Relationship between Foot Position and Lumbar Loads while Turning Patients on a Bed: An Investigation via Computational Simulation and Electromyography

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Abstract—Caregivers have lower back pain (LBP) since they must reposition patients in bed frequently. Thus, the low lumbar load posture for turning patients should be explored. In this study, we focused on foot position because it can be easily adjusted to reduce back pain. The hypothesis was that short anteroposterior foot distance could reduce lumbar loads because closer position to patient made smaller moments. Therefore, this study aimed to investigate the relationship between foot position and lumbar loads while turning patients on beds. Furthermore, we compared compression stresses of L4–L5 via computational simulation and erector spinae muscle activities obtained from electromyography (EMG) in nine foot positions. The results showed that short anteroposterior foot distance reduced lumbar loads while turning a patient on a bed.

Keywords—caregiver, patient handling, foot position, lumbar load.

1 Introduction

Caregivers have lower back pain (LBP) due when handling patients while providing care [1]–[4]. Particularly, turning a patient on a bed causes LBP because this motion is frequently performed to reposition a patient on a bed [5]. Thus, the low load posture and movement for turning a patient should be investigated to prevent LBP among caregivers. In the literature, several previous studies investigated postures, movement, and devices to reduce the lumbar load during patient handling [6]–[10]. These studies found that assistive devices such as sliding sheets could reduce lumbar loads during patient handling [6]. Additionally, turn-assist devices could reduce the caregiver's load when repositioning a patient on a bed [9, 10]. However, these assistive devices were not used in several workspaces because caregivers require time-efficient, comfortable, and cost effective devices [11].

Body mechanics-based patient handling could reduce lumbar loads without using assistive devices [7, 8]. Body mechanics provides several strategies, such as moving the center of gravity closer to the patient, to reduce lumbar loads [7]. However, there are no definitive postural parameters to realize these strategies. Thus, effective parameters and thresholds should be investigated to optimize body-mechanics-based patient handling. Posture adjustment using a wearable feedback system has been useful for reducing lumbar loads [12]. Doss et al. could improve posture and movement of nursing students during patient handling by intervention including wearable feedback system for spine angle [12]. This wearable feedback system is monitoring and giving feedback on spine angle through inertial sensors [12]. Although their intervention required verbal coaching about lower limb postures [12], this study indicates that threshold and feedback for parameters related to lower limbs are necessary for providing low load patient handling.

From these backgrounds, we are focusing on foot position as an effective parameter to reduce lumbar loads during patient handling since foot position can be adjusted easily in initial posture [13, 14]. Our previous study found that the foot position with a wide stance (anteroposterior 55% and mediolateral 20% of body height) can reduce lumbar loads during patient handling for sit-to-stand movement [14]. However, a suitable foot position for turning a patient on a bed has not been investigated.

This study investigates the relationship between foot position and lumbar loads in turning patients on a bed. Moving the center of gravity closer to the patient is an effective strategy to reduce lumbar loads because the shorter distance concluded smaller moments on the lumbar [7]. Thus, this study hypothesized that short anteroposterior foot distance could reduce lumbar loads due to closeness to the patient.

The rest of the paper is organized as follows. Section 2 introduces an experimental method to investigate the relationship between foot position and lumbar load while turning a patient on a bed. Section 3 presents experimental results. Section 4 presents discussions for this study. Finally, the conclusions of this paper are presented in Section 5.

2 Method

2.1 Participants

The study included four young, healthy male participants as simulated caregivers (age, 23.0 ± 0.700 years; body height, 1.74 ± 0.04 m; body weight, 61.4 ± 3.00 kg) and a healthy male participant as a simulated patient (age, 22.0 years; body height, 1.62 m; body weight, 58.3 kg). The participants had no experience in care activities that include patient handling. All participants provided verbal informed consent before the experiment.

2.2 Materials

Computational simulation and electromyography (EMG) were used to investigate the relationship between foot position and lumbar loads.

A computational simulation was used to investigate the compression stress of lumbar vertebrae (L4–L5). Compression stress of L4–L5 is an important factor as lumbar load because compression stress of vertebral causes serious injuries such as hernia [15]–[17]. However, directly measuring the compression stress of L4–L5 is difficult.

