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Air-assisted devices reduce biomechanical loading in the low back and upper extremities during patient turning tasks

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ABSTRACT

This laboratory study evaluated different assistive devices for reducing biomechanical loading during patient turning tasks. Twenty caregivers (18 females and 2 males) performed standardized patient turning tasks with two simulated patients (body mass: 74 kg and 102 kg). The turning tasks were performed in two turning directions (toward vs. away relative to caregivers) using five device conditions: draw sheet, friction-reducing turning sheet, air-assisted transfer device, air-assisted turning device, and no assistive device. Low back and upper extremity muscle activity, trunk and shoulder postures, low back moment, and self-reported usability ratings were evaluated. While all assistive devices reduced trunk flexion, both air-assisted transfer and turning devices reduced the trunk flexion (p's < 0.001) and muscle activity (p's < 0.001) in the erector spinae and triceps compared to no assistive device condition. These results suggest that the air-assisted devices have potential as an effective intervention to considerably reduce physical risk factors associated with caregivers' musculoskeletal disorders in low back and upper extremities.

1. Introduction

In the US, work-related musculoskeletal disorders (WMSDs) are highly prevalent (17,240 WMSD cases, an incidence rate of 140.5 per 10,000 full-time workers) among healthcare workers, especially nursing assistants (Bureau of Labor Statistics, 2018). Nursing assistants' low back and shoulders are the most affected areas (Davis and Kotowski, 2015). The high prevalence and incidence rates among nursing assistants are thought to be due to patient handling tasks that pose physical risk factors (Choi and Brings, 2016).

Previous studies have shown that manual patient handling tasks require high biomechanical loading that increases the risk of WMSDs among caregivers (Hwang et al., 2019a, 2019b; Marras et al., 1999; Nagavarapu et al., 2016; Wiggermann, 2015). Patient turning is one of the most common patient handling tasks performed on the patients with impaired mobility (Garg et al., 1991; Owen and Garg, 1989; Skotte, 2001) for various purposes including preventing immobility-related complications, physical assessment, wound care, and applying/removing medical devices (Brindle et al., 2013; Fragala and Fragala, 2014; Nagavarapu et al., 2016). However, patient turning poses several significant biomechanical loadings due to the caregivers' awkward postures (e.g., bending, twisting, and reaching), patients' characteristics (e.g., weight, size, physical disabilities, and level of cooperation), and confined workspace (e.g., hospital, nursing home) (Choi and Brings, 2016; Nelson and Baptiste, 2006). For instance, low back spinal loadings were significantly increased with higher patient weight (100 kg) than lower patient weight (54 kg) during the application and removal of lifting slings (Nagavarapu et al., 2016).

Previous studies have evaluated different intervention strategies to reduce a risk of injuries among caregivers (Fragala and Fragala, 2014; Wiggermann, 2015). Briefly, a friction-reducing turning sheet with a wedge foam reduced perceived exertion in the shoulders and low back compared to a conventional draw sheet method during turning and positioning tasks (Fragala and Fragala, 2014). Another study showed that a hospital bed with turn-assist features (inflated air bladders in a mattress) reduced the spinal compression and shear forces and hand pull force compared to no assistive device (Wiggermann, 2015). A recent study found that a turn-assist bed reduced the hand force and biomechanical exposure in the spine and shoulders during turning away and toward (Budarick et al., 2019). Air-assisted transfer and air-assisted turning devices have been developed to more effectively reduce the biomechanical loading during patient handling. An air-assisted transfer

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device is designed to reduce friction by circulating low pressure, high volume air through thousands of micro perforations (Baptiste et al., 2006). A previous study showed the potential effectiveness of an air-assisted transfer device for reducing hand pull force during patient lateral transfers (Hwang et al., 2019a, 2019b). In practice, manufacturers also suggest using the air-assisted transfer device for turning tasks as an alternative technique. The air-assisted turning device is portable and solely designed for patient turning using two inflatable chambers, which could reduce the biomechanical loading of caregivers and increase patient comfort (Hwang et al., 2019a, 2019b). However, the effectiveness of the turning function embedded in air-assisted transfer devices has not been compared with air-assisted devices solely designed for turning.

Despite anecdotal evidence suggesting assistive devices' potential benefits, there is lack of scientific research that systematically evaluates the relative benefits of different patient turning devices for reducing biomechanical exposure, specifically for patient turning tasks. A comprehensive appraisal of turning devices could facilitate clearer practice guidelines for safe patient turning techniques and provide more insights into how to improve the ergonomic designs of assistive devices. Therefore, the aim of this study was to assess the effectiveness of different patient turning devices (draw sheet, friction-reducing turning sheet, air-assisted transfer device, and air-assisted turning device) for reducing biomechanical exposures during standardized patient turning tasks with two simulated patients and two different weights (74 kg and 102 kg). We hypothesized that 1) there would be differences in biomechanical exposure in the upper extremities and low back among different patient handling devices and 2) the biomechanical exposures would be affected by the patient's weight.

