

An ergonomic assessment of using laterally-tilting operating room tables and friction reducing devices for patient lateral transfers

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ABSTRACT

Patient lateral transfers between two adjacent surfaces pose high musculoskeletal disorder risks for nurses and patient handlers. The purpose of this research was to examine the ergonomic benefits of utilizing the laterally-tilting function of operating room (OR) tables during such transfers – along with different friction-reducing devices (FRD). This method allows the patient to slide down to the adjacent surface as one nurse guides the transfer and another controls the OR table angle with a remote control. Sixteen nursing students and sixteen college students were recruited to act as nurses and patients, respectively. Two OR table angles were examined: flat and tilted. Three FRD conditions were considered: a standard blanket sheet, a plastic bag, and a slide board. Electromyography (EMG) activities were measured bilaterally from the posterior deltoids, upper trapezii, latissimus dorsi, and lumbar erector spinae muscles. The Borg-CR10 scale was used for participants to rate their perceived physical exertions. The efficiency of each method was measured using a stopwatch. Results showed that the tilted table technique completely replaced the physical efforts that would have been exerted by the pushing-nurse, in that muscle activation did not increase in the pulling-nurse. On the contrary, EMG activities of the pulling-nurse for most of the muscles significantly decreased ($p < 0.05$). The subjective Borg-ratings also favored the tilted table with significantly lower ratings. However, the tilted table required on average 7.22 s more than the flat table to complete the transfer ($p < 0.05$). The slide board and plastic bag were associated with significantly lower Borg-ratings and EMG activities for most muscles than blanket sheet, but they both were not significantly different from each other. However, they each required approximately 5 s more than the blanket sheet method to complete the patient transfer ($p < 0.05$). By switching from flat + blanket sheet to tilted + slide board, EMG activities in all muscles decreased in the range of 18.4–72.3%, and Borg-ratings decreased from about 4 (somewhat difficult) to 1 (very light). The findings of this study propose simple, readily available ergonomic interventions for performing patient lateral transfers that can have significant implications for nurses' wellbeing and efficiency.

1. Introduction

The nursing profession continues to have one of the highest rates of injuries relative to other occupations. In the US in 2018, nursing assistants alone had a higher annual injury and illness incidence rate (255.7) than: laborers and freight, stock, and material movers; construction laborers; and maintenance and repair workers (Bureau of Labor Statistics, 2019). Also, registered nurses had an incidence rate (88.4) greater than that of highway maintenance workers, manufactured building installers, and aircraft structure assemblers. The most common form of injury and illness among both nursing assistants and registered nurses was

work-related musculoskeletal disorders (WMSD), which accounted for 49.7% and 48.5%, respectively, of the total injury and illness cases (BLS, 2019). A systematic review of 34 articles revealed that WMSDs are prevalent among nurses globally (33–88% prevalence range), mainly operating room (OR) nurses and intensive care nurses (Soylar and Ozer, 2018). The most affected body parts were lower back, shoulders, neck, knees, and wrists. In Lebanon, a cross-sectional study of 2852 nurses in 39 acute care hospitals revealed that 71.3% of participants had a WMSD in the previous year (Younan et al., 2019). The most prevalent symptom reported was back pain (83.7%) followed by leg pain (12.3%).

A major cause of WMSDs in nursing is the performance of physically

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strenuous tasks, such as repositioning a patient in bed, sitting the patient on the side of the bed, transferring patients between a wheel-chair and a bed, and pulling or pushing a patient from one bed to a stretcher (Jager et al., 2013; Vieira & Kumar, 2009). Patient handling tasks can be more physically demanding than handling inanimate objects. Patients do not have handles, nor do they have an even distribution of weight, which can lead to unexpected and awkward postural stress (Nelson and Baptiste, 2006). Patients weigh more than the material handled in other occupations, with the average adult (>20 years) weighing at approximately 81.9 kg (Fryar et al., 2012). Moreover, patients can be uncooperative or combative and may require special care of broken bones or surgery wounds when being handled (Waters et al., 2011; Owen et al., 2002). Such conditions can make patient handling even more difficult and harmful than handling heavy material.

