

# Compressive and Shear Forces of L5/S1 during Patient Transfer in Different Loads on Hands

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**Abstract** Patient transfer is the primary cause of lower back pain among caregivers because it requires awkward postures and movements such as twisting, lifting, and lowering with heavy external loads such as body weight. To prevent lower back pain, the relationship between lumbar loads and external loads from patient weight should be investigated to explore the hazardous limits of external loads during patient transfer. However, this investigation requires frequent trials and heavier loads than the hazardous limit. Therefore, we have used a computational musculoskeletal simulation for patient handling without the actual measured load data of human subjects. A previous study used a musculoskeletal simulation of sit-to-stand assistance motion; however, this simulation did not consider twisting and lowering patient transfer. Hence, this study aims to investigate the relationship between lumbar loads and external loads during patient transfer, including twisting and lowering. The musculoskeletal simulation for this investigation was implemented using the 3D Static Strength Prediction Program. First, the implemented musculoskeletal simulation was validated by comparison with related research using actual measured motion data and an optical motion capture system. Furthermore, the relationship between lumbar loads (compressive and shear forces of L5/S1) and external loads during patient transfer was investigated using a validated musculoskeletal simulation. According to the results, the compressive and shear forces of L5/S1 during patient transfer exceeded the limits of safety when the external load was more than 40 kgf. These findings will contribute to the prevention of lower back pain due to patient transfer.

**Keywords** musculoskeletal simulation, patient transfer, lower back pain, compressive force, shear force, external load

## I. INTRODUCTION

### A. Background

Patient handling cause Lower Back Pain (LBP) among caregivers [1–5]. In particular, patient transfer is the primary cause of LBP because it requires awkward movements such as twisting, lifting, and lowering with a

heavy external load from patient weight [6–8]. Therefore, the relationship between lumbar loads and external load from patient weight should be investigated for LBP prevention.

### B. Previous Studies

Previous studies explored the risk factors of patient transfer by measuring actual patient transfer [9–11]. According to Xiang et al., the external load for patient transfer should be less than 15 kgf in an experimental study because the lumbar compressive force of a participant might exceed the injury threshold (3400 N) [12] defined by the National Institute of Occupational Safety and Health (NIOSH) [11]. This report suggests that the effect of heavy weight on patient transfer cannot be investigated through an experimental study alone. Thus, a computational musculoskeletal simulation of patient transfer that does not require actual transfer motion is necessary to investigate the effect of weight. Our previous studies used a computational musculoskeletal simulation of assistive motion for sit stand [13, 14] which could provide the relationship between external and lumbar loads with actual motion data. However, this simulation cannot consider twist and lowering in patient transfer as it focuses only on sit-to-stand. Because asymmetric posture relates to lumbar loads, lumbar loads during twisting of patient transfer should be considered in particular [15–17]. Therefore, a new computational musculoskeletal simulation for patient transfer should be developed.

### C. Objective

This study aims to investigate the relationship between lumbar loads and external load during patient transfer including twisting and lowering. Computational musculoskeletal simulations for patient transfer including twisting and lowering were developed and validated to perform the investigation.

## II. MUSCULOSKELETAL SIMULATION

### A. Implementation

Computational musculoskeletal simulation was implemented using the 3D Static Strength Prediction

Program (3DSSPP, University of Michigan, USA). The study on patient transfer using marker-based musculoskeletal model for the computational simulation measurement [29] Table I shows the parameters of the was based on Beattie et al. model provided in the implemented simulation for this verification. The external 3DSSPP [18-19]. The 3DSSPP was selected because load on the hands was set 30 kgf compared with Rajaei et al. [19] reported that it could correctly calculate previous study [29] In addition, the specifications of the the compressive force of the lumbar vertebral while caregiver (gender, body height, and body weight) were manual handling tasks such as asymmetry postures also determined by a previous study [20]. The sampling Furthermore, the 3DSSPP has been used occupational rate of 25 Hz depended on the specifications of the health for musculoskeletal disorders in various fields 3DSSPP. The time of motion was determined by a video including airline baggage handling, manufacturing, and of patient transfer [25] used for the implemented construction [20,23]. In addition, our previous research simulation. The compressive force L5/S1 was compared used the 3DSSPP to investigate the relationship between the implemented simulation and previous study foot position and lumbar loads in turning patients on a bed [24].