2. Methods

2.1. Participants

Twenty professional caregivers (18 females and 2 males) were recruited via email solicitation and printed flyers. The mean and standard deviation of age, height, weight, and caregiving experience were 23.4 ± 3.7 years, 163.8 ± 9.0 cm, 70.3 ± 15.1 kg, and 3.6 ± 1.6 years, respectively. Inclusion criteria was 1) a minimum of 6 months of caregiving experience, 2) no restriction in physical activity, 3) no current musculoskeletal pain (past 7 days), and 4) no current medication related to MSDs or cardiovascular diseases.

Two male subjects were recruited as normal (body mass index [BMI] less than 25 kg/m^2) and obese (BMI higher than 30 kg/m^2) simulated patients, and their characteristics are summarized in Table 1. Simulated patients were instructed to provide minimal support to caregivers to represent a "fully dependent" bedridden patient in practice. All participants gave their informed consent, and the study was approved by the Institutional Review Board of the university.

2.2. Experimental protocol

2.2.1. Patient turning tasks and devices

After signing the consent form, the participants were instructed how to use each device for turning patients per the manufacturers' recommendations and methods described in the literature (Schibye et al., 2003). For the draw sheet, the participants grasped the rolled draw sheet to turn the simulated patient. For the friction-reducing turning sheet, the participants used the handle to roll the simulated patient over. For the air-assisted transfer device, a tucking method for the patient turning-toward task (Fig. 1. ATR) and a push-down method for the patient turning-away task (Fig. 2. ATR) were performed per the manufacturer's recommendations. Briefly, the air-assisted transfer device required an additional helper to operate the device but not to assist or intervene in the participants' patient turning activities. For the tucking method, half of the device was rolled and tucked under the patient. By inflating the device, the patient turned toward the caregiver (Fig. 1. ATR). For the push-down method, while an additional helper pushed down on one side of the device to tilt the patient, the main caregiver (participant) grasped the device handles and turned the patient. The rationale for using this air-assisted transfer device was to determine whether one device can effectively reduce biomechanical risks for two different patient handling tasks (i.e., lateral transfer and turning), which could be a cost-effective ergonomic intervention.

Table 1
Characteristic of two simulated patients.

Variable	Normal	Obese
Age (year)	24	26
Height (cm)	174	180
Weight (kg)	74	102
BMI (kg/m^2)	24.1	31.4

The participants practiced until they were comfortable with using all devices. The participants were asked to turn a simulated patient on a hospital gurney (Prime Series; Stryker; Portage, MI) with two different directions (toward and away relative to the participants). Two simulated patients wore standard hospital gowns to maintain consistent friction between the simulated patient and a gurney. Four different patient turning devices were used (Table 2): 1) a non-stretchable draw sheet (Patient Bath Blanket; Linteum Textile Supply; Little Ferry, NJ), 2) a friction-reducing turning sheet (TomiTurn; TomiTurn; Athens, AL), 3) an air-assisted transfer device (HoverMatt; HoverTech International; Allentown, PA), and 4) an air-assisted turning device (Q2Roller; HoverTech International; Allentown, PA) shown in Figs. 1–2. Each patient turning device was initially installed on a gurney by a researcher. In practice, the draw sheet and air-assisted devices are designed to be left under the patient. When using air-assisted devices, the amount of the air flow was controlled via an air supply keypad to maintain consistent inflation of devices throughout the experiment. For the air-assisted turning device, the patient lateral turning degree was set as 30° per the manufacturers' guideline, and it took 5 s to inflate.

During the patient turning-toward task (Fig. 1), the simulated patient's head turned to the left, the right knee was bent, and the right arm was crossed over the torso, whereas the mirrored posture was applied during the patient turning away task (Fig. 2) (Schibye et al., 2003). The gurney height was set at each participant's knuckle height to minimize the low back stress during the repositioning tasks (Nagavarapu et al., 2016), and the horizontal distance between the simulated patient and participants was set at 65 cm. To prevent potential falling of the simulated patient, both side rails were raised. While performing the patient turning tasks for both directions, the participants were instructed not to lean against the gurney rails to minimize any artifacts in joint (L5/S1) moment estimation. The order of turning direction and turning devices was counterbalanced and randomized to minimize any systematic bias due to the experimental order. A total of 20 turning tasks (2 turning directions × 2 patient weights × 5 turning devices) was performed by each participant.

