International Journal of Research in Orthopaedics
Uchimura R et al. Int J Res Orthop. 2025 Jan;11(1):1-5
http://www.ijoro.org

Original Research Article

DOI: https://dx.doi.org/10.18203/issn.2455-4510.IntJResOrthop20243773

Musculoskeletal simulation for patient transfer using hand load measurement device

Ryo Uchimura[1]*, Ryohei Fushitani[1], Kodai Kitagawa[2], Chikamune Wada[1]

[1]Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Kitakyushu, Japan
[2]Mechanical and Medical Engineering Course, National Institute of Technology, Hachinohe College, Hachinohe, Japan

Received: 20 November 2024
Accepted: 06 December 2024

***Correspondence:**
Dr. Ryo Uchimura,
E-mail: uchimura.ryo839@mail.kyutech.jp

ABSTRACT

Background: Unsuitable posture in patient transfer motion causes lower back pain (LBP) among caregivers. The suitable postures to reducing lumbar loads during patient transfer are investigated by musculoskeletal simulation. However, existing musculoskeletal simulation cannot accurately predict lumbar loads because the existing musculoskeletal models are generated by only motion data. Thus, this study aimed to propose and evaluate an accurate musculoskeletal model using hand load data obtained from a hand load measurement device.
Methods: Motion and hand load data for the musculoskeletal model were measured during patient transfer by an inertial measurement unit (IMU)-based motion capture system and hand load measurement device. The existing model without using hand load data and the proposed model using hand load data predicted the activity of the erector spinae muscles and the compressive force of L4-L5. The correlation of erector spinae muscle activity was compared between the predicted and ground truth (surface electromyography) values. Furthermore, predicted compressive forces of L4-L5 were compared with reference value reported by previous study related to *in vivo* intradiscal pressures measurement.
Results: The proposed model could predict erector spinae muscle activity with a correlation that was significantly greater than that of the existing model ($p<0.05$). Furthermore, the proposed model could predict compressive forces of L4-L5 with approximate values close to *in vivo* intradiscal pressures measurement.
Conclusions: Proposed musculoskeletal model may more accurately predict lumbar loads during patient transfer than the existing model. Proposed musculoskeletal model will be applied to explore suitable postures for preventing LBP.

Keywords: Caregiver, Patient transfer, Muscle activity, Spinal load, Musculoskeletal simulation, Hand load

INTRODUCTION

Unsuitable posture in patient transfer motion causes LBP among caregivers.[1] Assistive tools such as a sliding sheet and a lifting device are used for preventing LBP among caregivers.[2,3] These assistive devices could reduce the lumbar load during patient transfer; however, these assistive devices cannot be used in several cases because of the working space and time efficiency.[2,3] Therefore, new approaches to reduce lumbar loads during patient transfer are necessary when assistive devices cannot be used.

Postural adjustment is considered as an approach to reduce lumbar loads during patient transfer.[4] Thus, exploring a suitable posture is effective for reducing lumbar loads without assistive devices. Previous have studies indicated that the adjustment of trunk and lower limb movement could reduce lumbar loads.[4] However, the relationships between posture and various lumbar loads such as erector spinae muscles (inner and outer) activities and spinal load were nearly not investigated.[5] It is difficult to directly and non-invasively measure lumbar load such as inner muscle activity and spinal load.

Previously, we investigated the relationship between lumbar loads and posture during patient handling through musculoskeletal simulation.[5] Musculoskeletal simulation can be used in non-invasive evaluation of lumbar loads, including inner muscles.[6] However, existing musculoskeletal simulations cannot accurately predict lumbar loads because the existing musculoskeletal models are generated by only motion data.[5] A previous study found that ground reaction force as input data contributed to the improvement of prediction accuracy in musculoskeletal simulation.[7] Thus, external force data may improve prediction accuracy in musculoskeletal simulation. The hand load is one of the external forces during patient transfer. The effect of hand load data on the accuracy of musculoskeletal simulation for patient transfer has not been investigated. From this background, this study aimed to propose and evaluate a novel accurate musculoskeletal model using hand load data obtained from a hand load measurement device.