Fig. 1 shows the data processing of the computational musculoskeletal simulation for this research. Input data for the simulation were patient transfer motion, external load on the hands of the patient, and body parameters of the musculoskeletal model. Fig. 2 shows the patient transfer motion of the simulation. This patient transfer motion was built based on the patient transfer video published by the patient handling section of the Japanese society of nursing art and science [25]. Output data were the lumbar compressive and shear forces between the L5/S1, known as lumbar loads related to LBP [26, 27]. These lumbar forces were calculated using inverse kinematics-based posture and static force prediction and Beattie et al. model in the 3DSSPP [18].

Notably, this verification was not required for the ethics committee review because this procedure did not require participants and measurement for actual motions.

TABLE I. PARAMETERS OF THE IMPLEMENTED SIMULATION IN VERIFICATION

Parameters	Value/Status
Gender of Caregiver	Female
Body Height of Caregiver [m]	1.78
Body Weight of Caregivers [kg]	95
External Load on the Hands [kgf]	30
Orientation of External Load	Vertical
During Time of Motion [seconds]	3.12 (Each Phase: 1.04)
Sampling Rate [Hz]	25
Outcome of Lumbar Loads	Compressive Force of L5/S1

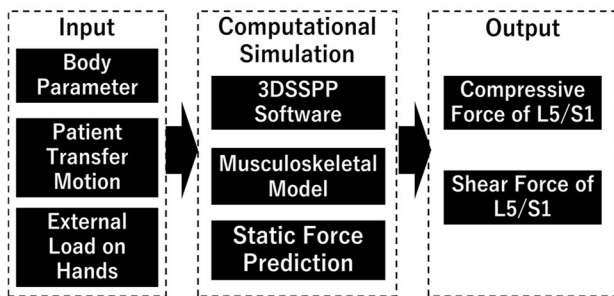


Figure 1. Data processing of the musculoskeletal simulation.

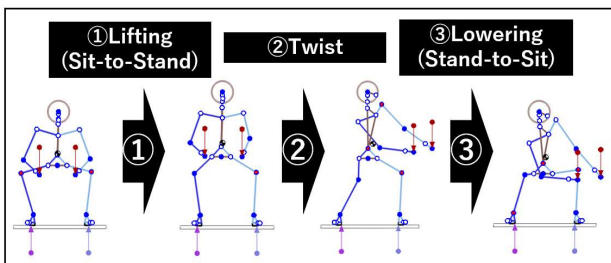


Figure 2. Patient transfer motion of the musculoskeletal simulation.

B. Verification

As mentioned previously, the patient transfer motion was built from the video data, which the motion capture system did not record. Therefore the implemented motion should be verified because it does not use high accurate motion data obtained from marker-based measurement [28]. Thus, in this study, the output of the implemented simulation was compared with a previous

C. Results of Verification

Fig. 3 shows the temporal waveform of the simulated compressive force of L5/S1 during patient transfer. The mean values of the simulated compressive force of L5/S1 for each section are shown in Table I.

The mean of the simulated compressive force during all sections was 5281 N (Table I). According to a previous study, the compressive force of L5/S1 during patient transfer with a 30 kgf external load was approximately 5000 N [29]. As mentioned previously, the specifications of caregivers (gender, body height, and body weight) were set to similar values as in this previous study [29]. These results indicate that the implemented computational musculoskeletal simulation could provide almost accurate lumbar loads during patient transfer.

The temporal waveform (Fig. 3) and mean values of each section (Table I) showed that the simulated compressive force of the sit-to-stand (lifting) section exceeded that of the stand-to-sit (lowering) section. This agrees with the results of previous study using optical motion capture systems [11]. These results indicate that the implemented computational musculoskeletal simulation can calculate accurate lumbar loads during patient transfer, including asymmetric postures. Thus, the implemented simulation was used to investigate the relationship between external load and lumbar loads during patient transfer.

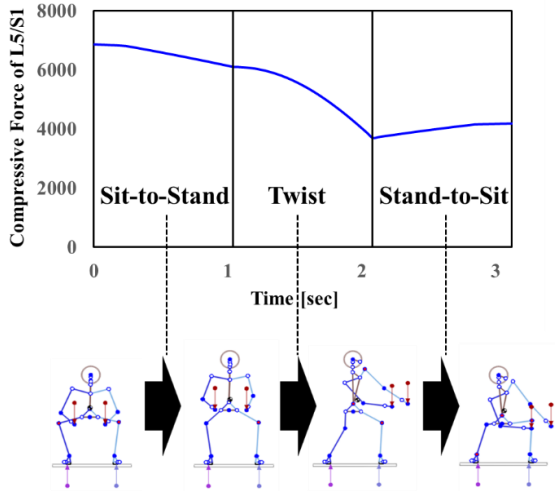


Figure 3. Simulated compressive force of L5/S1 in verification (external load was 30 kgf).