Thus, the compression stress of L4–L5 based on the caregiver's posture was estimated using the 3D Static Strength Prediction Program (3DSSPP, University of Michigan, USA). The 3DSSPP can estimate the compression stress of L4–L5 during manual handling by Bean et al.'s musculoskeletal model [18, 19]. A previous study reported that the 3DSSPP could accurately estimate the compression stress of L4–L5 during manual handling with various postures such as asymmetry and standing postures; thus, the 3DSSPP was selected for computational simulation [19]. Furthermore, in many previous studies, the 3DSSPP was used to evaluate lumbar loads during patient handling [20]–[22].

A digital camera (LUMIX, Panasonic Co., Japan) and the Kinovea (Joan Charmant & Contrib, France) were used to measure the positions and angles of body segments for the input of the 3DSSPP. The Kinovea can calculate kinematic values such as joint angle from 2D movies and images [23]–[26]. Since the Kinovea had been validated for measuring kinematic values in various fields such as clinical and sports biomechanics, it was selected as the motion analysis software [23]–[26].

The erector spinae muscle activity was evaluated using surface electromyography (sEMG). Previous studies indicated that increasing the erector spinae muscle activity caused LBP; thus, it was investigated as lumbar loads [27]–[30]. Furthermore, Callaghan et al. reported that erector spinae muscle activity increased with spine load during trunk movement [28]. The electrode positions for repeatable measurement were clarified in a previous study; thus, the sEMG was selected for evaluating the erector spinae muscle activity [31].

2.3 Experimental procedure

The caregivers performed turning a patient on the bed (width, 0.95 m; length, 2.00 m; height, 0.88 m) in nine foot positions with different foot distances. Based on previous studies, the size and height of the bed were determined [32, 33]. Figure 1 shows the movement of turning a patient on a bed. The caregivers turned a patient from supine to lateral position on the bed. The nine foot positions are shown in Figure 2. The nine foot positions had different foot distances normalized by body height (unit, %height). The range of foot distance was defined to keep subjective comfortability for patient handling among all caregivers. The right foot was placed in front of and near the patient's hip. Turning the patient was repeated five times for each foot position. The order of foot position was randomized for each caregiver.

