International Journal of Human Movement and Sports Sciences 10(5): 1060-1066, 2022 http://www.hrpub.org
DOI: 10.13189/saj.2022.100524

Foot Placement and Arm Movement Combination while Turning Patients to Prevent Lower Back Pain

Kodai Kitagawa[1,*], Koji Matsumoto[2], Hayato Nodagashira[1], Takayuki Nagasaki[3], Sota Nakano[4], Mitsumasa Hida[5], Shogo Okamatsu[2,6], Chikamune Wada[2]

[1]Mechanical and Medical Engineering Course, Department of Industrial Systems Engineering, National Institute of Technology, Hachinohe College, Hachinohe, Japan
[2]Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Kitakyushu, Japan
[3]Department of Physical Therapy, Reiwa Health Science University, Fukuoka, Japan
[4]Department of Rehabilitation, Kyushu University of Nursing and Social Welfare, Tamana, Japan
[5]Department of Physical Therapy, Osaka Kawasaki Rehabilitation University, Kaizuka, Japan
[6]Rehabilitation Center Will KATANO, Hot-Will Co., Ltd., Kitakyushu, Japan

Received July 15, 2022; Revised September 30, 2022; Accepted October 25, 2022

Cite This Paper in the Following Citation Styles

(a): *[1] Kodai Kitagawa, Koji Matsumoto, Hayato Nodagashira, Takayuki Nagasaki, Sota Nakano, Mitsumasa Hida, Shogo Okamatsu, Chikamune Wada , "Foot Placement and Arm Movement Combination while Turning Patients to Prevent Lower Back Pain," International Journal of Human Movement and Sports Sciences, Vol. 10, No. 5, pp. 1060 - 1066, 2022. DOI: 10.13189/saj.2022.100524.*

(b): *Kodai Kitagawa, Koji Matsumoto, Hayato Nodagashira, Takayuki Nagasaki, Sota Nakano, Mitsumasa Hida, Shogo Okamatsu, Chikamune Wada (2022). Foot Placement and Arm Movement Combination while Turning Patients to Prevent Lower Back Pain. International Journal of Human Movement and Sports Sciences, 10(5), 1060 - 1066. DOI: 10.13189/saj.2022.100524.*

Abstract Nurses and caregivers experienced lower back pain (LBP) as a result of patient handling motions to assist in wheelchair or bed transfer and repositioning. Therefore, previous studies provided assistive tools and devices to reduce lumbar loads while these patients handling motions. However, these devices and tools could not be used in several facilities because these facilities require comfortability, time efficiency, and low cost. Therefore, from these backgrounds, LBP prevention is required for any facility and situation without assistive devices and tools. Low load posture and movement of patient handling motions should be provided for LBP prevention without devices and tools. In our previous study, we explored suitable foot placement to reduce the lumbar load during turning a patient on a bed because patient repositioning on a bed is a serious cause of LBP. However, our previous study indicates that lumbar loads while turning patients cannot be improved only by foot placement adjustment. Postural asymmetry is related to lumbar load and cannot be avoided with only suitable foot placement. On the other hand, adjustment of both arm movement and foot placement has a possibility that reduces lumbar loads due to asymmetry posture. This study aims to explore a suitable combination of foot placement and arm movement order while turning patients for LBP prevention. A total of nine lumbar load combinations consisting of three foot placements (parallel stance, left forward, and right forward) and three arm movement orders (parallel, right first, and left first) were investigated via surface electromyography (sEMG) measurement during patient turning. The results of sEMG showed that a combination using anteroposterior foot placement (right forward) and parallel arm movement (both left and right arm operated at the same time) performed turning patient with the smallest activity for both left and right erector spinae muscles. These results indicate that a combination of anteroposterior foot placement and parallel arm movement could provide a suitable posture to reduce lumbar loads during patient turning.