2.2.2. Kinematic and kinetic data

An optical motion capture system (Optitrack, Natural Point, OR) with 8 Flex 13 infrared cameras was used to measure kinematics of the trunk and shoulders at 100 Hz. Thirty-five reflective markers were attached to the participant's whole body according to the standard full body marker set in Optitrack's Motive software. A force plate (AccuGait Optimized™, AMTI; Watertown, MA) at 1,000 Hz was used to measure the three-dimensional ground reaction force of the participants. Based on the four markers attached to the anterior and posterior sides of the pelvis; the location of a virtual maker at L5/S1 was estimated (Seay et al., 2008; Xu and McGorry, 2015). The moment arm (horizontal distance) was computed between the torso center of mass and the L5/S1 (Picchiotti et al., 2019). The L5/S1 sagittal flexion/extension moment

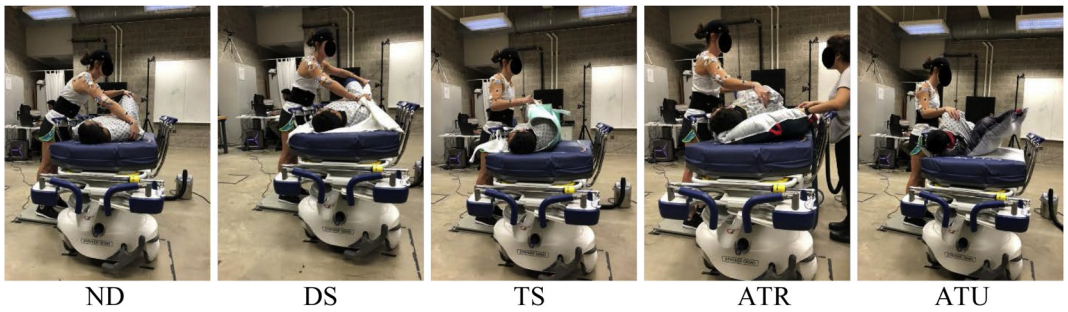

Fig. 1. Patient turning toward the caregiver by ND: no assistive device; DS: draw sheet; TS: friction-reducing turning sheet; ATR: air-assisted transfer device; and ATU: air-assisted turning device.

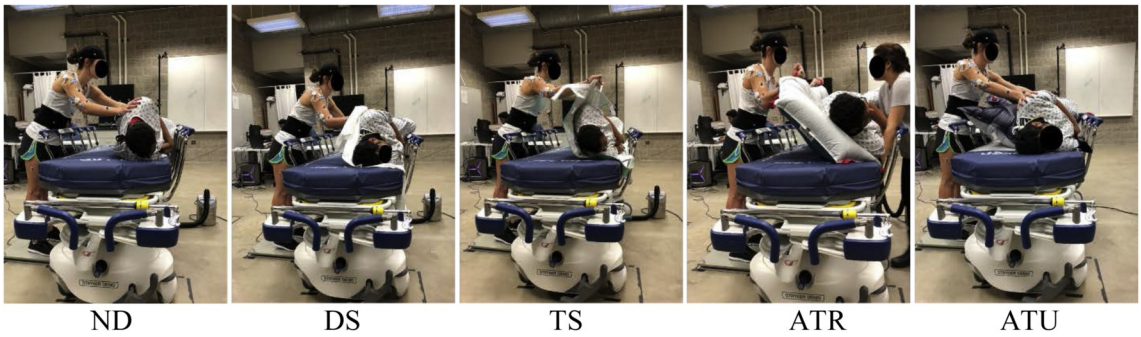

Fig. 2. Patient turning away from the caregiver by ND: no assistive device; DS: draw sheet; TS: friction-reducing turning sheet; ATR: air-assisted transfer device; and ATU: air-assisted turning device.

Table 2
Characteristic of patient turning devices.

Devices	Surface Materials	Handles Used
Draw sheet	Cotton	No
Friction-reducing turning sheet	Polyester	Yes
Air-assisted transfer	Nylon twill	Yes[a]
Air-assisted turning	Non-woven polypropylene fiber	No

[a] Handles are used only for patient turning away task.

was calculated using the bottom-up approach based on the ground reaction force (vertical and horizontal forces) and kinematic data of the lower extremities (Skotte, 2001). The peak L5/S1 flexion was determined by the 90th percentile value, and the extension moment (Nm) was defined by the 10th percentile value for each task. The moment-arm was calculated as a horizontal distance between the torso's center of mass and the L5/S1 (Picchiotti et al., 2019). The individual body segment mass and center of mass locations were estimated relative to total body mass and segment length of each participant (De Leva, 1996). The trunk sagittal flexion/extension angle was computed relative to the global axis, while the shoulder flexion/extension angle was calculated relative to the local coordinate system of the thorax. For the thorax coordinate system, the axial axis was defined from the midpoint between the jugular notch and the 7th cervical vertebrae (C7) as well as the midpoint between the Xiphoid process of the sternum (STRN) and the 10th thoracic vertebrae (T10); the anterior-posterior axis was defined by the midpoint between the jugular notch and STRN.