METHODS

Proposed musculoskeletal model

Figure 1 shows an overview of the proposed musculoskeletal model. The input data of the proposed model are the motion data obtained from the wearable IMU-based motion capture system (Perception neuron 2, Noitom, Ltd.) and the hand load data obtained from the hand load measurement device. The wearable IMU-based motion capture system measures motion including finger movement during patient transfer by 31 IMUs. The musculoskeletal model with this motion and hand load data was implemented by the AnyBody modeling system (Anybody technology A/S). The AnyBody modeling system can predict lumbar loads more accurately than other musculoskeletal simulations during various manual handling tasks.[8] Lumbar loads such as erector spinae muscle activity and spinal load are predicted by inverse dynamics and optimization for muscle activity via functions in the AnyBody modeling system.

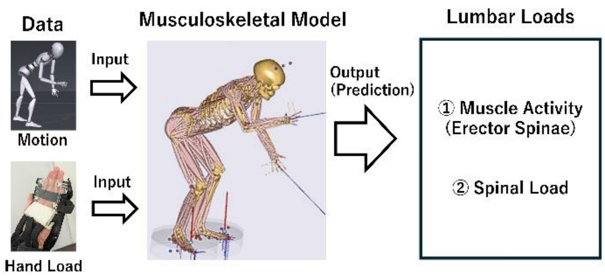

Figure 1: Overview of the proposed musculoskeletal model.

The hand load measurement device was manufactured by the authors. An overview of the hand load measurement device is shown in Figure 2. The measurement plate of this device is shown in Figure 3. This device is manufactured from pressure sensors (FlexiForce A201-100, Tekscan, Inc.), amplifier circuits (FlexiForce Adapter 1120, Phidgets, Inc.), and a data logger (P-WS1311, Logical Product Co., Ltd.). The selected pressure sensor (FlexiForce) is known as a suitable sensor for hand force measurement.[9]

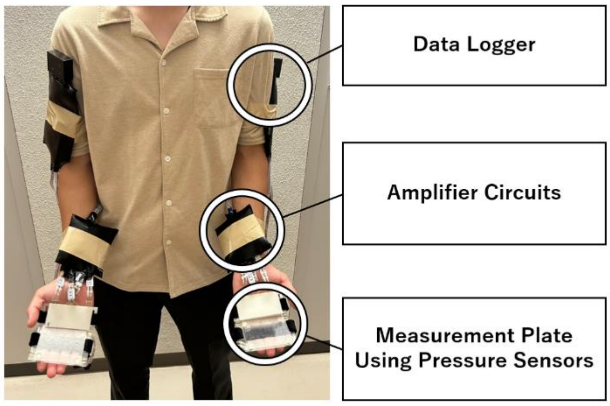

Figure 2: Hand load measurement device.

Measurement plates were fixed on the fingers and palms of the left and right hands. As shown in Figure 3, four pressure sensors with spacers were placed on each acrylic measurement plate. Each measurement plate was calibrated using a load cell (PLP-10L-180L, Toyo Sokki Co., Ltd). The specification of this device was validated in our previous study.[10]

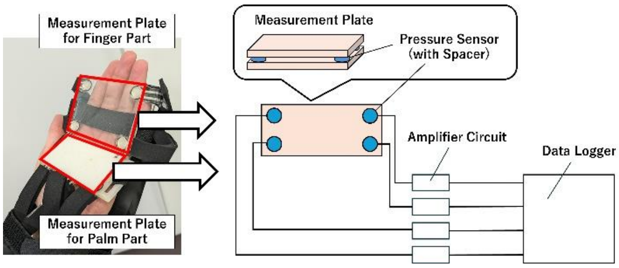

Figure 3: Measurement plate of the hand load measurement device.