Keywords Turning Patient, Arm Movement, Foot Placement, Surface Electromyography, Lumbar loads

1. Introduction

Nurses and caregivers experienced lower back pain (LBP) as a result of patient handling motions to assist in wheelchair or bed transfer and repositioning [1–4]. Therefore, previous studies provided assistive tools and devices to reduce lumbar loads while handling patients [4–8]. Schibye et al. reported that using a sliding sheet could reduce compressive forces at L4/ L5 compared with self-righting motions [5]. Additionally, assistive beds with automatic turn functions contributed to preventing lumbar loads during repositioning and turning patients on a bed [6–8]. Iridiastadi et al. found that a lifting machine could reduce compressive and shear forces on the vertebra during patient handling motion for transfer [9]. These findings suggest that these assistive devices and tools can prevent LBP due to patient handling motions. However, these devices and tools could not be used in several facilities because these facilities require comfortability, time efficiency, and low cost [10]. Moreover, Robielo et al. showed that lifting devices caused physical loads to caregivers when several parameters such as assistive force and size of sling were unsuitable [11]. Thus, from these backgrounds, LBP prevention is required for any facility and situation without assistive devices and tools.

Posture and movement education is considered one solution for LBP prevention without specific devices. Body mechanics provides ergonomically suitable posture and movement during patient handling techniques [12,13]. Ibrahim and Elsaay indicated that a body mechanics-based education program delivered knowledge about LBP prevention [12]. Conversely, Karahan et al. reported that more than 50% of nurses did not use body mechanics for assistive motion [13].

This reason needs to be considered because body mechanics-based posture and movement are difficult to perform as body mechanics often incorporate active correction, such as the trajectory of the center of gravity [13]. A simpler and easier strategy is considered necessary for implementing suitable posture and movement to prevent LBP due to patient handling. Thus, our previous studies focused on the adjustment of initial foot placement in patient handling since initial posture can be adjusted statically and easily [14–16]. Our previous studies showed that quantitative adjustment for anteroposterior and lateral distance between both feet could reduce lumbar loads during assistive sit-to-stand motion [14,15]. However, erector spinae muscle loads were not changed for different foot placements while turning the patient in bed [16]. The previous study indicates that lumbar loads while turning patients cannot be improved only by foot placement adjustment. Lumbar loads of turning patients should be avoided since this patient handling motion is frequently performed for repositioning on a bed [17].

We focused on both the lower limb and upper limb for reducing lumbar loads while turning patients because previous study found that only initial foot placement is insufficient for reducing lumbar loads [16]. We hypothesize that adjusting both lower limbs and upper limbs can contribute to avoiding asymmetry and posture twisting related to lumbar loads [18]. The present study focuses on arm movement order for upper limb adjustment because arm movement order is an easy and simple parameter compared with other dynamic adjustments. Furthermore, this study focuses on initial foot placement for lower limb adjustment based on our previous studies [14–16].

This study aims to explore a suitable combination of initial foot placement and arm movement to reduce lumbar loads while turning a patient in bed.

2. Materials and Methods

2.1. Participants

Four young males (24.7 ± 0.8 years, 1.72 ± 0.05 m, 67.00 ± 10.79 kg) participated as simulated caregivers. They had no caregiver or nurse experience. One young male (25.00 years, 1.69 m, 70.00 kg) participated as a simulated patient. All participants provided their verbal informed consent before the experiment.

2.2. Materials

Surface electromyography (sEMG) was used to evaluate lumbar load muscle activity. Shair et al. suggested that sEMG can be applied to assess fatigue in manual handling activities [19]. Nelson et al. evaluated sEMG as body stress during patient handling motions [20]. Itami et al. used sEMG obtained from erector spinae muscles for muscle load evaluation whereas caregivers use assistive motion [21]. These studies indicate that sEMG can be used for the assessment of muscle loads while turning patients.

The erector spinae muscle was selected to evaluate lumbar muscle loads. Callaghan et al. found that erector spinae muscle activity is caused by lumbar loads due to trunk movement [22]. Previous studies evaluated erector spinae muscle activity as lumbar loads during assistive motion [21]. Thus, sEMG of erector spinae muscle was used for the evaluation of lumbar loads in this study.