A commonly performed task by nurses and among the most high risk tasks for WMSDs is the lateral transfer of a lying patient between two adjacent surfaces, such as an OR table and a stretcher (Nelson and Baptiste, 2006; Nelson et al., 2003; Waters et al., 2007). Lateral transfers are the most frequent cause of back and shoulder WMSDs in general nursing practice (Waters et al., 2011). Weiser et al. (2008) estimated that 234.2 million major surgical procedures are undertaken every year worldwide, each of which requires the lateral transfer of a patient before and after the surgery. Two or more nurses often perform this task, with one pushing and the other pulling the patient between the two surfaces. Additional caregivers (e.g. anesthesia care provider) lift and stabilize the head and/or legs during the transfer. Conventionally, a draw sheet placed under the patient is utilized to improve the hand grip interface and facilitate the transfer. In this method, it is estimated that nurses exert a pull force up to 72.6% of the patient's weight (Waters et al., 2011; Lloyd and Baptiste, 2006). Alternatively, nurses have completed this task by inserting a plastic trash bag under the draw sheet to reduce friction between the patient and the bed surface. Another method involves the use of friction reducing devices (FRD, e.g. slide boards), which was shown to reduce subjective musculoskeletal discomfort, muscle loading/activation, and hand forces (Hwang et al., 2019; Lloyd and Baptiste, 2006; Baptiste et al., 2006; Nelson et al., 2003). For cases where a patient weighs more than 71.21 kg (157 lb), nurses are recommended to use a mechanical lifting device, mechanical lift with supine sling, mechanical lateral transfer device, or air-assisted lateral transfer device (Waters et al., 2011). However, even with the availability of such lifting equipment, nurses tend to rely more on manual transfers to avoid searching for equipment and/or because the manual transfer is more time-efficient. In a prospective study of three hospitals in the US, Kucera et al. (2019) found that lifting equipment were used by nurses on average 21% of the time, with a range of 3–41% depending on the type of lifting equipment. Similarly, several other studies have shown that lifting equipment are not regularly used in patient-handling tasks despite their availability (Lee and Rempel, 2020; Radin Umar et al., 2018; Lee and Lee, 2017; Gomaa et al., 2015; Lee et al., 2013). They are avoided – especially mechanical lifting devices – for various reasons such as: the time and effort required to locate equipment; the perceived extra time required to set up equipment; equipment not readily available; the social pressure to just get the transfer over with quickly; inadequate training; other staff unavailable to assist; and lack of perceived need for equipment (Kucera et al., 2019; Noble and Sweeney, 2018; Myers et al., 2012; Weiler et al., 2012; Schoenfisch et al., 2011; Holman et al., 2010).

Since patient handling tasks are often performed manually, we proposed and evaluated an alternative manual method for specifically performing patient lateral transfers. The alternative method involves tilting the OR table sideways using its remote control to facilitate the patient transfer. Instead of having one person pull and another push the patient across (referred to hereafter as the “pulling-nurse” and the “pushing-nurse,” respectively), the proposed method requires one person to guide rather than pull the patient, as another person controls the tilt of the OR table. The tilted-table has the advantage and assistance of

the gravitational force, allowing the patient to slide down to the adjacent stretcher with potentially less effort from the caregiver. The person operating the tilt of the OR table becomes free from any physical exertion. In conjunction with the proposed tilting mechanism, we also evaluated the use of low-cost, simple FRDs (blanket sheet [control], plastic trash bag, and slide board), since they are easier to handle and transport than mechanical lifts. The main purpose of this research was to determine whether utilizing the tilt function of the OR table replaces the physical efforts that would have been exerted by the pushing-nurse and whether it reduces the physical loads acting on the pulling-nurse. For this, we analyzed the effects of the OR table angle (flat vs tilted) along with three different FRD conditions on the pulling-nurse's muscle activation levels and ratings of perceived physical exertion; also, efficiency was analyzed by measuring the time to complete each patient transfer. The tilting OR table would prove to replace the physical efforts of the pushing-nurse, if the physical loads acting on the pulling-nurse does not increase. This research hypothesized that the tilting OR table with the slide board FRD would not only replace the physical efforts of the pushing-nurse, but also reduce the physical loads acting on the pulling-nurse.

2. Methods

2.1. Participants

Two groups of participants were recruited to serve as nurses and patients. In the nurse group, a total of 16 male nurse students in good health were recruited from the American University of Beirut – Medical Center (AUB-MC). An additional 16 participants in good health were recruited from the university student population to act as patients. Although the call for patient participants was open for both genders, only male participants responded. In recruiting different individuals to act as patients – as opposed to recruiting one person or using a dummy – the resulting patient group more accurately resembled the patient population, in that both include real people with varying weights and anthropometry. The experimental procedures were explained to all participants, and their signatures were obtained on informed consent forms approved by the AUB institutional review board. The Physical Activity Readiness Questionnaire (PAR-Q; British Columbia Ministry of Health, 1978) was used to screen participants for cardiac and other health problems, such as dizziness, chest pain, or heart trouble (Hafen and Hoeger, 1994). Any participant who answered yes to any of the questions on the PAR-Q were excluded from the study. Table 1 summarizes the demographic information of the participants, including their gender, age, weight, and height.

2.2. Experimental Design and Procedures

The experiment involved the performance of different patient lateral transfers by the nurse participant and an assistant. The experimenter served as the assistant in all experiments to maintain a consistent level of assistance across all participants. Patient participants were transferred

Table 1
Summary demographic information and the inclusion criteria for the nurse and patient participants, including the averages and standard deviations (in brackets).

	Nurse Group (n = 16 males)	Patient Group (n = 16 males)
Age (year)	19.2 (0.8)	20.6 (1.5)
Height (cm)	178.6 (3.8)	177.1 (6.0)
Weight (kg)	76.6 (14.1)	75.4 (11.8)
Inclusion Criteria	<ul style="list-style-type: none"> • Male • Nursing student • Healthy (did not answer “yes” on any of the PAR-Q questions) 	<ul style="list-style-type: none"> • Male or female • University students

from an OR table (AMSCO 3085, Lebanon) to a stretcher (Stryker, Lebanon). Both the OR table and stretcher were adjustable in height, and the OR table was also adjustable in the level of its sideways-tilt, up to 18°. Two independent variables were controlled during the patient transfers, including the FRD used and the OR table angle. Three FRD conditions were tested as described below:

