Spine loading during the application and removal of lifting slings: the effects of patient weight, bed height and work method

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ABSTRACT

The biomechanical loading on the lumbar spine was assessed as 12 female nurses applied and removed slings under two patients of differing weights (54 and 100 kg), using two work methods, and while working at three bed heights (56, 71, 93 cm). Three-dimensional spine loads at the L2/L3, L3/L4, L4/L5 and L5/S1 disc levels were measured using a validated EMG-assisted biomechanical model. Anterior/posterior (A/P) shear loading at the L5/S1 level consistently exceeded the tolerance threshold limit for disc failure. The peak compression values exceeded the 3400 N tolerance threshold for several participants when placing the sling under the 100-kg patient. In general, working from both sides of the bed generated slightly higher A/P shear loading than the one-sided method. Raising the bed significantly decreased compression and A/P shear forces. Therefore, raising the bed to at least the nurse's knuckle height is recommended when applying and removing patient slings.

Practitioners Summary: We investigated the spine loading associated with placing and removing slings used for the mechanised lifting of patients. Peak compression and anterior shear forces exceeded recognised thresholds when placing slings underneath heavier patients. Raising the bed to at least knuckle level helps mitigate these spinal loads.

Introduction

Researchers have reported the extent of low back pain prevalence and onset in nursing personnel (Jensen 1987; Pheasant and Stubbs 1992; Moffett, Hughes, and Griffiths 1993; Hignett 1996; Smedley et al. 1997, 2005; Feng, Chen, and Mao 2007; Collins, Bell, and Grönqvist 2010; Bhimani 2016). The onset of low back pain in nurses was estimated to be around 38% through longitudinal studies (Smedley et al. 1997, 2005). The point prevalence of low back pain was reported as 17% by Pheasant and Stubbs (1992) and the 12-month prevalence was reported to be around 43–66% by several studies (Pheasant and Stubbs 1992; Feng, Chen, and Mao 2007). Epidemiological studies have identified manual patient handling as one of the key risk factors associated with the onset of low back pain in nurses (Stubbs et al. 1983; Harber et al. 1985; Pheasant and Stubbs 1992; Moffett, Hughes, and Griffiths 1993; Hignett 1996; Smedley et al. 1997, 2005; Feng, Chen, and Mao 2007; Waters 2007; Yassi and Lockhart 2013). Manual transfer of patients between beds and chairs was identified to be of key concern by these studies (Smedley et al. 1997, 2005; Feng, Chen, and Mao 2007; Waters 2007). Biomechanics

studies looked into the loading on the L5/S1 joint of the lumbar spine during the performance of several manual patient handling activities and documented the generation of loads in excess of the NIOSH recommended tolerance threshold limit for the initiation of vertebral endplate fractures (NIOSH 1981; Garg, Owen, and Carlson 1992; Winkelmolen, Landeweerd, and Drost 1994). Marras et al. (1999) studied several one-person and two-person manual patient handling activities and reported that all the manual patient handling activities put nurses at high risk for low back disorders. The study also reported that the compression, anterior–posterior shear and lateral shear loading on the L5/S1 joint are all higher than respective tolerance threshold limits suggested (McGill 1997; Marras et al. 1999; Gallagher and Marras 2012). This study strongly recommended the use of mechanical lifting aids for the performance of patient handling activities.

Hoists used for lifting, transferring and repositioning patients can be floor-based or ceiling mounted. Patients are lifted in a sling, which is attached to the hoist. These assistive devices have been shown to reduce the loads generated at L5/S1 joint relative to those experienced

during manual patient handling (Garg and Owen 1992; Zhuang et al. 1999; Engst et al. 2005) and reduce the incidence of injury (Evanoff et al. 2003; Andersen et al. 2014; Holtermann et al. 2015; Tompa et al. 2016). A comparison between ceiling lifts and floor lifts for a set of patient transfer activities found that the ceiling lifts generated lower spinal loads than the tolerance threshold limits for endplate fractures (Marras, Knapik, and Ferguson 2009; Dutta et al. 2012).