The sEMG was measured using a data logger (Logical Product Co., Fukuoka, Japan), EMG sensor (Logical Product Co., Fukuoka, Japan), and electrodes (Ambu, Ballerup, Denmark). Figure 1 shows electrode placement for sEMG of erector spinae muscle. The placement was determined by a previous study by McGill [23]. The sampling frequency of sEMG was 1 kHz.

A bed (width, 0.95 m; length, 2.00 m; height, 0.88 m) was used for turning a patient. The height and size of this bed were selected based on previous study recommendations [24,25]. Bed height was considered suitable for lumbar loads during assistive motion beside the bed [24]. Additionally, bed size was able to cover the area of patient turning [25].

Figure 1. Electrodes Placement for sEMG on Erector Spinae Muscle

2.3. Procedure

The simulated caregivers performed patient turning in bed with different combinations of initial foot placement and arm movement order. Figure 2 shows patients turning in bed. Figure 3 shows three initial foot placements (parallel stance, left forward, and right forward) in patient turning. Anteroposterior length and mediolateral width between both feet were set at 25% of body height and shoulder width [26]. Shoulder width was considered a suitable width for self-adjusting of foot placement because shoulder width is used in coaching various human movements, such as squats [27,28]. Figure 4 shows three arm movement orders (parallel, right first, and left first) in patient turning. In “parallel,” the participants were asked to move both arms at the same time. In “right first” and “left first,” the participants were asked to move their arms at different times.

Figure 2. Turning Patient on a Bed

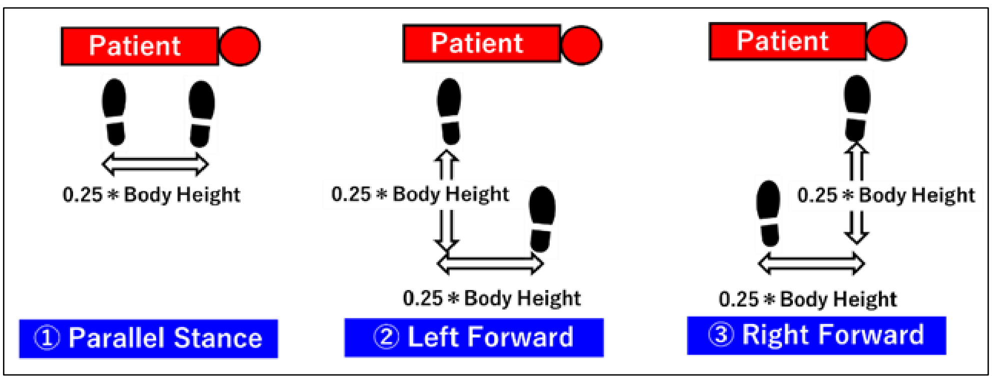

Figure 3. Initial Foot Placements

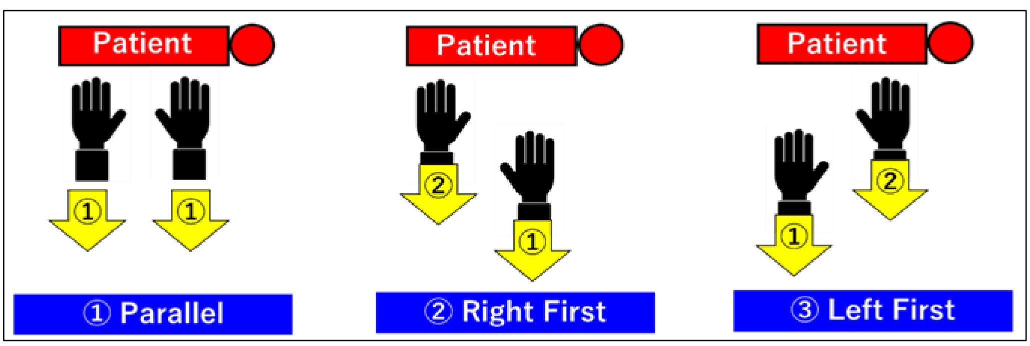

Figure 4. Arm Movement Order

Table 1 shows nine combinations with these initial foot placements and arm movement orders. The simulated caregivers performed patient turning from supine to lateral position in bed with these nine combinations. Turning patient was repeated 10 times for each combination and then a total of 40 trials were performed on all participants in each combination. The order of combinations was randomized for each caregiver. The sEMG of both left and right erector spinae muscles of each simulated caregiver were measured during each patient turning.