- **Blanket Sheet (Fig. 1a):** Before performing the lateral transfer, a blanket sheet was placed on the OR table beneath the patient. To transfer the patient, the nurse participant pulled and slightly lifted the blanket from one end, and the assistant pushed and slightly lifted the blanket from the other end. This is the traditional and more common approach utilized in the OR unit at AUB-MC.
- **Slide Board (Fig. 1b):** This method involved using the blanket sheet in addition to a slide board placed flat over the adjacent sides of the OR table and the stretcher. The board was also positioned to be beneath the blanket and patient's side. The purpose of the board was to reduce the surface frictions over the OR table and stretcher in hopes of easing the transfer. Then the nurse participant and assistant performed the transfer across the slide board using the blanket sheet method.
- **Plastic Bag (Fig. 1c):** This method involved using the blanket sheet in addition to a plastic bag. The bag was placed in between the adjacent sides of the OR table and the stretcher in order to reduce the surface frictions during the transfer. The bag was also positioned to be beneath the blanket and patient's side. Then the nurse participant and assistant performed the transfer across the plastic bag using the blanket sheet method.

The OR table angle, which was the second independent variable, was either in a flat, horizontal position or laterally tilted during the transfers (Fig. 2). In the tilted condition, the assistant – instead of pushing the patient across – controlled the OR table angle using a remote control. The OR table was continually tilted to have the patient slide down to the stretcher as the nurse participant guided the transfer. Given that the FRD factor had three levels and the OR table angle had two levels, a total of six technique combinations were examined. The order of the experimental tasks were randomized for each participant, in order to control the variability caused by the learning effect. Prior to each experimental task, participants were trained on the proper technique and were allowed to practice until they performed it correctly. Furthermore, they were instructed to perform each patient lateral transfer with a gradual increase in force, without jerking, in order to avoid muscle strain. At least 3 min of rest were provided between trials (De Salles et al., 2009), and if requested, they were given more time to rest. Patient participants were instructed to act as unconscious patients or conscious, cooperative patients specifically by remaining loose and still during transfers without providing assistance to nurse participants. In all experiments, the stretcher height was set at the nurse participant's waist level to control the effect of height. The OR table height was set at the same level as the stretcher when the OR table was flat and approximately 7–8 cm above the stretcher when the OR table was to be tilted. This height was determined through basic trigonometry, while also considering patient

safety. Given a maximum 18° tilt and an OR table width of 50.8 cm, the OR table would have to be about 15.7 cm above the stretcher in order for their edges to be aligned at the maximum tilted position. However, taking into consideration that participants may slide down before the maximum tilt angle was achieved, almost half that height was used (7–8 cm).

A Tringo wireless EMG system (Delsys Inc., Boston, MA, USA) was used to measure the maximum muscle activation at the shoulder, neck, and back. Eight rectangular (37 mm x 26 mm x 15 mm, 14g) Ag/AgCL sensors were used and attached to the right and left upper trapezii, posterior deltoids, latissimus dorsi, and erector spinae muscles. The Tringo electrodes had a band-pass filter of 20–450 Hz and a common mode rejection ratio of 80 dB. EMG data was collected at a sampling rate of 2000 Hz and processed using the root mean square (RMS) method with a time window of 0.125 s and an overlap of 0.0625 s (De Luca, 1997; Konrad, 2005). The EMGworks software (Delsys Inc., Boston, MA, USA) was used for processing and analyzing the collected data. As EMG preparation, any hair on the skin was removed over the muscle sites. The areas were also cleaned with alcohol to remove dead skin cells, dirt, and sweat. Then the EMG electrodes were attached to the muscles of interest at the locations suggested by Criswell (2010). To enable EMG comparisons between and within participants, EMG data was normalized to each participant's maximum voluntary contractions (MVC). MVCs were performed for each individual muscle against manual resistance from the experimenter. The maximum EMG amplitude was used for normalizing EMG data; hence, EMG data was reported as a percentage of each muscle's MVC (%MVC). The following MVC exercises were employed for each muscle:

- **Upper trapezius:** participants performed a form of resisted shoulder abduction (Ekstrom et al., 2005; Zanca et al., 2014). In this exercise, the arm was abducted 90° while the neck was laterally flexed to the same side, rotated to the opposite side, and extended. Resistance was applied at the elbow against further arm abduction and at the head against further neck extension.
- **Posterior deltoid:** participants were asked to lie in the prone position with the shoulder abducted 90° and the elbow flexed 90°. Shoulder extension was performed against manual resistance at the distal end of the humerus (Delagi and Perotto, 1980).
- **Latissimus dorsi:** participants performed a chest-supported shoulder extension (Beaudette et al., 2014). This exercise began in a standing position with a flexed back, while resting the chest on an examination table. Maximal shoulder extension was performed against manual resistance at the elbow.
- **Erector spinae:** The starting position in this exercise required participants to lie prone with their hands under their forehead. They were then asked to gradually hyperextend their upper trunk and hips as much as possible against gravity (Ng and Richardson, 1994; Konrad, 2005).