2.2.3. Electromyography

Surface electrodes were attached over seven muscles including the right side of the upper trapezius, anterior deltoid, middle deltoid, biceps, triceps, and bilateral erector spinae following standard placement guidelines (Hermens et al., 1999). Muscle activities (electromyography: EMG) were collected via a wireless data logger (WBA; Mega Electronics; Kupio, Finland) at 1000 Hz. At the end of the experiment, the maximum voluntary contractions (MVC) and the reference voluntary contractions (RVC) were collected. Standardized isometric exertions were applied to obtain the MVCs of the upper trapezius, anterior/middle deltoid, biceps and triceps muscles (Boettcher et al., 2008). To avoid potential back injury, 30° forward trunk bending was executed to collect the submaximal RVCs of the bilateral erector spinae (Soderberg and Knutson, 2000). Each participant repeated MVC/RVC three times, and a 2-min rest break was provided between trials to minimize the residual fatigue.

Collected EMG raw data were initially band-pass filtered from 10 to 350 Hz. The root mean square EMG was then calculated by a 125-ms moving window (MegaWin; Mega Electronics; Kupio, Finland). The MVC/RVC data were used to normalize the EMG data (%MVC/RVC), and the peak (90th percentile) normalized muscle activity during the task period was extracted using the Amplitude Probability Density Function (APDF) (Jonsson, 1982). Since overexertion is one of the leading causes of WMSDs in caregivers, we only chose the 90th percentile values in this study.

2.2.4. Usability

After using each patient turning device, the participants provided subjective ratings of overall difficulty (1 = very difficult to 7 = very easy), perceived concern of potential injury of the caregiver (1 = highly concerned to 7 = not at all), and perceived concern of the patient falling (1 = highly concerned to 7 = not at all) using the 7-point Likert scale.

2.3. Data analysis

The independent variables of this study were the device and the patient's weight; the dependent variables were the trunk and shoulder flexion angles, the L5/S1 moment, muscle activity, and subjective usability ratings. Separate statistical tests were conducted for turning toward and turning away tasks. The normality of the dependent variables was assessed prior to formal statistical analyses. For normally

distributed variables, repeated measures analyses of variance (ANOVA) were performed to determine the effect of patient weight and patient turning devices on the dependent variables, including the trunk and right shoulder's flexion angle. For the non-normality data (left shoulder flexion angle and L5/S1 moment), the logarithm, or Johnson transformation was applied to meet the normality assumptions of ANOVA. If transformed data were still non-normal, non-parametric (*Friedman*) tests were used to assess the effect of patient turning devices on the usability ratings. For significant variables, post-hoc pairwise tests (*Tukey* HSD or *Wilcoxon* signed rank test) were used to assess the difference among turning devices. Statistical significance was set with $p < 0.05$; means and standard errors were used to summarize the dependent variables.

3. Results

3.1. Kinematic data

3.1.1. Trunk and shoulder postures

Peak trunk and shoulder flexion angles were significantly different for patient turning devices during both patient turning toward and away tasks (p's < 0.001). All four patient turning devices significantly reduced the trunk flexion angle compared to no assistive device condition (Fig. 3). During the turning toward task, the left shoulder flexion was significantly lower with the air-assisted devices (transfer and turning), while the right shoulder flexion was significantly decreased by all four turning devices as compared to no assistive device. During the turning away task, the draw sheet and air-assisted transfer device showed significant reduction of the left/right shoulder flexion relative to no assistive device.

Turning the obese simulated patient caused a greater flexion angle of the trunk ($25.8 \pm 1.3°$ vs. $23.5 \pm 1.2°$) and right shoulder ($73.3 \pm 1.8°$ vs. $67.6 \pm 1.7°$) than the light patient while turning the patients toward the caregivers (p's < 0.007). During the turning away task, the patient weight did not affect the trunk and shoulder flexion angles (p's > 0.07).

3.1.2. L5/S1 moment

The L5/S1 extension moment was significantly affected by different patient turning devices during the turning toward task ($p = 0.001$). The use of the friction-reducing turning sheet resulted in greater L5/S1 extension moment than when using no assistive device (Table 3). The flexion moment at the L5/S1 was significantly different during both the turning toward and away tasks (p's < 0.005). The L5/S1 flexion moment was significantly reduced by the air-assisted turning device during the turning toward task ($p = 0.002$), and by the air-assisted transfer device during the turning away task ($p = 0.005$), compared to no assistive device. The L5/S1 moment was not affected by patient weight (p's > 0.10).