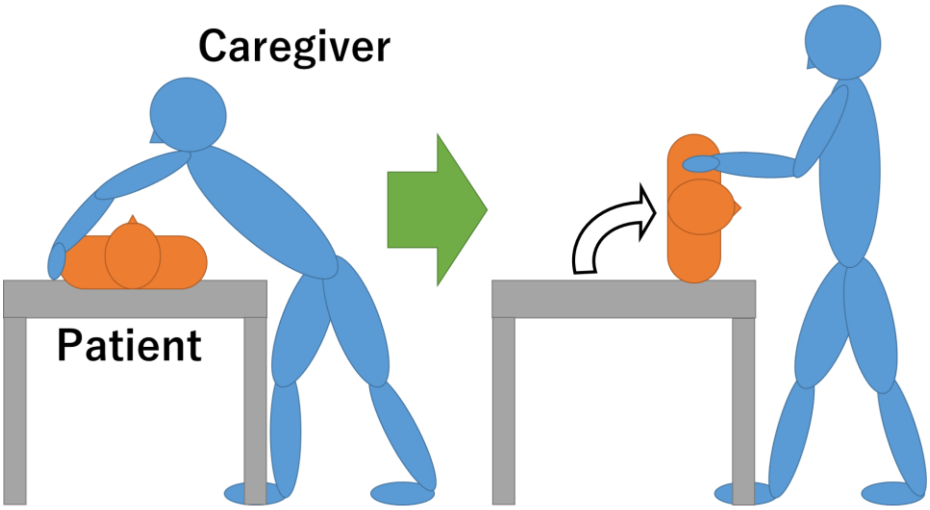

Fig. 1. Turning patient on a bed

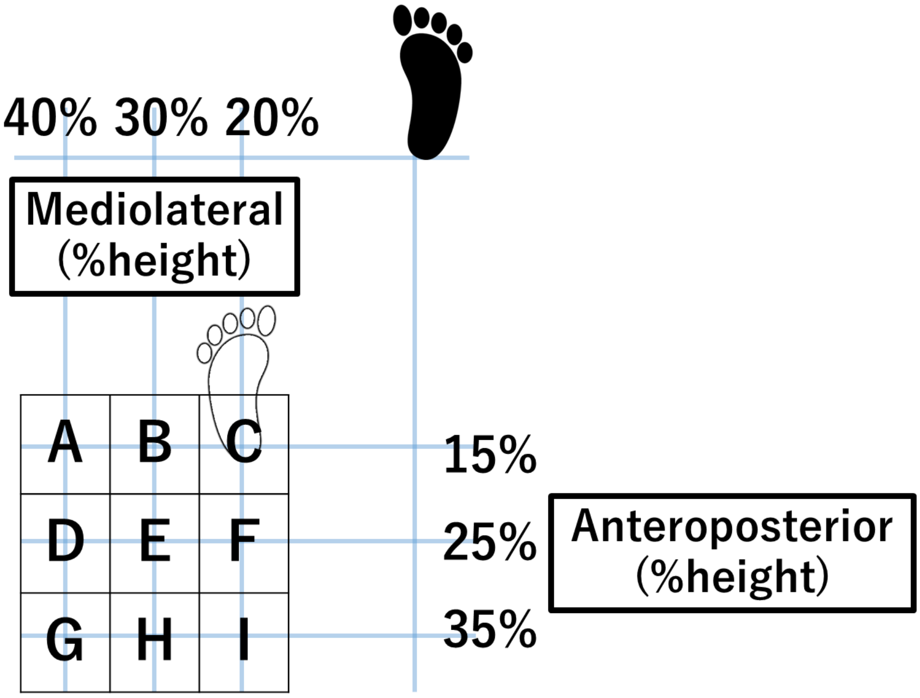

Fig. 2. Nine foot positions in turning patient

The turning patient motions performed by one of the four simulated caregivers (age, 22.0 years; body height, 1.74 m; body weight, 59.2 kg) were recorded using a digital camera for computational simulation. Furthermore, the joint angles and positions on the sagittal plane of each motion were calculated by Kinovea. These joint angles and positions were input into the 3DSSPP. Figure 3 shows the simulation model of 3DSSPP for turning a patient on a bed. Instead, of a patient, loads equal to the patient's body weight were applied on both hands of the caregiver. The compression stress of L4–L5 for each motion was calculated using the 3DSSPP with a 25 Hz sampling frequency. Mean and maximum values of the compression stress of L4–L5 for each trial were calculated for comparison. Furthermore, the distance between the center of mass of caregiver and patient in initial posture was calculated for each foot position. We calculated these distances to verify our hypothesis that short foot distance could reduce lumbar loads due to closeness to the patient.

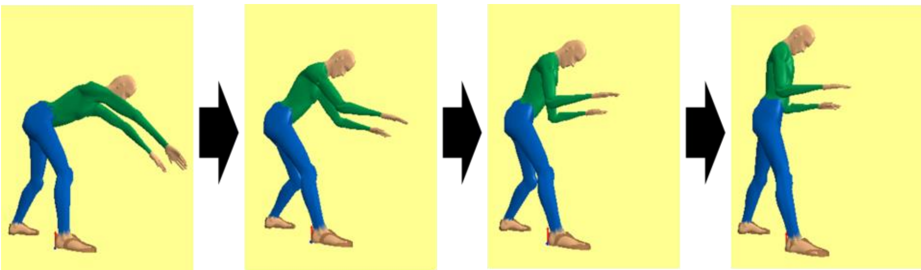

Fig. 3. Turning patient on a bed in the 3DSSPP

The sEMGs of left and right erector spinae muscles were measured for all trials and caregivers. Blue Sensor P (Ambu, Ballerup, Denmark) and the EMG Logger (LP-WS1402-W, Logical Product Inc., Fukuoka, Japan) were used to measure the sEMG with 1 kHz sampling frequency. The electrode position was based on McGill's investigation [31]. The sEMG values were normalized by maximal voluntary contractions based on Daniels and Worthingham's muscle test (unit, %MVC) [34]. Integrated EMG (iEMG) values were calculated from the rectified signal of sEMG. The iEMG values were normalized temporally by total motion time for each trial. This signal processing was performed by MATLAB R2020b (MathWorks Inc., USA).