In performing MVCs, participants were asked to gradually exert up to their maximal force in 3–5 s, maintain it for 3 s, and gradually decrease their force in 3 s (Konrad, 2005). Each MVC exercise was repeated three

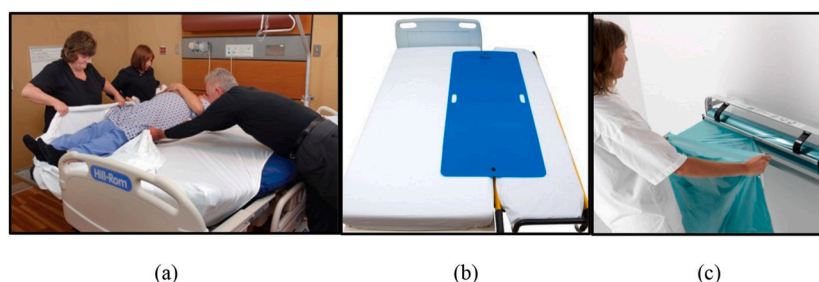


Fig. 1. Three FRD conditions were examined including the: a) blanket sheet, b) slide board, and c) plastic bag.

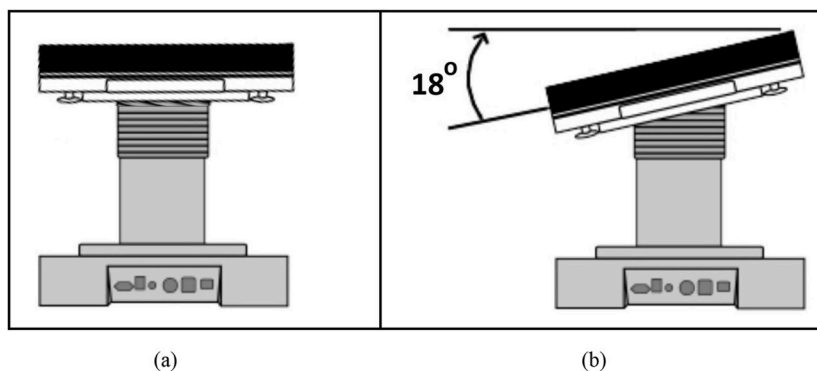


Fig. 2. OR table angle in the: (a) flat and (b) tilted positions.

times, and the maximum EMG amplitude of the three repetitions was used for EMG normalization. Repetitions were separated with 30–60 s of rest, and MVC sets were separated with 2 min of rest (Konrad, 2005).

The time to complete each experimental task was recorded using a stopwatch. The start time for the transfers differed depending on the FRD used, regardless of the OR table angle condition. In the blanket sheet method, the blanket was assumed to be beneath the patient participant before beginning the time measurements, which is common in practice. At the start time signal, nurse participants directly began performing the lateral transfer. As for the plastic bag and slide board, the assumption was that they were readily available but not yet placed beneath the patient. Therefore, before starting the time measurements, nurse participants already had the FRD in their hands. At the start signal, they began by slipping the FRD beneath the patient. The experimenter, who acted as the pushing-nurse, assisted in these tasks by rolling/twisting patients to their sides, in order for the nurse participant to slip the FRD beneath them. Specifically, the FRD was placed partially beneath the patient and also in between the OR table and stretcher, serving as a bridge. Once this was achieved, the nurse participant proceeded with the actual transfer. The end time for all experimental tasks was upon completing the patient transfer to the stretcher.

After each task, participants were asked to rate their perceived physical exertion on a Borg CR-10 scale (Fig. 3; Borg, 1970; Borg, 1982; Noble et al., 1983; Chen et al., 2002). The scale ranged between 0 and 10, where 0 meant that there was no physical exertion at all involved in the task and a 10 meant that the task was physically “very, very

difficult.” An exertion falling between the two extremes was rated with any number between zero and ten. Participants were free to use intermediate decimal numbers. They were instructed to base their ratings solely on how they personally perceived the physical task to be without considering the thoughts of others.

2.3. Statistical Analysis

Repeated measures analysis of variance (ANOVA) was used to assess the effects of OR table angle and the FRD type on the means of the maximum EMG activities, times to complete the transfers, and Borg-ratings. The experiment was replicated 16 times. The replicates served as blocks to control variabilities caused by between-patients and between-nurses effects. Within each replicate, the order of the experimental conditions were randomized. For all significant effects, post hoc analyses in the form of Tukey tests were performed to determine the source(s) of the significant effect(s). The significance level (α) was set at 5%. Statistical significance was based on calculated p-values.

3. Results

3.1. EMG Readings per Intervention Type

Table 2 summarizes the p-values from the ANOVA output for the main and interaction effects for each of the eight muscles. In reviewing first the OR table angle*FRD interaction effects, only the right and left posterior deltoid muscles were found to have a statistically significant interaction ($p < 0.05$). Hence, for these two muscles, the individual main effects were not examined; rather, only their interactions were considered and will be discussed separately later in this section. For all other muscles, the angle*FRD interaction effect was not significant, allowing us to analyze the individual main effects.

The OR table angle had a significant effect on the EMG of all muscles, except for the right and left latissimus dorsi muscles. Fig. 4 presents the mean EMG activities for the different muscles when performing a patient lateral transfer using a flat OR table vs a tilted OR table. The Tukey letter groupings are provided over each bar on the graph. Within each muscle, these letter groupings indicate that means without at least one letter in common are considered significantly different from each other ($p < 0.05$). As so, the mean EMG activities of the right and left trapezii and erector spinae muscles were significantly lower using a tilted OR table angle ($p < 0.05$); the mean EMG activities dropped by 21.1%–26.9% depending on the muscle. On the other hand, the mean EMG activities of the right and left latissimus dorsi were not significantly affected by the OR table angle ($p > 0.05$).