Evaluation of the musculoskeletal model

In the experiment, the accuracies of the muscle activity prediction of the proposed and existing musculoskeletal models were evaluated via comparison with surface electromyography (sEMG) on the erector spinae muscles during patient transfer. In addition, the compressive forces of L4-L5 as the spinal load predicted from the existing model and the proposed model were compared with the reference value reported by a previous study related to *in vivo* intradiscal pressure measurements.[11] The existing musculoskeletal model was implemented with only motion data. The proposed musculoskeletal model was implemented with both motion and hand load data.

Participants were five healthy men (22.2±0.75 years, 169±6.03 cm, 55.6±3.72 kg, mean±SD). This study was approved by the National Institute of technology, Hachinohe college ethics review board (approval number: R4-2). The participants were asked to perform the patient transfer motion. The patient transfer motion is shown in Figure 4. The participants transferred the doll as a patient from the bed to a chair with a left turn. Each participant performed this motion three times. A total of 15 trial data were measured via this experiment. Note that a light doll (5 kg) as the patient was used for saving physical loads for the participants.

Figure 4: Patient transfer motion in the experiment.

Motion data for the musculoskeletal model were measured during patient transfer by a wearable IMU-based motion capture system with 60 Hz sampling rate. Hand load data were measured during patient transfer by a hand load measurement device with a 1 kHz sampling rate. The sampling rate of the hand load data was adjusted to 60 Hz via a second-order Butterworth low-pass filter. To obtain the ground truth of muscle activity, sEMG on the erector spinae muscles during patient transfer was measured by sEMG sensor (LP-WSD1402-0A, logical product Co., Ltd.) with a 1 kHz sampling rate. Noises of measured sEMGs were removed via a second-order bandpass filter ($20 \leq fs < 500$ Hz). In addition, the measured sEMGs were full-wave rectified. The sampling rate of the rectified sEMGs were adjusted to 60 Hz via a zero phase-shift fifth-order Butterworth low-pass filter. Finally, filtered sEMGs were normalized by the muscle activity of maximal voluntary contraction (unit: %MVC). The existing musculoskeletal model predicted erector spinae muscle activity during patient transfer using only motion data. The proposed musculoskeletal model predicted erector spinae muscle activity and compressive forces of L4-L5 during patient transfer using both motion and hand load data. These predictions were performed using the AnyBody modeling system.

The correlation of erector spinae muscle activity between the predicted (musculoskeletal model) and ground truth (sEMG) values was calculated from the time waveforms of each trial. Correlation values with the ground truth were calculated for both the proposed and existing musculoskeletal models. Correlation values between the proposed and existing musculoskeletal models were compared using the Wilcoxon signed-rank test. The mean value of the compressive forces of L4-L5 was calculated from the time waveform for each trial. The mean values of the predicted compressive forces of L4-L5 were compared with the reference value (approximately 2400 N) from a previous study related to *in vivo* intradiscal pressure measurements.[11] This previous study showed that the compressive force was approximately 2400 N when participants were holding two 4-kg weights on their hands with 30° trunk flexion.[11] The posture between this motion in the previous study and patient transfer to this study are similar. The mean values of the predicted compressive forces of L4-L5 were compared between the proposed and existing musculoskeletal models by the Wilcoxon signed-rank test. The significance level was set as $p<0.05$. These statistical tests were performed using EZR.[12]

RESULTS

Figures 5 and 6 show an example of the time waveform of the erector spinae muscle activities during patient transfer. Time waveforms showed small or negative correlations in muscle activities between the ground truth values (sEMG) and the predicted values from the existing model using only motion data. In addition, the existing model predicted a decreasing trend of muscle activity when the ground truth of muscle activity was an increasing trend. Whereas a positive correlation was found between the muscle activities between the ground truth values and the predicted values from the proposed model using both the motion and hand load data.

Correlations with the ground truth values are shown in Figures 7 and 8. The results showed that the correlation of the proposed model with the ground truth was significantly greater than that of the existing model in the left and right erector spinae muscles ($p<0.05$). In addition, the correlations between the ground truth and the existing model were small or negative values.

