of the low back extension moment. Previous studies reported that low back joint load could be reduced by decreasing the horizontal distance from the low back to the object being lifted[14, 15, 23, 24], which is in good agreement with the findings of the present study with regard to person transfers.

The coefficients of determination from the multiple regression analyses under the LBB and TB conditions were higher than that under the WD condition.

Variations in transfer among individual subjects might be attributable to the lifting procedure they used and/or unstable grip on the simulated patient under WD transfer. Subjects were instructed to use a specific lifting technique in the LBB transfer condition, although the handgrip used might contribute to stable transfer of the simulated patient among subjects under the LBB transfer condition. Moreover, sliding the simulated patient from the wheelchair to the bed might also contribute to the reduced variability seen among caregivers under the TB condition. Accordingly, the coefficients of determination from the multiple regression analyses under the LBB and TB conditions imply a consistency of movement among subjects during transfers.

These results suggest that, irrespective of using assistive devices, establishing a posture that decreases the distance between the COGs of the caregiver and the patient should be a more effective transfer technique than using flexion of the knee joints and avoiding flexion of the back.

Limitations

The number of participants might have been insufficient to have applied multiple regression analysis. However, the coefficient of determination from the multiple regression analysis was extremely high. In addition, only two parameters—the distance between the COGs and the vertical component of the ground reaction force—were selected by multiple regression analysis. Thus, there should not be any problems with this statistical method.

To carry out these experiments, we chose students as caregivers rather than clinicians. This might have affected the results of our study because of differences in experience and technique between students and experienced clinicians. We plan to confirm our results in a future study with a larger number of clinicians.

The positions of the caregiver's feet were arbitrarily fixed on the boards to measure floor reaction force of both subjects in this study. This might have increased rotation of the lumbar region to compensate for the restricted movement range while transferring the patient. This increase in rotation of the lumbar region might, in turn, have increased the low back torsion moment. A previous study demonstrated that even a small increase in the low back torsion moment caused large compression force because of inefficient moment arm to create that moment[25]. In addition, the low back torsion moment cause imbalance of the acting force on the vertebral body, and in this way the moment would trigger LBP. We also plan to confirm the effect of these general principals on not only the extension moment but also the torsion moment by repeating our experiments in a setting that better conforms to the real clinical setting.

Our present findings indicated the effect of general principals on low back load, considering 'lifting techniques' as general principles. However, the technique was represented by a combination of distance, trunk bend, and knee bend. Thus, we could not compare real individual effects between parameters. We plan to conduct a future study where we manipulate each variable while holding the others constant and analyze how these affect the low back moment of each participant.

Conclusions

This study showed the effects of several general principles for guiding person transfer maneuvers on caregivers' low back loads. Overall, the results suggest that whether the posture involves bending the knee or trunk, moving closer to patient would be a preferable technique to decrease low back load during person transfers.

Our future work will investigate the effects of transferring patients with musculoskeletal problems or neurological disease on the low back load of caregivers. We will investigate different types of transfer methods, including the effects of contact between the caregiver's and patient's legs, on low back load. These procedures may have effects different from those of the techniques found in the present study on low back load.

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