2.4 Statistical analysis

Spearman's rank correlations between the maximum compression stress of L4–L5 and distance between caregiver and patient were calculated (significant level, $p < 0.05$). The Kruskal–Wallis test and Bonferroni method were used to compare the iEMG values of left and right erector spinae muscles of the nine foot positions (significant level, $p < 0.05$). These statistical tests were performed by EZR (Kanda, Japan) [35].

3 Results

Figure 4 shows the temporal waveforms of compression stress of L4–L5. The maximum compression forces were in the initial posture for all foot positions. Figure 5 shows the compression stress of L4–L5 and also the injury threshold (3400 N) defined by the National Institute of Occupational Safety and Health (NIOSH) [36]. The results revealed that the compression stress of L4–L5 in foot positions A, B, and C with short anteroposterior foot distance were less than 3400 N, and the maximum compression stresses of L4–L5 were more than 3400 N in other foot positions. Figure 6 shows distances between the center of mass of caregiver and patient in the initial posture of the nine foot positions. The distances of foot positions A, B, and C with small compression stress of L4–L5 were shorter than those of other foot positions. In addition, there was a significant correlation between the maximum compression stress of L4–L5 and distance ($r = 0.917$; $p < 0.05$).

Figures 7 and 8 show left and right erector spinae muscle activity in nine foot positions. In both left and right erector spinae muscles, no significant difference was observed for all foot positions ($p > 0.05$).