The majority of the focus of existing research with respect to patient handling has been on the actual transfer process. However, the use of mechanical assistive devices requires the preparation of patients for the transfer by placing a sling under them, as they lie supine on a bed. Similarly, the slings have to be removed from under the patients once the transfer task is completed. Sling manufacturers typically provide instructions on the techniques to be used during sling application and removal (Ergolet America 2011; Guldmann 2013). These sling application and removal activities involve considerable manual handling of the patient in terms of rolling, pushing and pulling of the patient on the bed.

However, there has been limited research on the biomechanical loads experienced during the sling application and removal process. The compression forces on the L5/S1 joint during the task of manually turning a patient in bed were reported to be as high as 3526 N (Gagnon et al. 1987). Zhuang et al. reported L5/S1 compression load ranges of 2094–4367 N when rolling a patient towards the nurse and 1804–4745 N when rolling a patient away from the nurse (Zhuang et al. 1999). However, another study reported that the median compression and shear loading at the L5/S1 joint for the sling application were 1400 N and 250–300 N, respectively (Santaguida et al. 2005). Knapik and Marras (2009) reported the presence of extensive A/P shear loading at the upper lumbar levels of the spine during pushing and pulling tasks; activities that are part of the recommended techniques for the sling application and removal. Hence, there is a need to study the biomechanical loads experienced during sling application and removal at all the levels of the lumbar spine and understand the specific factors that affect these loads.

Given that the shear loading on the spine during pushing and pulling tasks was found to increase with increased weight that was being handled (Knapik and Marras 2009), the biomechanical loading during sling application and removal is expected to be sensitive to patient weight. Other factors that can influence the biomechanical loading include the specific application method used and the height of the bed when the sling application or removal occurs. Studies have shown improved spine posture and spine kinematics when the bed height was adjusted to a nurse-preferred height for patient handling activities (de Looze et al. 1994; Caboor et al. 2000).

The recommended technique for the sling application by a single nurse can essentially be split into five tasks: (a) rolling the patient away from the nurse by a pushing action, (b) spreading a half of a rolled up sling onto the bed, (c) rolling the patient towards the nurse by a pulling action, (d) spreading the other half of the sling on the bed and (e) rolling the patient supine back onto the sling. While all these tasks can be performed from one side of the bed, it is possible that the nurse could walk around the bed to complete the latter three tasks of the process. This converts the sling application process into an activity consisting only of pushing tasks as opposed to the one-sided technique, which has both pushing and pulling tasks. One study demonstrated lesser compressive forces on the L5/S1 joint during the pushing tasks than the pulling tasks that are involved in patient handling (Zhuang et al. 1999). It should also be noted that, depending upon the body size of the care provider and the body size of the patient, the one-sided application and removal process may not be possible.

The objective of this study was to determine if the sling application and/or removal processes generate excessive spinal loads that can potentially contribute to the onset of low back pain in nurses. In other words, does the sling application and removal tasks result in compressive forces above the 3400 N, a threshold advocated by NIOSH (1981) or shear forces in excess of the 1000 N threshold advocated for infrequent tasks (Gallagher and Marras 2012). In addition, this study was designed to investigate the effects of three factors hypothesised to influence the loading on the spine during these tasks: the method for sling application and removal, the bed height and the weight of the patient. Specifically, this study tested the following hypotheses:

(1) Raising the bed height reduces the spine loading during sling application and removal.
(2) Having the nurse work on both sides of the bed during the sling application and removal reduces the biomechanical loading of the spine.
(3) A heavier passive patient leads to greater biomechanical loads during the sling application and removal that those experienced with a lighter passive patient.

Methods

Subjects

Twelve female participants were recruited for the study. Three were professional nurses, three were nursing assistants and six were nursing students. The average age,

height and weight of the subjects were 26.8 (SD = 4.01), 168.4 cm (SD = 2.91) and 73.33 Kg (SD = 15.83), respectively. Inclusion criteria required participants be between the ages of 18 and 65 years, that they were not pregnant, they had not experienced an episode of low back pain lasting for more than 24 hours in the previous 12 months and that they were not experiencing pain from any other injury in the previous year that prevented them from performing any physical activity. All participants signed a consent document approved by the University's Institutional Review Board.