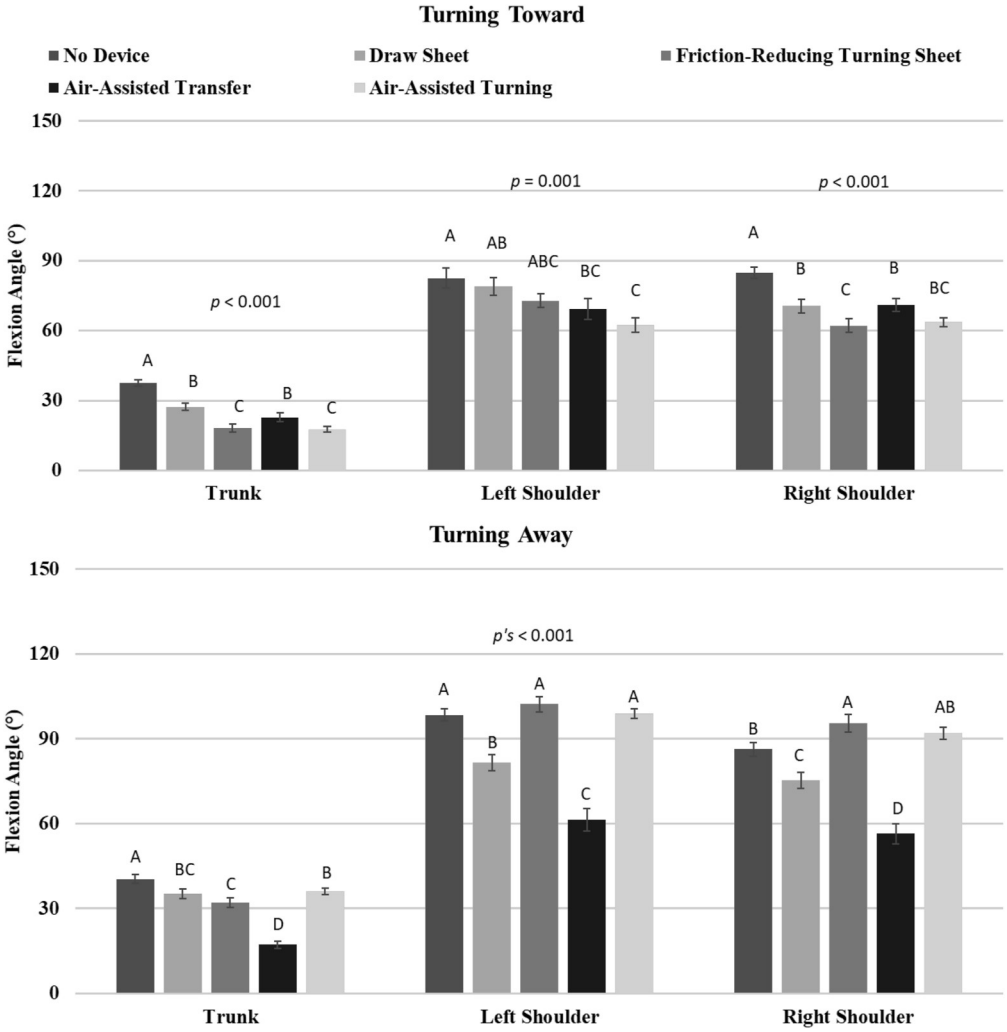

Fig. 3. Mean (standard error) of peak (90th percentile) flexion angle (°) of the trunk, left/right shoulders among five different patient turning devices during the turning toward and away tasks. Different alphabets (A, B, C, and D) indicate significant differences among the turning device groups based on Tukey HSD post-hoc tests.

Table 3
Mean (standard error) of peak L5/S1 flexion measured by the 90th percentile value and extension moment (Nm) measured by the 10th percentile value among five different patient turning devices during turning toward and away tasks.

Device condition	L5/S1 Flexion moment (Nm)		L5/S1 Extension moment (Nm)		L5/S1 Moment-arm (cm)	
	Tuning toward	Turning away	Tuning toward	Turning away	Tuning toward	Turning away
No assistive device	59.8^{A} (8.0)	136.0^{A} (11.1)	-133.0^{B} (14.7)	-35.7^{AB} (3.7)	25.6^{A} (0.5)	26.4^{A} (0.5)
Draw sheet	68.2^{A} (8.1)	135.2^{A} (15.4)	-139.1^{AB} (15.2)	-73.0^{A} (10.9)	22.5^{B} (0.7)	25.2^{AB} (0.5)
Friction-reducing turning sheet	56.3^{AB} (10.0)	126.4^{AB} (15.1)	-162.8^{A} (15.7)	-50.0^{AB} (7.7)	19.1^{C} (0.7)	24.2^{B} (0.5)
Air-assisted transfer device	55.5^{A} (7.0)	99.2^{B} (13.7)	-110.2^{B} (15.5)	-47.6^{AB} (9.4)	21.0^{B} (0.8)	18.9^{C} (0.6)
Air-assisted turning device	37.8^{B} (7.4)	124.4^{A} (8.7)	-119.9^{B} (12.6)	-30.7^{B} (5.2)	18.7^{C} (0.6)	26.6^{A} (0.6)

Note: Different alphabets indicate significant difference between turning devices based on Tukey HSD post-hoc tests. The moment arm was a horizontal distance between the torso's center of mass and L5/S1.

3.2. Electromyography (EMG)

The muscle activity in all seven muscles (i.e., trapezius, anterior/middle deltoid, biceps, triceps, and left/right erector spinae) was significantly affected by the turning devices during both the turning toward and away tasks (p's < 0.01), as shown in Fig. 4. During the turning toward task, both the air-assisted transfer and turning devices showed significantly less muscle activity in the biceps, triceps, and left/right erector spinae compared to no assistive device (p's < 0.01). During the turning away task, the air-assisted turning device showed significantly lower muscle activity in all the muscles (p's < 0.001) except the right erector spinae ($p = 0.98$) as compared to no assistive device. Patient weight did not significantly affect muscle activity in all the muscles (p's > 0.21).