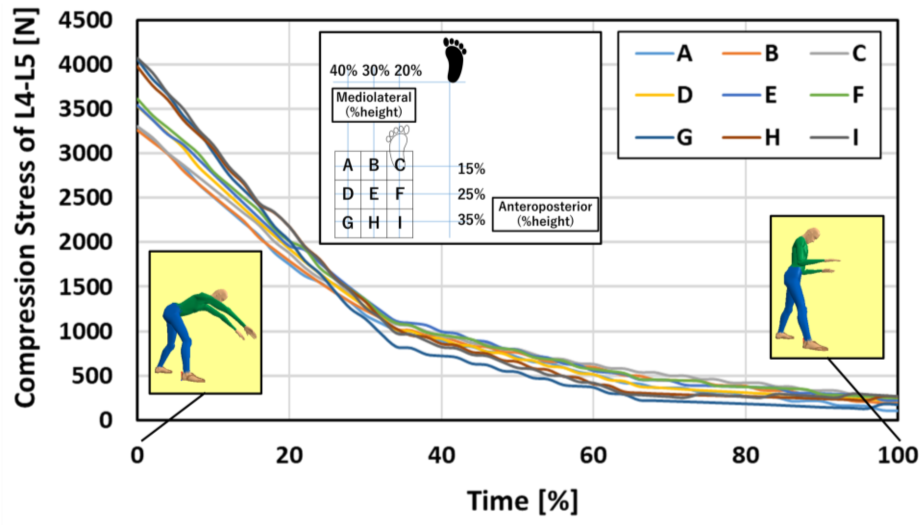

Fig. 4. Temporal waveforms of compression stress of L4–L5

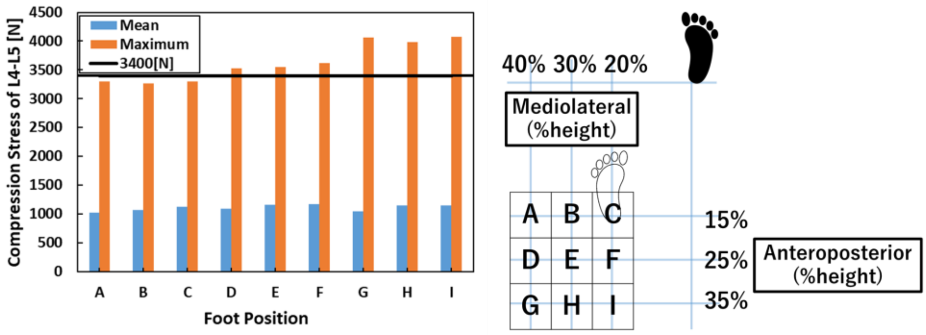

Fig. 5. Compression stresses of L4–L5 in nine foot positions

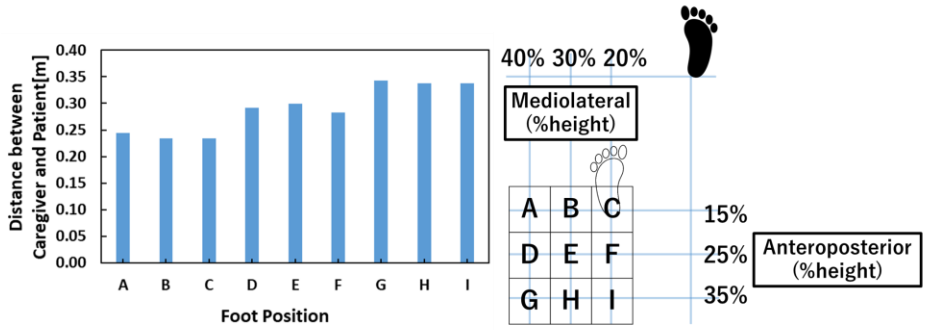

Fig. 6. Distance between caregiver and patient in the initial posture of nine foot positions

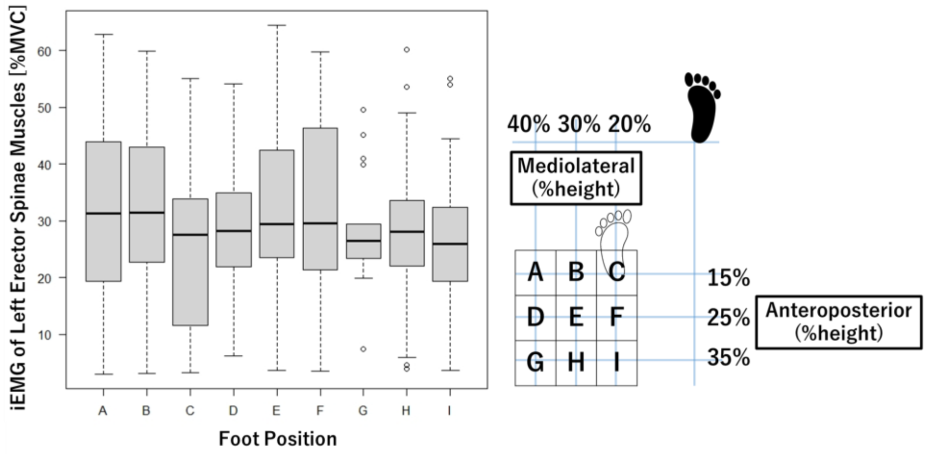

Fig. 7. iEMG of left erector spinae muscle of nine foot positions

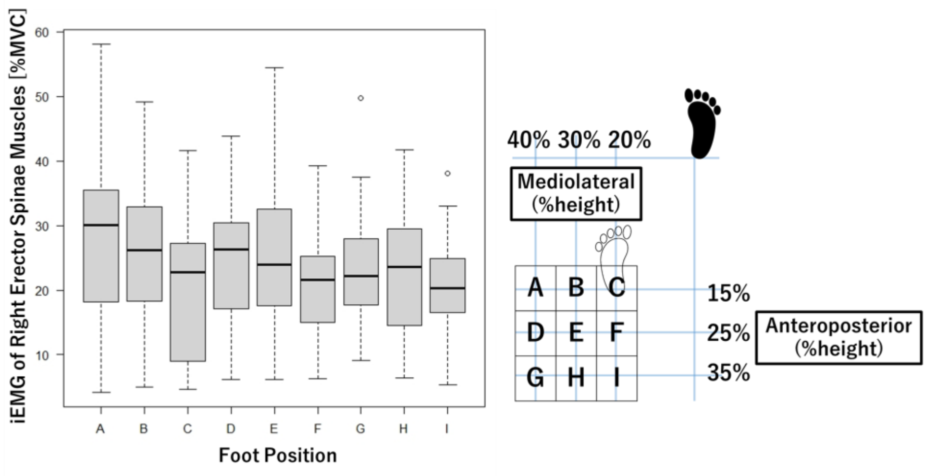

Fig. 8. iEMG of right erector spinae muscle of nine foot positions

4 Discussion

This study investigated the relationship between foot position and lumbar loads while turning patients on a bed.