Table 1. Initial Foot Placement and Arm Movement Order Combinations

Combination	Initial Foot Placement	Arm Movement Order
#1	Parallel stance	Parallel
#2	Parallel stance	Right first
#3	Parallel stance	Left first
#4	Left forward	Parallel
#5	Left forward	Right first
#6	Left forward	Left first
#7	Right forward	Parallel
#8	Right forward	Right first
#9	Right forward	Left first

The sEMG values were normalized via maximal voluntary contractions (MVC). The MVC of each participant was measured via Daniels and Worthingham's muscle test [29]. Integrated EMG (iEMG) values were calculated from rectified sEMG for each patient turning. Additionally, iEMG values were normalized by the total time for each motion. Processing was performed via MATLAB R2020b (MathWorks Inc., USA). The iEMG values were compared in nine combinations. The Bonferroni method and Kruskal–Wallis test were used to statistically test this comparison of iEMG. These statistical tests were performed for both left and right erector spinae muscles. Significant level was set as $p < 0.05$. These statistical tests were performed using EZR (Kanda, Japan) [30].

3. Results

Table 2 and Table 3 show erector spinae muscle iEMG in nine combinations. The results showed that the iEMG values of combination #7 were the smallest in both left and right erector spinae muscles. The iEMG of combination #7 was significantly smaller than four combinations (#2, #3, #5, and #6) in the left erector spinae muscle ($p < 0.05$). Conversely, the iEMG of combination #3 was the largest in the left erector spinae muscle and was significantly larger than four combinations (#4, #7, #8, and #9) in the left erector spinae muscle ($p < 0.05$). Furthermore, the iEMG of combination #2 was the largest in the right erector spinae muscle.

Table 2. Left Erector Spinae Muscle iEMG in Nine Combinations

Combination	iEMG [%MVC] (Mean±S.D.)	Significant Difference (p < 0.05)
#1	22.7 ±12.9	None
#2	25.0 ±9.98	>#4, #7
#3	31.8 ±17.2	>#4, #7, #8, #9
#4	17.4 ±10.8	<#2, #3
#5	20.2 ±8.22	>#7
#6	22.7 ±9.38	>#7
#7	14.2 ±7.72	<#2, #3, #5, #6
#8	19.7 ±10.2	<#3
#9	18.3 ±11.2	<#3

Table 3. Right Erector Spinae Muscle iEMG in Nine Combinations

Combination	iEMG [%MVC] (Mean±S.D.)	Significant Difference (p < 0.05)
#1	35.3 ±15.8	None
#2	37.7 ±12.1	>#7, #9
#3	33.5 ±13.0	None
#4	30.6 ±13.5	None
#5	33.3 ±11.8	None
#6	30.8 ±11.2	None
#7	27.4 ±11.8	<#2
#8	30.1 ±10.5	None
#9	28.3 ±10.7	<#2

4. Discussion

The results showed that combination #7, using anteroposterior foot placement (right forward) and parallel arm movement (both left and right arm operated at the same time) performed turning patient with the smallest activity for both left and right erector spinae muscles. These results indicate the possibility that a combination of anteroposterior foot placement and right and same order left arm movement contribute to reducing erector spinae muscle load during patient turning in bed.

Lumbar loads of anteroposterior foot placements (#4, #5, #6, #7, #8, and #9) were smaller than parallel stance (#1, #2, and #3). Anteroposterior foot placement during patient handling motion is recommended by body mechanics because this foot placement broadens the base of support [13]. Conversely, anteroposterior foot placement has a disadvantage in reducing lumbar loads since this foot placement provides asymmetry and twist postures cause lumbar loads [18]. It is considered that parallel arm movement using combination #7 avoided this disadvantage because of the asymmetry of anteroposterior foot placement. Therefore, combination #7 is considered a suitable combination for preventing LBP during patient turning in bed.