3.3. Usability

Usability ratings were significantly different among the turning devices ($p < 0.01$). The results showed that the study participants felt it was significantly easier to turn the patients and were less concerned about their potential injuries when using the air-assisted devices (transfer and turning) compared to turning patients with no assistive device (Fig. 5). However, the usability ratings on the draw and friction-reducing turning sheets were not different than the no assistive device condition (p's > 0.11). Lastly, the participants' concern about their patient's fall risk during the turning tasks was significantly greater with the air-assisted transfer device than the other devices ($p = 0.01$).

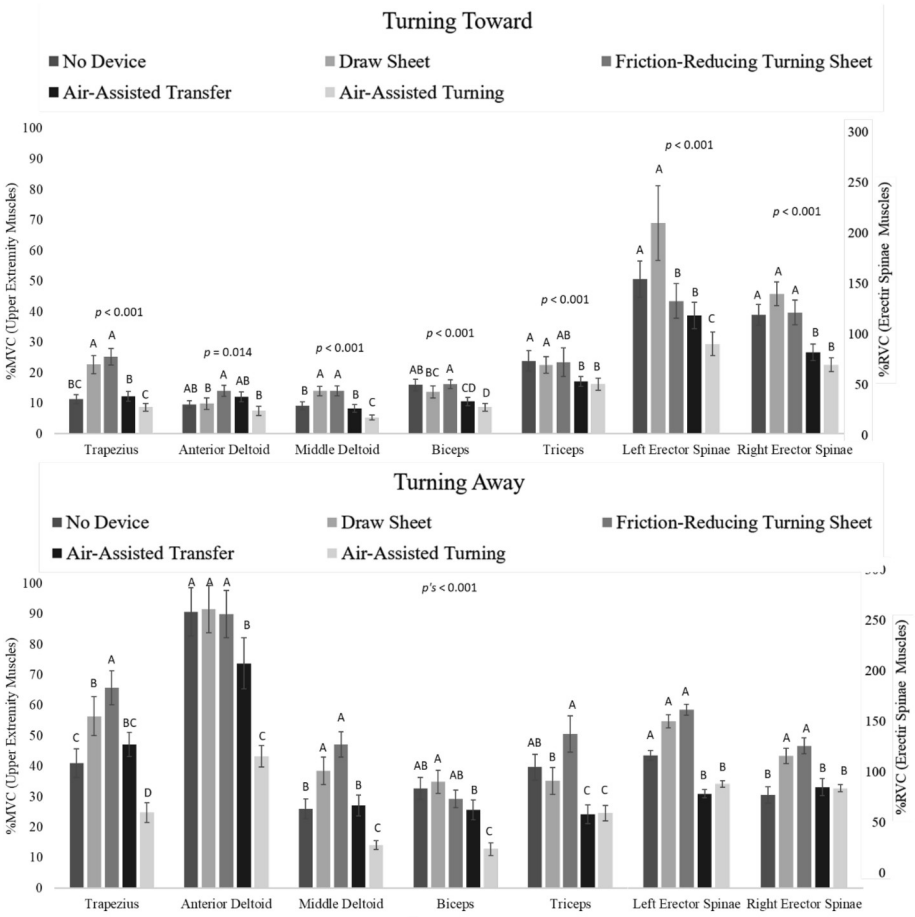

Fig. 4. Mean (standard error) of peak (90th percentile) normalized muscle activity (%MVC or %RVC) of upper trapezius, anterior/middle deltoid, biceps, triceps, and left/right erector spinae across five different patient turning devices during the turning toward (top) and turning away tasks (bottom). Different alphabets indicate significant difference among the turning devices based on Tukey HSD post-hoc tests.