TABLE II. PARAMETERS OF THE IMPLEMENTED SIMULATION IN VERIFICATION

Section	Mean of Simulated Compressive Force of L5/S1 [N]
Sit-to-Stand	6554
Twist	5324
Stand-to-Sit	3991
All	5281

### III. SIMULATION-BASED EXPERIMENT

The relationship between external and lumbar loads during patient transfer was investigated using a validated musculoskeletal simulation. Table II shows the parameters of the implemented simulation. The external load was set as 50 kgf. Compressive and anteroposterior shear forces of L5/S1 were calculated as lumbar loads. The other parameters were the same as verification (Table ).

The relationships between external and lumbar loads were investigated using linear regression. The correlations between the lumbar and external loads were investigated using Spearman rank correlation coefficient. In these analyses, the mean values of the temporal waveform for each external load were used for compressive and anteroposterior shear forces of L5/S1. The significance level was  $p < 0.05$ . These statistical analyses were performed using EZR [30].

Notably, this experiment did not require an ethics committee review because the procedure did not need real participants and measurements for actual motions.

TABLE III. PARAMETERS OF SIMULATION FOR EXPERIMENT

Parameters	Value/Status
External load [kgf]	0-50
Outcome of Lumbar Loads	Compressive Force of L5/S1
	Anteroposterior Shear Force of L5/S1

### IV. RESULTS

Figs. 4 and 5 show the relationships between the mean value of lumbar loads and external load. Data distributions for each external load are shown in Figs. 6 and 7.

There was a significant positive correlation between the compressive force of L5/S1 and the external load during patient transfer ( $p < 0.05$ ) (Fig. 4). For compressive force, the results of linear regression showed that the compressive force of L5/S1 exceeded the injury threshold (3,400 N) [12] when the external load exceeded approximately 15 kgf. These results agree with a previous study of patient transfer using an optical motion capture system [11]. The data distribution indicated that all compressive forces exceeded the injury threshold (3,400 N) [12] in 30 kgf, 40 kgf, and 50 kgf external loads (Fig. 6).

There was a significant positive correlation between the anteroposterior shear force of L5/S1 and external load during patient transfer ( $p < 0.05$ ) (Fig. 5). The linear regression results for the anteroposterior shear force showed that the shear force of L5/S1 exceeded 500 N when the external load exceeded approximately 40 kgf. McGill et al. recommended that the shear force of the lumbar vertebral should be less than 500 N to prevent LBP [31]. Data distribution indicated that all shear forces exceeded the injury threshold (500 N) [12] at a 50 kgf external load (Fig. 7).

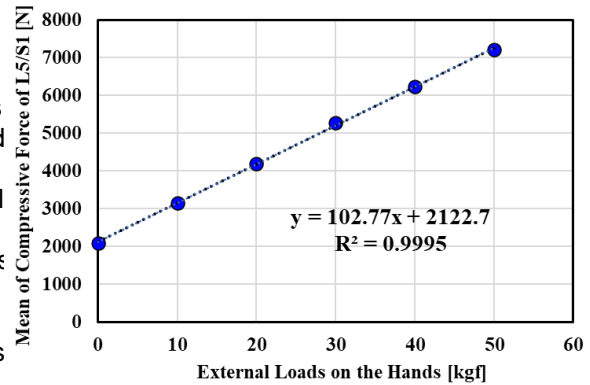


Figure 4. Relationship between the compressive force of L5/S1 (mean values) and external load.

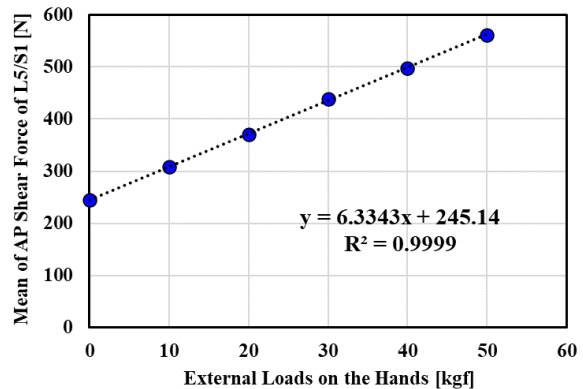


Figure 5. Relationship between anteroposterior shear force of L5/S1 (mean values) and external load.