Initial foot placement can be statically adjusted before movement initiation. Arm movement of combination #7 can be performed by only adjusting timing. Therefore, these initial foot placement and arm movements might be applied for easy and simple implementation for low load posture during patient handling. Additionally, initial foot placement and arm movement might be instructed via a wearable system because these postures can be measured by wearable sensors for human movements [31–36]. Previous systems for LBP prevention could not provide how to improve posture because these systems only assessed trunk bending [32–35]. Previous systems required additional commands for posture adjustment from an instructor such as "use legs instead of back" [37]. Initial foot placement instruction and arm movement related to posture adjustment will contribute to developing a novel wearable instruction system for LBP prevention among caregivers and nurses.

This study was limited because only young, inexperienced males participated. Additionally, the experiment environment was not in an actual clinic. Therefore, future studies should evaluate the usefulness of posture using anteroposterior foot placement and parallel arm movement for experienced staff in an actual clinic. These investigations should also be considered for females as there are patient handling motion differences between males and females [41]. Moreover, other lumbar loads, such as vertebral stress [37,38] should be investigated.

5. Conclusions

In this study, we explored the suitable combination of initial foot placement and arm movement order during turning patients for LBP prevention. The results showed that a combination of anteroposterior foot placement and parallel arm movement could provide a suitable posture to reduce lumbar loads during turning patients. In future studies, combination usefulness will be evaluated among experienced caregivers and females in an actual clinical setting. Moreover, effective methods and system implementation of suitable posture using this combination will be advanced.

Acknowledgements

This work was supported by JSPS KAKENHI (Grant Number: 22K12908).

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

[1] A. Holtermann, T. Clausen, M. B. Jørgensen, A. Burdorf, and L. L. Andersen, "Patient handling and risk for developing persistent low-back pain among female healthcare workers," *Scandinavian journal of work, environment & health*, pp. 164–169, 2013.

[2] J. Smedley, P. Egger, C. Cooper, and D. Coggon, "Manual handling activities and risk of low back pain in nurses.," *Occupational and environmental medicine*, vol. 52, no. 3, pp. 160–163, 1995.

[3] S. Kai, "Consideration of low back pain in health and welfare workers," *Journal of Physical Therapy Science*, vol. 13, no. 2, pp. 149–152, 2001.

[4] K. Kitagawa, T. Nagasaki, S. Nakano, M. Hida, S. Okamatsu, and C. Wada, "Analysis of Occupational Injury Reports Related to Patient Care Activities Using Text Mining Technique," in *11th Asian-Pacific Conference on Medical and Biological Engineering: Proceedings of the Online Conference APCMBE 2020, May 25-27, 2020*, 2021, vol. 82, pp. 153–158.

[5] B. Schibye, A. F. Hansen, C. T. Hye-Knudsen, M. Essendrop, M. Böcher, and J. Skotte, "Biomechanical analysis of the effect of changing patient-handling technique," *Applied ergonomics*, vol. 34, no. 2, pp. 115–123, 2003.

[6] N. Wiggermann, "Biomechanical evaluation of a bed feature to assist in turning and laterally repositioning patients," *Human factors*, vol. 58, no. 5, pp. 748–757, 2016.

[7] N. Wiggermann, J. Zhou, and N. McGann, "Effect of repositioning aids and patient weight on biomechanical stresses when repositioning patients in bed," *Human factors*, vol. 63, no. 4, pp. 565–577, 2021.

[8] A. R. Budarick, U. Lad, and S. L. Fischer, "Can the use of turn-assist surfaces reduce the physical burden on caregivers when performing patient turning?," *Human factors*, vol. 62, no. 1, pp. 77–92, 2020.