The effects of the OR table angle on the EMG of the right and left posterior deltoids depended on the FRD used as shown in Fig. 5. When using the blanket sheet or the plastic bag, the mean EMG activities of both muscles were not significantly affected by the OR table angle;

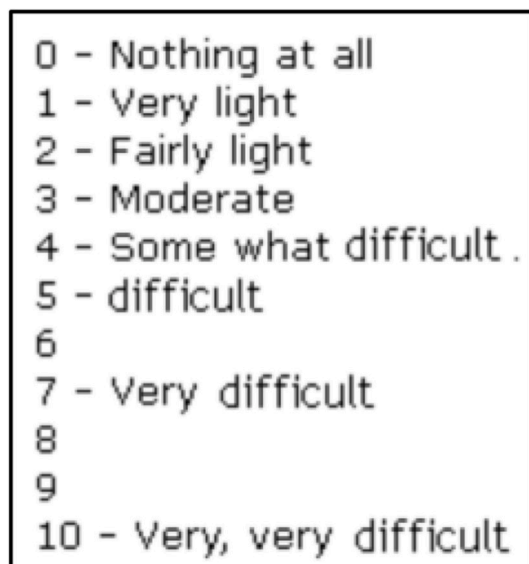


Fig. 3. Borg CR-10 scale.

Table 2

The p-values of the main and interaction effects associated with each muscle's EMG data. Values with asterisks (*) represent significant p-values.

Effect	R-Trap	L-Trap	R-Del	L-Del	R-Lat	L-Lat	R-ES	L-ES
Angle	0.006*	0.001*	0.021*	0.053	0.451	0.139	<0.0005*	<0.0005*
FRD	<0.0005*	<0.0005*	<0.0005*	<0.0005*	0.136	0.001*	<0.0005*	<0.0005*
Angle*FRD	0.239	0.192	0.025*	0.006*	0.071	0.832	0.122	0.767

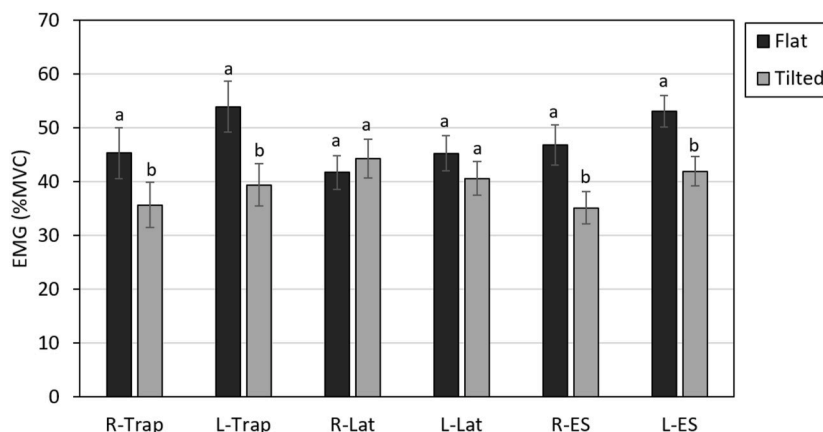


Fig. 4. Mean EMG activities (including standard error bars) of each muscle for the OR table angle main effect, excluding muscles that had a significant angle*FRD interaction effect. The Tukey letter groupings within each muscle indicate that means without at least one letter in common are considered significantly different from each other ($p < 0.05$).

however, when the slide board was used, both muscles showed a significant decrease in mean EMG activity by using the tilted OR table. Also, Fig. 5 shows that, overall, the slide board was the most effective FRD condition in reducing mean EMG activity for both muscles; this effect was more apparent when using the tilted OR table.

The FRD main effect was associated with significant p-values for all muscles except the right latissimus dorsi. Fig. 6 shows the mean EMG activities of each muscle under the different FRD conditions. The trend generally showed the slide board as most favorable with the lowest EMG activities and the blanket sheet as least favorable with the highest EMG activities. However, differences in mean EMG activities were not always statistically significant as can be seen from the Tukey letter groupings.

In summary, the tilted OR table angle reduced muscle loading for most muscles, and similarly, the slide board reduced muscle loading, especially relative to the blanket sheet. Together, they reduced muscle loading substantially in comparison to the conventional method of performing patient transfers (i.e. flat OR table with a blanket sheet). Fig. 7 shows the percent reduction in mean EMG activity for all muscles by using both the tilted OR table and slide board instead of the conventional method.

3.2. Borg-Ratings per Table Angle and FRD Type

The ANOVA output for the Borg-ratings showed that the angle*FRD interaction effect was not statistically significant ($p = 0.811$); however, both main effects (OR table angle and FRD) had significant p-values less than 0.0005. Hence, the rest of the analysis focused on the individual main effects. Table 3 presents the Borg-rating means associated with each main effect. As for the OR table angle, participants perceived the tilted table as less physically strenuous than using the flat OR table ($p < 0.05$). Also, they viewed the slide board as the least physically demanding FRD; however, its mean Borg-rating was not significantly different than the mean of plastic bag. Overall, the combination of a flat OR table with a blanket sheet was associated with the highest mean Borg-rating (4.31), which is described as “somewhat difficult” on the Borg-scale (Fig. 3). Whereas, the least physically demanding combination was the tilted OR table with a slide board, which had a mean Borg-