Figure 9 shows the predicted compressive forces of L4-L5 during patient transfer. The results showed that the compressive forces of L4-L5 predicted from the proposed model were significantly larger than those predicted from the existing model ($p<0.05$). As mentioned previously, a previous study using *in vivo* intradiscal pressure measurement showed that the compressive force of the lumbar vertebra was approximately 2400 N.[11] The proposed model could predict compressive forces of L4-L5 with approximate values (around 2000 N) close to *in vivo* intradiscal pressures measurement.[11] On the other hand, the existing model predicted the compressive forces of L4–L5 to be <2000 N in all trials.

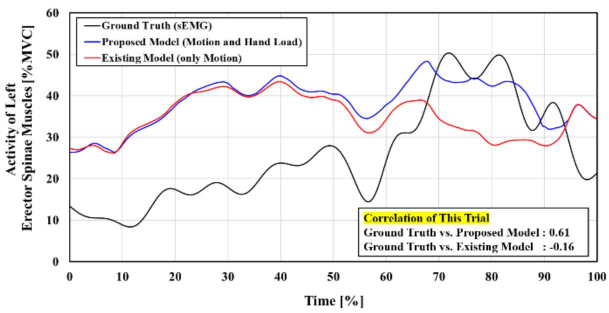

Figure 5: Example of left erector spinae muscle activities.

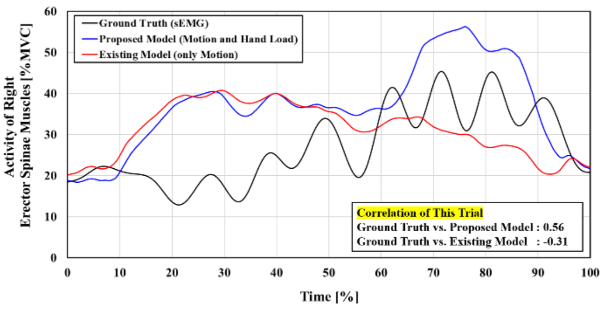

Figure 6: Example of right erector spinae muscle activities.

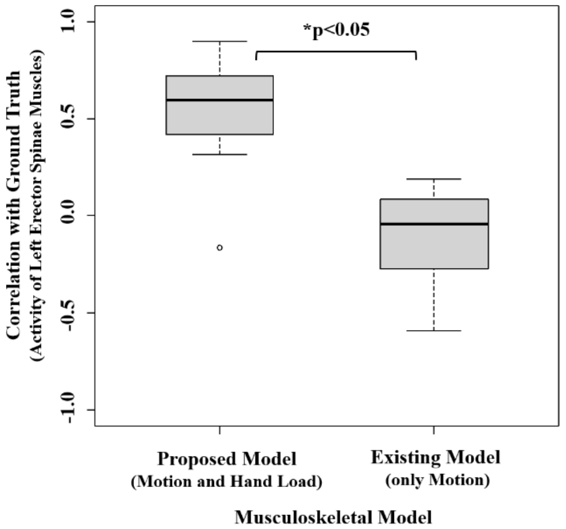

Figure 7: Correlation between the predicted and ground truth muscle activity in the left erector spinae muscles.

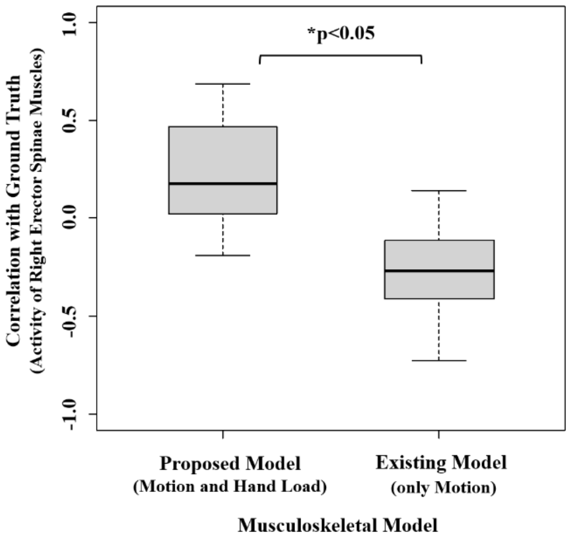

Figure 8: Correlation between the predicted and the ground truth muscle activity in the right erector spinae muscles.