[9] H. Iridiastadi, T. Vani, and P. A. R. Yamin, "Biomechanical Evaluation of a Patient-Handling Technology Prototype," *International Journal of Technology*, vol. 11, no. 1, pp. 180–189, 2020.

[10] S. Sivakanthan, E. Blaauw, M. Greenhalgh, A. M. Koontz, R. Vegter, and R. A. Cooper, "Person transfer assist systems: a literature review," *Disability and Rehabilitation: Assistive Technology*, pp. 1–10, 2019.

[11] R. A. C. Robielos, K. C. A. Sambua, and J. G. Fernandez, "Ergonomic intervention for healthcare workers and patients: a development of patient handling device," in *Congress of the International Ergonomics Association*, 2018, pp. 615–638.

[12] R. Ibrahim and O. Elsaay, "The effect of body mechanics training program for intensive care nurses in reducing low back pain," *IOSR Journal of Nursing and Health Science*, vol. 4, no. 5, pp. 81–96, 2015.

[13] A. Karahan and N. Bayraktar, "Determination of the usage of body mechanics in clinical settings and the occurrence of low back pain in nurses," *International Journal of Nursing Studies*, vol. 41, no. 1, pp. 67–75, 2004.

[14] K. Kitagawa, Y. Nishisako, T. Nagasaki, S. Nakano, and C. Wada, "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," *Journal of Mechanics in Medicine and Biology*, vol. 19, no. 02, p. 1940016, 2019.

[15] K. Kitagawa, T. Nagasaki, S. Nakano, M. Hida, S. Okamatsu, and C. Wada, "Optimal foot-position of caregiver based on muscle activity of lower back and lower limb while providing sit-to-stand support," *Journal of Physical Therapy Science*, vol. 32, no. 8, pp. 534–540, 2020.

[16] K. Kitagawa, K. Yamamoto, and C. Wada, "Relationship between Foot Position and Lumbar Loads while Turning Patients on a Bed: An Investigation via Computational Simulation and Electromyography.," *International Journal of Online & Biomedical Engineering*, vol. 17, no. 10, pp. 131–143, 2021.

[17] H. Wardell, "Reduction of injuries associated with patient handling," *Aaohn Journal*, vol. 55, no. 10, pp. 407–412, 2007.

[18] S. GALLAGHER, C. A. HAMRICK, A. C. LOVE, and W. S. MARRAS, "Dynamic biomechanical modelling of symmetric and asymmetric lifting tasks in restricted postures," *Ergonomics*, vol. 37, no. 8, pp. 1289–1310, 1994.

[19] E. F. Shair, S. A. Ahmad, M. H. Marhaban, S. B. Mohd Tamrin, and A. R. Abdullah, "EMG processing based measures of fatigue assessment during manual lifting," *BioMed research international*, vol. 2017, 2017.

[20] A. Nelson, J. D. Lloyd, N. Menzel, and C. Gross, "Preventing nursing back injuries: redesigning patient handling tasks," *AAOHN journal*, vol. 51, no. 3, pp. 126–134, 2003.

[21] K. ITAMI, T. YASUDA, Y. OTSUKI, M. ISHIBASHI, and T. MAESAKO, "Development of a checking system for body mechanics focusing on the angle of forward leaning during bedmaking," *Educational technology research*, vol. 33, no. 1–2, pp. 63–71, 2010.

[22] J. P. Callaghan, J. L. Gunning, and S. M. McGill, "The relationship between lumbar spine load and muscle activity during extensor exercises," *Physical therapy*, vol. 78, no. 1, pp. 8–18, 1998.

[23] S. M. McGill, "Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: implications for lumbar mechanics," *Journal of orthopaedic research*, vol. 9, no. 1, pp. 91–103, 1991.

[24] M. P. De Looze *et al.*, "Effect of individually chosen bed-height adjustments on the low-back stress of nurses," *Scandinavian journal of work, environment & health*, pp. 427–434, 1994.

[25] N. Wiggermann, K. Smith, and D. Kumpar, "What bed size does a patient need? The relationship between body mass index and space required to turn in bed," *Nursing research*, vol. 66, no. 6, p. 483, 2017.