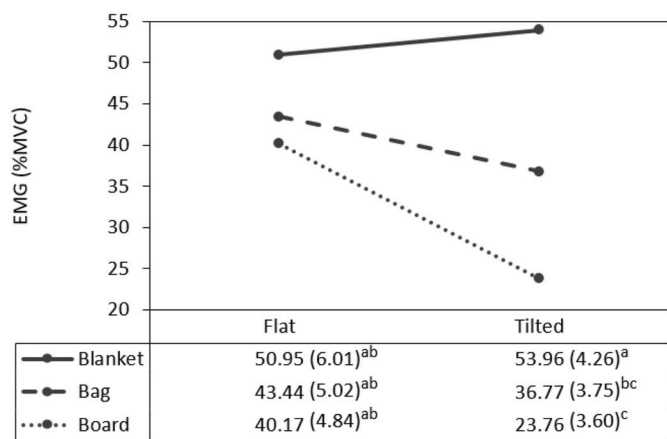
rating of 1.13 (described as “very light” on the Borg-scale).

3.3. Time Differences per Table Angle and FRD Type

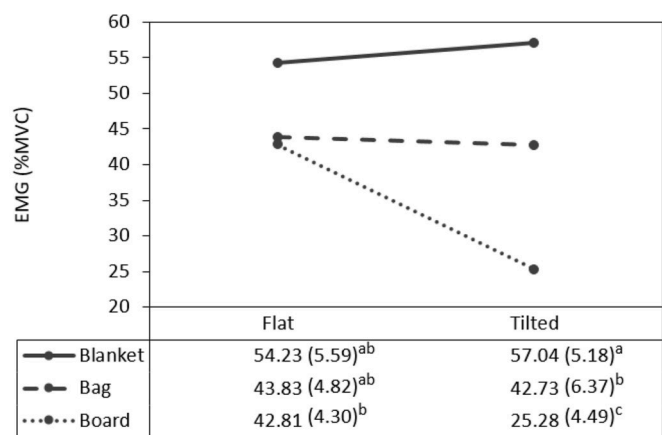
Also, time did not have a significant angle*FRD interaction effect ($p = 0.489$). However, both main effects were statistically significant with p-values of less than 0.0005. Hence, we focused on assessing each main effect individually. Table 4 presents the mean times to complete a patient transfer under each main effect. The tilted table required more time than using the flat OR table. As for the FRD main effect, plastic bag and slide board required more time than blanket sheet, but both were not significantly different from each other. Although statistically significant differences existed in the mean times, the largest difference was only 7.22 s (= 13.82–6.60).

4. Discussion

This study examined the effects of different methods for performing patient lateral transfers on the patient-handler's muscle loading, perceived physical exertion, and efficiency (i.e. time to complete a transfer). The different methods included using a flat OR table vs a tilted OR table along with three different FRD conditions (blanket sheet, plastic bag, and slide board). Regarding the OR table angle main effect, mean EMG activities of all muscles did not increase by using the tilted OR table angle, indicating this method replaced the physical efforts that would have been exerted by the pushing-nurse. In addition, EMG activities of the pulling-nurse – specifically at the right and left trapezii and erector spinae muscles – showed a significant decrease when using the tilted OR table angle; whereas, the EMG activities of the right and left latissimus dorsi were unaffected. The different EMG responses between muscles may be explained by the fact that the tilted OR table angle benefits from the gravitational force, which allows the patient to slide down to the adjacent surface, reducing the need for a lifting action but not necessarily a pulling action. The nurse would still have to pull the patient in order to guide and facilitate the slide across the two adjacent surfaces. Lifting tasks have been shown to place biomechanical loads on not only the upper extremity, but also, the neck, shoulders, and low back



(a)



(b)

Fig. 5. Factor plots of the angle*FRD interaction effects, including the EMG means (standard errors), for the: a) right posterior deltoid and b) left posterior deltoid. The Tukey letter groupings (presented as superscripts) indicate that means without at least one letter in common are considered significantly different from each other ($p < 0.05$).

(Nimbarte, 2014; Hoogendoorn et al., 2000; Maher et al., 2017). The reduced need for lifting when using the tilted OR table angle may explain the drop in the EMG activities of these muscles. As for the latissimus dorsi muscle, one of its main functions are arm extension or medial rotation (Criswell, 2010), which are movements performed when pulling an object; this may indicate that a similar pulling exertion was

required in both OR table angles, since the latissimus dorsi EMG activities were unaffected. Similar research (Lavender et al., 2007; Conrad et al., 2008) developed different ergonomic interventions to facilitate lateral patient transfer, which included: a bridgeboard to reduce the frictional force resisting the lateral sliding of the patient, the use of rods along each side of the patient to facilitate the grasping and handling of the bedsheet, and a single rod that, when rolled in the bedsheet, resulted in the task being changed from a lifting task to a pulling task. They found that erector spinae EMG activity decreased with the use of the bridgeboard and the single rod both individually and together. However, the single rod increased the EMG activity of the latissimus dorsi in comparison to the standard bedsheet transfer condition, although, this effect was moderated when the single rod was used with the bridgeboard. Similarly, in the present study, the tilted OR table angle reduced the EMG activities of all muscles, except the latissimus dorsi. However, unlike in Lavender et al.'s (2007) study, the latissimus dorsi EMG activity did not increase, but rather, it remained unaffected. Moreover, the subjective Borg-ratings were also in agreement with the objective EMG measures, favoring more the tilted table angle.