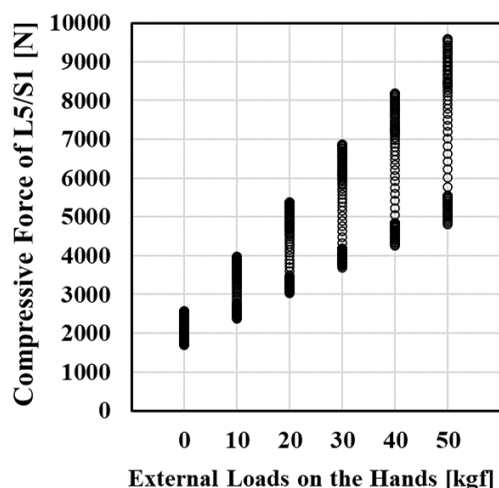


Figure 6. Data distribution of compressive force of L5/S1.

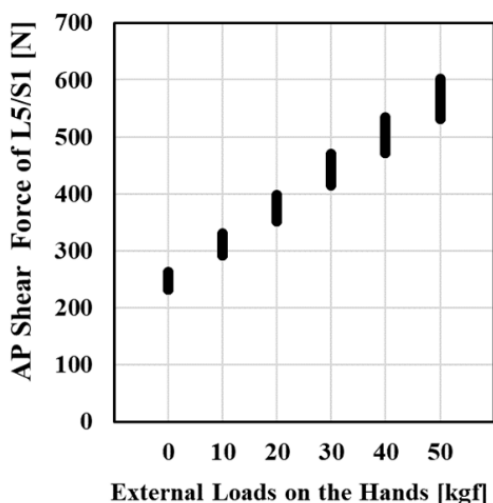


Figure 7. Data distribution of the anteroposterior shear force of L5/S1.

## V. DISCUSSION

According to the results, the compressive and anteroposterior shear forces of L5/S1 exceeded the injury threshold when the external load was more than approximately 40 kgf. The results indicate that the injury threshold of the anteroposterior shear force of L5/S1 allows a heavy external load than compressive force. The results of this study and a previous study [11] suggest that the compressive force of L5/S1 exceeds the injury threshold when the external load is more than 15 kgf. Thus, caregivers are recommended to avoid more than 15 kgf of external load. In particular, more than 40 kgf of external load is dangerous because both the compressive and anteroposterior shear forces of L5/S1 exceed the injury threshold. These findings will contribute to the proposed limits of external load during patient transfer.

The advantage of the implemented computational musculoskeletal simulation is that it does not require actual participants or motion measurements. The external load should be less than 15 kgf for safety when participants perform patient transfer [11]. However, there is a possibility of a larger external load in actual patient

handling in clinical fields. On the other hand, the implemented simulation can investigate patient transfer with heavy external loads, such as clinical conditions, because this simulation does not require actual participants or frequent motion measurements. The other advantage of the implemented simulation is that the 3DSSPP can change the joint angles and positions of the full body. This advantage will contribute to the investigation suitable posture and movement to prevent LBP owing to patient transfer.

This study's limitation was that verification of the implemented simulation was only compared with previous studies. Ideally, the output of the implemented simulation should be compared with the reference signals obtained from the experiment. Furthermore, the specifications of the caregiver were only one type. Therefore, various genders, weights, and heights should be applied in future studies. In particular, the injury thresholds might be changed for other specifications of the participants [32]. The implemented computational musculoskeletal simulation has some limitations. The orientation of the external load was only vertical in the implemented simulation. Other vectors of external loads should be considered in manual handling [33]. In addition, the implemented simulation calculated only lumbar vertebral forces. Other lumbar loads, such as muscle activity, should be investigated [34]. Finally, the movement and effort of the lower and upper limbs are important factors in preventing LBP [34, 35].

## VI. CONCLUSION

This study investigated the relationships between lumbar loads and external loads during patient transfer using musculoskeletal simulation.

The implemented simulation was validated by comparison with a previous study using an optical motion capture system. The results showed that both the compressive and shear forces of L5/S1 during patient transfer exceeded the limits of safety when the external load were more than 40 kgf. These findings will contribute to the prevention of LBP due to patient transfer.

The implemented simulation will be validated for various specifications of caregivers in future studies. In addition, other factors, such as posture and movement, will be investigated to prevent LBP due to patient transfer.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

## AUTHOR CONTRIBUTIONS

Conceptualization: K.K. and C.W.; methodology: K.K., H.N., T.K., H.M., and C.W.; software: K.K.; validation: K.K., H.N., T.K., H.M., and C.W.; formal analysis: K.K.; investigation: K.K., H.N., T.K., H.M., and C.W.; resource: C.W.; data curation: K.K. and H.M.; writing<sup>2</sup> original draft preparation: K.K.; writing<sup>2</sup> review and editing: K.K., H.N., T.K., H.M., and C.W.; and supervision: K.K. and C.W. All authors have read and agreed to the final version of the manuscript.

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