[26] D. A. Winter, *Biomechanics and motor control of human movement*. John Wiley & Sons, 2009.

[27] S. Gianotti, P. A. Hume, and H. Tunstall, "Efficacy of injury prevention related coach education within netball and soccer," *Journal of Science and Medicine in Sport*, vol. 13, no. 1, pp. 32–35, 2010.

[28] J. M. Cissik, "Coaching the front squat," *Strength & Conditioning Journal*, vol. 22, no. 5, p. 7, 2000.

[29] H. J. Hislop, *Daniels and Worthingham's Muscle testing*. Saunders/Elsevier, 2007.

[30] Y. Kanda, "Investigation of the freely available easy-to-use software 'EZR'for medical statistics," *Bone marrow transplantation*, vol. 48, no. 3, pp. 452–458, 2013.

[31] K. Kitagawa *et al.*, "Posture Recognition Method for Caregivers during Postural Change of a Patient on a Bedusing Wearable Sensors," *Advances in Science, Technology and Engineering Systems Journal*, vol. 5, no. 5, pp. 1093–1098, 2020.

[32] Y. Tu, L. Liu, M. Li, P. Chen, and Y. Mao, "A Review of Human Motion Monitoring Methods using Wearable Sensors.," *International Journal of Online Engineering*, vol. 14, no. 10, 2018.

[33] A. C. Ferreira Geraldo, A. Maria Kuasne, H. U. Kurikic, and R. Marcelino, "Prototype of Wearable Technology Applied to the Monitoring of the Vertebral Column.," *International Journal of Online & Biomedical Engineering*, vol. 16, no. 1, 2020.

[34] Z. Choffin *et al.*, "Ankle Angle Prediction Using a Footwear Pressure Sensor and a Machine Learning Technique," *Sensors*, vol. 21, no. 11, p. 3790, 2021.

[35] P. D. Duong and Y. S. Suh, "Foot pose estimation using an inertial sensor unit and two distance sensors," *Sensors*, vol. 15, no. 7, pp. 15888–15902, 2015.

[36] K. Kitagawa *et al.*, "Foot Position Measurement during Assistive Motion for Sit-to-Stand Using a Single Inertial Sensor and Shoe-Type Force Sensors," *International Journal of Environmental Research and Public Health*, vol. 18, no. 19, p. 10481, 2021.

[37] R. Doss, J. Robathan, D. Abdel-Malek, and M. W. Holmes, "Posture coaching and feedback during patient handling in a student nurse population," *IISE Transactions on Occupational Ergonomics and Human Factors*, vol. 6, no. 3–4, pp. 116–127, 2018.

[38] M. Owlia, C. Ng, K. Ledda, M. Kamachi, A. Longfield, and T. Dutta, "Preventing back injury in caregivers using real-time posture-based feedback," in *Congress of the International Ergonomics Association*, 2018, pp. 750–758.

[39] M. Owlia, M. Kamachi, and T. Dutta, "Reducing lumbar spine flexion using real-time biofeedback during patient handling tasks," *Work*, vol. 66, no. 1, pp. 41–51, 2020.

[40] M. Kamachi, M. Owlia, and T. Dutta, "Evaluating a

wearable biofeedback device for reducing end-range sagittal lumbar spine flexion among home caregivers," *Applied Ergonomics*, vol. 97, p. 103547, 2021.

[41] T. Miyasaka *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," *International Journal of New Technology and Research*, vol. 5, no. 8, pp. 29–34, 2019.

[42] A. Nachemson, "The effect of forward leaning on lumbar intradiscal pressure," *Acta Orthopaedica Scandinavica*, vol. 35, no. 1–4, pp. 314–328, 1965.

[43] A. M. Genaidy, S. M. Waly, T. M. Khalil, and J. Hidalgo, "Spinal compression tolerance limits for the design of manual material handling operations in the workplace," *Ergonomics*, vol. 36, no. 4, pp. 415–434, 1993.