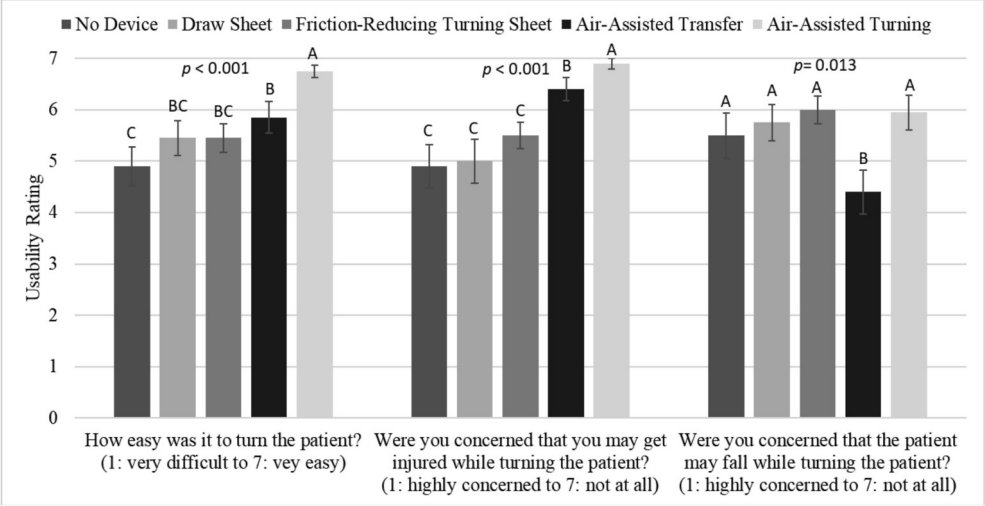

Fig. 5. Mean (standard error) usability rating among five different patient turning devices. Different alphabets indicate significant difference among the turning devices based on Wilcoxon signed rank tests.

4. Discussion

This study aimed to determine whether there were any differences in biomechanical exposure in the upper extremities and low back, and usability of five different commercially-available patient handling devices while professional caregivers performed patient turning tasks. The results showed that all assistive devices reduced the trunk flexion regardless of the different turning tasks. For the other biomechanical measures, the efficacy of the assistive devices was task-dependent. For the turning toward task, the draw sheet and friction-reducing turning sheet did not reduce the muscle activities and/or the L5/S1 moments. For the turning away task, the air-assisted turning device consistently reduced the muscle activities of all the muscles (especially in the anterior deltoid). As the secondary aim, we also evaluated the effects of two different patient weights on the outcome measures. The results showed that patient weight had no significant effects on most outcome measures.

4.1. Trunk and shoulder posture

Four different assistive devices tested in this study showed significantly lower trunk flexion (18–27°) compared to no assistive device (37°), especially when turning the patients toward the caregivers (participants). In our previous study, lateral patient transfer (pulling) task showed similar trunk flexion, ranging from 15° (air-assisted device) to 29° (draw sheet) (Hwang et al., 2019a, 2019b).

During the turning toward task, all assistive devices reduced the right shoulder flexion (62–71°) compared to no assistive device (85°). However, for the left shoulder flexion, only air-assisted transfer and turning devices reduced the shoulder flexion (62–69°) compared to no assistive device (82°). This asymmetry effect could be due to the nature of the study set-up and the turning tasks performed. The simulated patient's head was always positioned on the right side of the participants. During the turning toward task, the study required the participants to use their right and left hand to turn a patient's right shoulder and bent knee, respectively (Fig. 1). Turning the patient's right (bent) knee generally induced greater left shoulder flexion of the caregivers than turning the patient's shoulder due to the different proximity and grasping height of these two body parts.

During the turning away task, all assistive devices showed lower trunk flexion (17–36°) compared to no assistive device (40°). Shoulder flexion was significantly lower with the draw sheet and air-assisted transfer device (56–82°) compared to no assistive device (86–98°). The combination of handle and tilting assistance of the air-assisted transfer device may have reduced both trunk and shoulder flexion.

Despite previously-discussed biomechanical advantages of these assistive devices during patient turning, shoulder flexion angles ranged from 56° to 102° in all device conditions. Shoulder flexion exceeding 60° is known to be associated with increased risk of WMSDs in shoulder regions (Putz-Anderson et al., 1997). This suggests that further design improvement or innovative engineering control should be considered to reduce the caregivers' shoulder discomfort and injuries.

4.2. L5/S1 moment

During the turning toward tasks, the L5/S1 extension moment was significantly higher on the friction-reducing turning sheet (−163Nm) compared to all other device conditions (ranging from −133Nm to −110Nm) except the draw sheet. The friction-reducing turning sheet evaluated in this study was equipped with side handles, which required caregivers to reach over the patient and grasp the side handles. Such a far reach with the friction-reducing turning sheet could have increased the horizontal moment arm between the upper extremity and the L5/S1 (not measured in this study) and, therefore, resulted in higher L5/S1 moment than the other conditions.

Previous studies have reported that an extension moment of 200Nm was associated with the NIOSH action limit of the L5/S1 compressive force (3,400 N) during lifting tasks (Gallagher et al., 2009, 2002; Waters et al., 1993). Although a direct comparison is difficult due to different exertions (lifting vs. turning), the patient turning tasks measured in this study (up to 163Nm) showed lower moment than 200Nm. This corresponds to previous studies showing that low back compression forces of turning tasks (ranged from 1,161 N to 2,319 N) did not exceed 3,400 N (Budarick et al., 2019; Wiggermann, 2015). However, the study set-up (e.g., gurney height set at each participant's knuckle height and simulated patients' weight) was very controlled. In a realistic setting with non-optimal environment and bariatric patients, the L5/S1 moment during patient turning tasks can be high enough to increase risks for low back injuries (i.e., exceed the NIOSH action limit).