In regards to the right and left posterior deltoids, their OR table angle*FRD interaction effects were examined, since they were statistically significant. It was found that the tilted table angle led to a significant drop in mean EMG activities of both muscles only when the slide board was used. Similar to the latissimus dorsi, one of the main functions of the posterior deltoids is arm or shoulder extension (Criswell, 2010), a motion necessary during pulling. Therefore, it appears that less pull exertions were needed when the slide board was used with the tilted OR table angle in comparison to the other FRD conditions. This effect could be due to the fact that the slide board has a solid, low-friction surface, permitting a smoother transition between the two adjacent surfaces.

What appeared as a downside with the tilted OR table angle is that it took over twice as long to perform the patient transfer in comparison to the flat OR table angle. However, this difference was only a matter of seconds, specifically 7.22 s, which is a much smaller difference than switching to a mechanical lift. Garg and Owen (1992) found that using mechanical lifts – instead of a manual patient transfer – can increase this difference to around 1 min, with the manual transfer requiring 8–18 s and the mechanical lift requiring 73.7 s. A more recent study additionally considered the preparation time to using the mechanical lift for the same transfer task (e.g. requesting/obtaining help from other staff, explaining the task to patient/resident, obtaining equipment, etc.) and found that the total transfer time to be 273.6 s on average (Alamgir et al., 2009). In emergency or time-pressuring situations, 273.6 s (4.6 min) may be seen as a time burden and risky for the patient's health. In such circumstances, healthcare professionals may be forced to rely on manual methods when transferring the patient. A few studies have shown that lifting equipment, especially mechanical lifts, are under-utilized even when available primarily due to time-related factors (Kucera et al., 2019; Noble and Sweeney, 2018; Myers et al., 2012; Weiler et al., 2012;

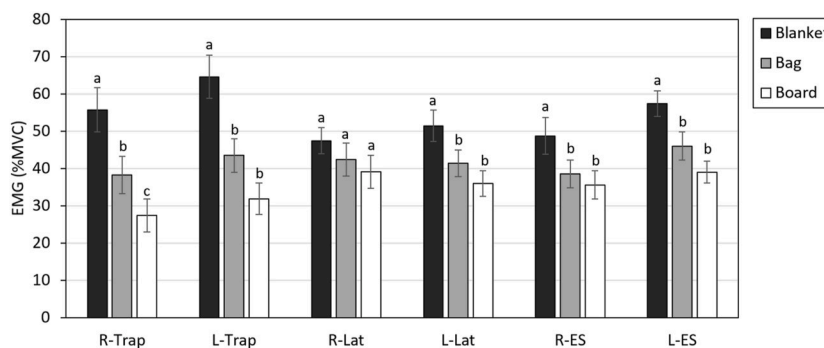


Fig. 6. Mean EMG activities (including standard error bars) of each muscle for the FRD main effect, excluding muscles that had a significant angle*FRD interaction effect. The Tukey letter groupings within each muscle indicate that means without at least one letter in common are considered significantly different from each other ($p < 0.05$).

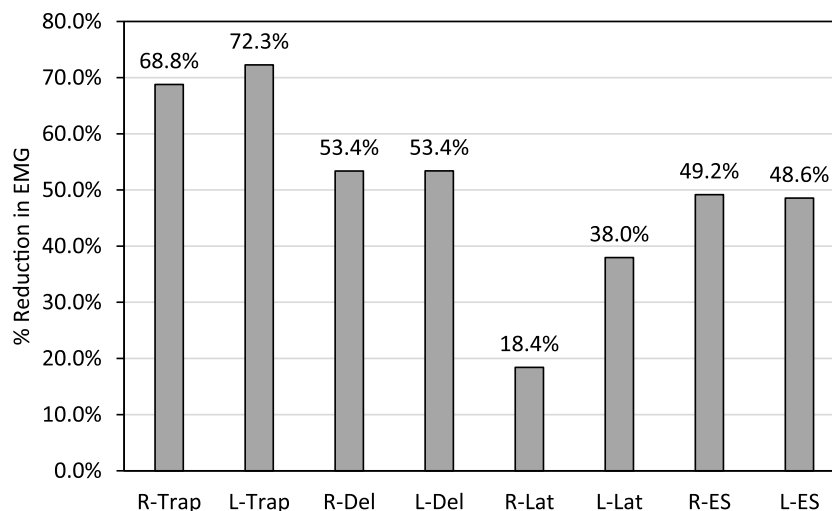


Fig. 7. Percent reduction in EMG means by using the tilted OR table with a slide board instead of the conventional flat OR table with a blanket sheet.

Table 3

Mean (standard error) Borg-ratings associated with each level of the OR table angle and FRD main effects. The Tukey letter groupings within each main effect indicate that means without at least one letter in common are considered significantly different from each other ($p < 0.05$).

	OR Table Angle		FRD		
	Flat	Tilted	Blanket	Bag	Board
Borg-Rating	3.02 (0.23) ^a	1.98 (0.23) ^b	3.72 (0.32) ^a	2.13 (0.23) ^b	1.66 (0.20) ^b

Table 4

Mean (standard error) times associated with each level of the OR table angle and FRD main effects. The Tukey letter groupings within each main effect indicate that means without at least one letter in common are considered significantly different from each other ($p < 0.05$).