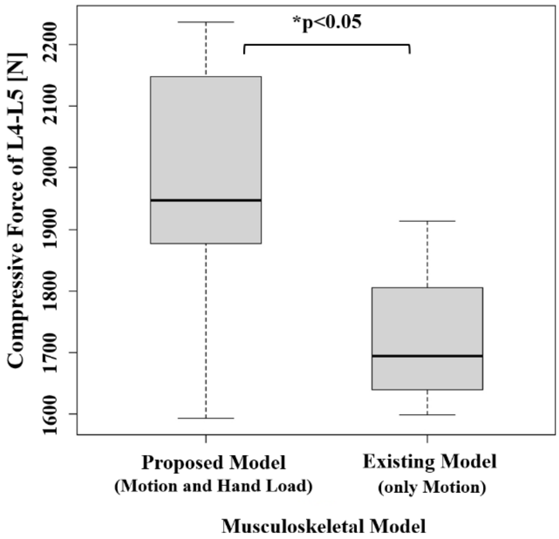

Figure 9: Predicted compressive force of L4-L5.

DISCUSSION

As mentioned previously, the results showed that the correlation of the proposed model with the ground truth (sEMG) was significantly greater than the existing model in the left and right erector spinae muscles. These results indicate that the proposed musculoskeletal model using both motion and hand load data more accurately predicts the trend of erector spinae muscle activity during patient transfer than the existing model using only motion data. Conversely, the existing musculoskeletal model predicted erector spinae muscle activity by a small or negative correlation with the ground truth. Furthermore, the time waveforms showed that the existing model predicted a decreasing trend of muscle activity when the ground truth of muscle activity was an increasing trend. The results of the compressive forces of L4-L5 showed that the proposed model could predict the compressive forces of L4-L5 with approximate values (around 2000 N) close to *in vivo* intradiscal pressure measurements.[11] On the contrary, the existing model underestimated the compressive forces of L4-L5 (<2000 N) compared with the *in vivo* intradiscal pressure measurements.[11]

In this study, existing models without hand load information could not predict the increase in erector spinae muscle activity and compressive forces of L4-L5 because of manual handling. The existing model without hand load underestimates the increase in lumbar loads during patient handling. Lumbar loads should not be underestimated in the investigation of a suitable posture for preventing LBP because of patient transfer. Therefore, it is considered that hand load data are necessary for accurate prediction of lumbar loads during patient transfer using a musculoskeletal model. In addition, it is considered that the proposed musculoskeletal model using both motion and hand load data and the manufactured hand load measurement device are useful for exploring suitable postures to reduce lumbar loads during patient transfer.

This study has some limitations. First, the participants were only young men. Patient handling varies because of due to experience and sex.[13,14] In addition, the proposed musculoskeletal model was evaluated for only patient transfer in the laboratory environment. Various tasks have different lumbar loads in patient handling.[15] In future works, the proposed musculoskeletal model should be investigated for various caregivers, motions, and fields. The proposed musculoskeletal model might be tested for various situations because motion and load data of the proposed musculoskeletal model can be measured using a hand load measurement device.

CONCLUSION

In this study, a musculoskeletal model was proposed and evaluated using motion and hand load data to explore the suitable posture and reduce lumbar loads during patient transfer. Moreover, the proposed method could accurately predict the activity of the erector spinae muscles and compressive forces of L4-L5 during patient transfer. These results indicate that the proposed musculoskeletal model can be applied to explore suitable postures and reduce lumbar loads during patient transfer. In future work, the proposed musculoskeletal model will be tested for various patient handling motions.

Funding: Funding sources by JSPS KAKENHI (Grant Number: 22K12908).
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee of National Institute of Technology, Hachinohe College ethics review board (approval number: R4-2).