For the calculation of L5/S1 moments, hand force (i.e. top-down approach) was not accounted for in this study since hand force transducers could disturb the caregivers' turning behavior. Exclusion of hand force may reduce the accuracy of L5/S1 moment calculations. However, the L5/S1 moment differences between the conditions appear to be in line with previous studies that evaluated hand force during patient turning tasks. Previous studies showed that turn-assist beds with

inflating air bladders significantly reduced the hand force for the turning toward (Wiggermann, 2015) and turning away (Budarick et al., 2019) tasks compared to manual turning. These corresponded with our results showing that L5/S1 flexion moment was significantly reduced by air-assisted devices during the turning toward and away tasks.

4.3. Muscle activity

Muscle activity in the low back (erector spinae) was lower with both the air-assisted transfer and turning devices compared to other device conditions during the turning tasks. The lower muscle activities in the low back are supported by the reduced L5/S1 moment with the air-assisted devices, since less muscular demand in the erector spinae may have been required to counterbalance the lower external moment.

The draw and friction-reducing turning sheets showed higher or similar muscle activity in the erector spinae when compared to the no assistive device condition that, was associated with the L5/S1 moment. However, the L5/S1 moment-arm (Table 3) and the trunk flexion of the draw and friction-reducing turning sheets were similar or even lower than the no assistive device condition. It indicates that use of draw and friction-reducing turning sheets could require greater forces to turn a patient compared to the no assistive device condition.

In general, muscle activity in the shoulder regions (deltoid and upper trapezius) was lower during the turning toward task compared to the turning away task (p's < 0.049). These muscle activity differences in the shoulder regions can be explained by greater shoulder flexion during the turning away task compared to the turning toward task. Furthermore, the anterior deltoid muscle is known to be much more active during pushing than pulling (Ohnishi et al., 2016). Significant pushing effort during the turning away task may have resulted in substantially higher muscle activity compared to the turning toward task which mainly involved a pulling effort. Our finding was also in line with a previous study showing that the turning away task revealed greater hand force and shoulder moment (especially in manual turning) compared to the turning toward task (Budarick et al., 2019). This indicates that turning toward caregivers could be a preferred technique in practice to reduce the risk of injuries in the shoulder regions.

The imbalance of the muscle activities between the left and right erector spinae was seen in both the turning toward and away tasks. On average, the left erector spinae showed greater muscle activity than the right erector spinae (135.7 vs. 107.9 %RVC). This might be partially related to the body mass distribution of the simulated patients since the simulated patient's head was positioned toward the right hand side of the caregivers.

4.4. Self-reported usability and preference

The usability ratings showed that the air-assistive turning device was consistently preferred in easiness and safety measure. The participants felt it was easier to turn the patients and were less concerned about potential injury while using the air-assistive turning device. However, limited differences in the usability ratings were found among the other device conditions. These self-reported usability findings were in line with the objective biomechanical measures discussed thus far. In addition, the caregivers felt more concerned about patient's falling during turning with the air-assisted transfer device compared to the other device conditions. During the turning away task, the caregivers grasped the handles and turned the air mattress, which could lead to a greater amount of patient migration than the other device conditions.

Although this study was carefully designed and conducted, there are some limitations worth noting. First, the limited range of the patients' weight (normal vs. obese) was considered, which may explain the lack of patient weight effects on biomechanical exposures. Due to such a narrow range in the patients' weight, the study findings on the relative benefits of different devices should be validated with broader ranges such as obesity class II (BMI of 35–39.9) or the morbid obesity (BMI $\geq$40) level of the patient. Second, the relative benefits of commercially-available patient turning devices were investigated in a controlled laboratory setting. Therefore, this study's findings may not provide implications regarding the long-term effect of implementing these devices in real healthcare settings regarding reducing the risk of WMSDs, which is our next logical step for future studies. Third, this study did not measure the hand force to avoid disrupting the caregivers' tasks. Due to the absence of hand force measurements (force magnitude and vector), we could not accurately calculate the spine compression and shear forces in this study. Measurement of the hand force merits future study.

5. Conclusion

The air-assisted transfer and turning devices showed potential benefits for reducing awkward postures (trunk and shoulder flexion), low back (L5/S1) moment, and muscle activity in the upper extremities and low back during patient turning tasks. The results suggest that the patient tilting assistance embedded in patient turning devices can be important ergonomic considerations for reducing caregivers' injury risks in the low back and upper extremities. The draw and friction-reducing turning sheets showed limited benefits for reducing biomechanical loading compared to the no assistive device condition. The turning toward task could be a preferred method compared to the turning away task, to reduce the risk of injuries to the shoulder muscles. Lastly, substantial shoulder flexion (exceeding 60°) regardless of device condition indicates that patient turning tasks pose significant risks for shoulder injuries; therefore, ergonomic interventions to reduce such risks are merited. These findings could be useful for promoting the implementation of these ergonomic interventions and for providing insights into improvements in the design features of assistive devices.

Declaration of competing interest

None.

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