	OR Table Angle		FRD		
	Flat	Tilted	Blanket	Bag	Board
Time	6.60 (0.38) ^a	13.82 (0.56) ^b	6.69 (0.67) ^a	11.9 (0.74) ^b	12.05 (0.83) ^b

Schoenfisch et al., 2011; Holman et al., 2010). The advantage of the tilted OR table angle is that it is readily available, since OR tables are already equipped with the tilting function, and it requires only a few seconds more to perform than conventional methods. Moreover, it does not involve any additional investment from the healthcare industry; this is a feature typically common in OR tables. It is therefore more likely to be accepted and adopted in practice. Furthermore, since the tilting adjustability is not common in regular hospital beds, the authors recommend that bed manufacturers incorporate this adjustability in future designs.

Since the current commonly used transfer methods include using FRDs, this research also examined the effects of using the standard blanket sheet, plastic bag, and slide board with both OR table angles. Our results were in agreement with the findings of past research that FRDs – such as plastic bag and slide board – can reduce perceived musculoskeletal discomfort and physical loads on the spine and shoulders (Hwang et al., 2019; Baptiste et al., 2006; Nelson et al., 2003; Lloyd and Baptiste, 2006; Lavender et al., 2007); however, the time needed to complete the transfer may increase by a matter of seconds. In comparing the effectiveness of the plastic bag and slide board FRDs, the latter always reported more favorable averages across all the response variables, but the differences were not always statistically significant. An

advantage of plastic bag, however, is that it is readily available in virtually all hospitals and requires no additional investment, unlike slide boards.

Overall, the tilted OR table angle in combination with a slide board or plastic bag led to the most favorable results in reducing biomechanical loads and the perceived physical exertion, without substantially increasing the time needed to complete a patient lateral transfer. In switching from the traditional flat OR table with a blanket sheet to the tilted table with a slide board, biomechanical loading at different muscle sites decreased by 18.4–72.3% (Fig. 7) and the ratings of perceived physical exertion decreased from “somewhat difficult” to “very light”. In practice, if both nurses take turns in operating the tilt of OR tables, then they will be exerting physical effort in only half of the total transfers, and in each transfer, they will be exposed to lower physical loads. Also, this method eliminates the need to search for and maneuver a mechanical lift to the site of the transfer since most OR tables are already electrically-adjustable.

This research had several limitations, which included the following:

- Nurse students were recruited instead of actual registered nurses or nurse assistants, who typically perform the patient lateral transfers. All participants, though, were trained on the proper techniques to perform the patient lateral transfers before data collection.
- The gender and age effects were not examined. Only male subjects (18–21 years) were recruited, since EMG sensor attachment required participants to be topless during experiments. This restriction has limited the ability to account for the gender distribution of the nursing workforce, which in the US is about 90.9% females (Smiley et al., 2018). There are numerous studies in the literature that examined gender differences in terms of biomechanics and/or kinematic measures under different lifting, pushing, and pulling conditions (Plamondon et al., 2014, 2017; Sheppard et al., 2016; Nimbarde, 2014; Sun and Nimbarde, 2011; Marras et al., 2003). Their findings indicated that females, under similar task conditions, work at closer levels to their maximal physical capabilities, increasing their risk of injury. This would have been reflected in the results with higher EMG activities (%MVC) and Borg-ratings. However, the relative effects of the different OR table angles and FRDs on females would have likely been similar to that on males. For example, Marras et al. (2003) showed that as the physical load in a lifting task decreased (or increased), trunk muscle activations in both genders also decreased (or increased) but in varying amounts.
- The patient weight effect – for example, “heavy” vs “light” patients – was not examined because it would have increased the sample size requirements. However, patients of varying weights (58.8–96.0 kg)

were recruited to ensure that results are more representative of a general population.

- The time measurements began assuming that the FRDs were readily available, when in practice nurses may have to search for them. Therefore, the authors recommend that appropriate FRDs are readily available in every OR room, especially since they are simple, compact, and economical lifting aids.
- The EMG activities while placing the FRD beneath the patient were not investigated. This task is likely associated with a physical load since patients must be twisted to their sides, in order to place the FRD partially beneath them and in between the OR table and stretcher.
- The bed angle was analyzed specifically for OR tables, since other beds do not commonly have a lateral or sideways tilt adjustability. The findings of this research, however, may encourage hospital bed manufacturers to incorporate such adjustability in future bed designs.

5. Conclusions

The tilted table proved to be an effective technique for reducing biomechanical loads during patient lateral transfers. It completely omitted the physical effort that would have been exerted by the pushing-nurse, given that he or she would now be controlling the OR table angle using a remote control, and it additionally reduced the EMG activities of most muscles on the pulling-nurse. Participants also favored the tilted table technique with significantly lower Borg-ratings. In comparing FRDs, the slide board and plastic bag were associated with significantly lower Borg-ratings and EMG activities for most muscles than blanket sheet, but they both were not significantly different from each other. The tilted table and slide board together had a significant impact on both EMG activities and Borg-ratings, without substantially compromising productivity. To further benefit from this method, we recommend that nurses take turns between operating the OR table angle and pulling the patient; this will allow them to exert physical effort in only half of the total transfers, reducing exposure to both acute and cumulative biomechanical loads. Furthermore, we hope the findings herein will encourage hospital bed manufacturers to incorporate laterally tilting adjustability in all their bed designs (not only in OR tables) given its positive implications for nurses' health and wellbeing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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