REFERENCES

1. Vinstrup J, Jakobsen MD, Madeleine P, Andersen LL. Physical exposure during patient transfer and risk of back injury and low-back pain: Prospective cohort study. BMC Musculoskel Dis. 2020;21(1):715.
2. Kucera KL, Schoenfisch AL, McIlvaine J, Becherer L, James T, Yeung YL, et al. Factors associated with lift equipment use during patient lifts and transfers by hospital nurses and nursing care assistants: A prospective observational cohort study. Int J Nurs Stud. 2019;91:35-46.
3. Omura Y, Yamagami Y, Hirota Y, Nakatani E, Tsujimoto T, Inoue T. Evaluation of the effectiveness of the sliding sheet in repositioning care in terms of working time and subjective fatigue: A comparative study with an experimental design. Int J Nurs Stud. 2019;99:103389.
4. Jäger M, Jordan C, Theilmeier A, Wortmann N, Kuhn S, Nienhaus A, et al. Lumbar-Load analysis of manual patient-handling activities for biomechanical overload prevention among healthcare workers. Ann Occup Hyg. 2013;57:528-44.
5. Kitagawa K, Nishisako Y, Nagasaki T, Nakano S, Wada C. Musculoskeletal simulation of the relationship between foot position and stress of the L4-L5 joint in supporting standing-up motion to prevent low back pain among caregivers. J Mech Med Biol. 2019;19:1940016.
6. Firouzabadi A, Arjmand N, Pan F, Zander T, Schmidt H. Sex-dependent estimation of spinal loads during static manual material handling activities-Combined *in vivo* and *in silico* analyses. Front Bioeng Biotechnol. 2021;9:750862.
7. Daroudi S, Arjmand N, Mohseni M, El-Rich M, Parnianpour M. Evaluation of ground reaction forces and centers of pressure predicted by anybody modeling system during load reaching/handling activities and effects of the prediction errors on model-estimated spinal loads. J Biomech. 2024;164:111974.
8. Rajaee MA, Arjmand N, Shirazi-Adl A, Plamondon A, Schmidt H. Comparative evaluation of six quantitative lifting tools to estimate spine loads during static activities. Appl Ergon. 2015;48:22-32.
9. Almassri AM, Wan Hasan WZ, Ahmad SA, Ishak AJ, Ghazali AM, Talib DN, et al. Pressure sensor: State of the art, design, and application for robotic hand. J Sensors. 2015;2015:846487.
10. Uchimura R, Fushitani R, Kitagawa K, Wada C. Evaluation of a system for measuring forces acting on the hand in assisting movements. In: Proceedings of 12th International Symposium on Applied Engineering and Sciences. 2024;172.
11. Schultz A, Andersson G, Ortengren R, Haderspeck K, Nachemson A. Loads on the lumbar spine. validation of a biomechanical analysis by measurements of intradiscal pressures and myoelectric signals. J Bone Joint Surg. 1982;64(5):713-20.
12. Kanda Y. Investigation of the freely available easy-to-use software ‘EZR’ for medical statistics. Bone Marrow Transplant. 2013;48(3):452-8.
13. Miyasaka T, Matsumoto M, Kamoshida M, Kawashima K, Ohtsu N, Tsukame T, et al. Study of evacuation techniques in the event of a night fire at a dementia group home - method of transferring evacuees from their beds to the floor. Int J N Technol Res. 2019;5(8):29-34.
14. Hodder JN, MacKinnon SN, Ralhan A, Keir PJ. Effects of training and experience on patient transfer biomechanics. Int J Ind Ergon. 2010;40(3):282-8.
15. Schibye B, Hansen AF, Hye-Knudsen CT, Essendrop M, Böcher M, Skotte J. Biomechanical analysis of the effect of changing patient-handling technique. Appl Ergon. 2003;34(2):115-23.

Cite this article as: Uchimura R, Fushitani R, Kitagawa K, Wada C. Musculoskeletal simulation for patient transfer using hand load measurement device. Int J Res Orthop 2025;11:1-5.