The compression stress of L4-L5 values obtained from this study were comparable to previous studies related to turning patient on a bed [6, 9, 10]. Initial posture had the largest compression stress of L4–L5 in turning a patient on a bed. The reason for this trend is that the largest trunk flexion of initial posture caused the largest compression force of L4–L5. As shown in our previous study, the initial posture with the largest trunk flexion had the largest compression force in assistive sit-to-stand motion [13]. Additionally, in previous studies, it was reported that trunk flexion increased compression stress of the lumbar vertebrae [37, 38]. Thus, caregivers should reduce trunk flexion of initial posture in turning patient on a bed.

The maximum value of compression stress of L4–L5 in foot positions A, B, and C with shorter anteroposterior foot distance was smaller than that of other foot positions. Additionally, the caregiver is close to the patient in foot positions A, B, and C, and a significant correlation between maximum compression stress of L4–L5 and distance was noted between caregiver and patient. These results support our hypothesis that foot positions with short anteroposterior foot distance contribute to reducing lumbar loads due to closeness to the patient. Closeness to the patient is recommended by body mechanics for patient handling [7]. However, foot positions with long foot distance reduced lumbar loads in assistive sit-to-stand motion [13, 14]. This motion required using lower limb movement obtained from long anteroposterior foot distance instead of lumbar movement [13, 14]. Turning a patient on a bed did not require using the lower limb; thus, a shorter anteroposterior foot distance is more suitable for turning the patient.

The maximum compression stresses of L4–L5 in foot positions A, B, and C were smaller than 3400 N as injury shreshould. These findings suggest that foot positions A, B, and C are recommended for turning patient on a bed. Particularly, foot position A with a wide stance is the most suitable position for turning patients on a bed because a wide stance is recommended to obtain a base of support in body mechanics [7].

There was no difference in mean compression stresses of L4–L5 and iEMG of erector spinae muscle activity in the nine foot positions. These results revealed that foot position affected lumbar loads for only the initial posture of turning patient on a bed. Therefore, other postural parameters such as trunk movement should be optimized to reduce lumbar loads other than the initial posture.

There is one limitation to this study. The participants were only males without experience in patient handling. Movement and lumbar loads of manual handling were affected by previous experience, gender, or age [39]–[41]. Thus, the relationship between foot position and lumbar loads should be investigated for clinical field and experienced caregivers. Furthermore, because the 3DSSPP was not able to process inertial data, this study did not consider the velocity and acceleration of joint movement. Future works should prepare different musculoskeletal computational simulations that can process velocity and acceleration data of motion. For example, the AnyBody Modeling System (AnyBody Technology A/S, Denmark) can build a computational musculoskeletal model that processes inertial data [42, 43].

The feedback system will be proposed for foot position while turning patient on a bed and should be simple and easy to use because caregivers require time-efficient, comfortability, and cost effective assistive devices [11]. Wearble sensors for human motion measurement [44, 45] will be applied for this feedback system. In addition, suitable motion with optimal foot position will be implemented to caregivers via online learning tools for nursing education [46].

5 Conclusion

This study investigated the relationship between foot position and lumbar loads while turning a patient on a bed to prevent LBP among caregivers. The results showed that foot position with short anteroposterior foot distance could reduce the largest lumbar loads of initial posture because of closeness to a patient. These findings suggest that foot position with short anteroposterior foot distance is recommended to prevent LBP due to turning the patient on a bed. Future studies should propose implementation methods for the foot position to prevent LBP due to turning a patient on a bed.

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