Experimental design

The experiment consisted of a single nurse applying the sling and removing it from underneath two simulated patients of different weights. For each patient weight condition, the bed height was varied to three different levels. At each height level, the sling was applied and removed using two methods. Thus, the independent variables for the experiment were the patient weight, the sling application and removal method, and the height of the bed. The dependent measures for the study were measured separately for both the sling application and removal activities.

The patient weight levels were fixed at 54 and 100 Kg. Both the patient volunteers were instructed and trained not to assist the nurse during the sling application or removal. This was done to simulate a worst-case scenario of sling use by nurses.

Three bed height levels were evaluated. The lowest and highest heights (56 and 93 cm from the floor to the top of the mattress) represent the end ranges of adjustment for the bed used in this study. In addition, each individual subject's standing knuckle height was chosen as the third height level as this could theoretically be self-selected for each nurse working with an adjustable height bed. Specifically, the knuckle height was defined as the height from the floor to the proximal inter-phalangeal joint of the right hand as the participant stood erect with their arms handing at their sides. On average, knuckle height for these participants was 71 cm.

Two methods of sling application and removal were also investigated. The 'One-sided' method involved the nurse standing only on one side of the bed while performing the sling application and removal. This technique involved both the activities of rolling (pushing) the patient away from the nurse and rolling (pulling) the patient towards the nurse as the sling is spread out on the bed. The 'Two-sided' method involved the nurse walking around to the far side of the bed for the latter half of the sling application task and for the first half of the sling removal task. This hypothesised advantage of this technique is that the patient rolling only requires the task of pushing the patient away from

the nurse. Both techniques of sling required the nurses to lift the strapped legs of the patient to put the leg support straps of the sling under the patient's legs.

Spine load predictions

The compression, anterior/posterior shear and lateral shear forces at the superior and inferior endplate levels between L2/L3 and L5/S1 of the lumbar spine were predicted by a subject specific, biologically assisted biomechanical model. This model has been developed and validated in prior research efforts (Marras and Sommerich 1991; Granata and Marras 1993, 1995; Marras and Granata 1995, 1997; Fathaliah et al. 1997; Jorgensen et al. 2001; Knapik 2005; Theado, Knapik, and Marras 2007). The model is suitable for any activity involving three-dimensional free dynamic lifting, pushing and pulling. The model uses subject specific anthropometry, body kinematics, task performance kinetics and surface electromyographic (EMG) data.

Apparatus

The sling used for the study was a multipurpose sling (OriginalSling, Hill-Rom, Chicago, IL, USA) with full back support and straps for supporting the legs. The sling was used on a bed (Total-Lift Bed, VitalGo Systems Ltd., Fort Lauderdale, FL, USA) on which the patient laid supine. The sling was applied and removed using techniques recommended by manufacturers (Ergolet America 2011; Guldmann 2013). To simulate a worst-case scenario where the patient remained completely passive, straps were wrapped around the patient's arms and legs to prevent individual movement of arms and legs. The straps were made of Velcro material and did not cause any discomfort to the simulated patients. The arms of the patients were crossed across the chest under the strap during the sling application and removal.

EMG data were captured bilaterally using 10 bipolar surface electrodes from the erector spinae, latissimus dorsi, internal oblique, external oblique and rectus abdominus muscles. The location of electrodes has been described in prior publications (Mirka and Marras 1993). The signals from the electrodes were captured using a Model 12 Neuradata Acquisition System (Grass Technologies West Warwick, RI, USA). Task kinetics in the form of ground reaction forces and moments were measured using two force plates (Bertec 4060A, Worthington, OH, USA). Full body kinematics for the subject were estimated using a three-dimensional motion capture system (Optitrack Motive, Natural Point Inc., Corvallis, OR, USA). Passive reflective markers, attached to different anatomical positions on the subject's body, were used during the motion capture process. A 20lb medicine ball was used for calibration
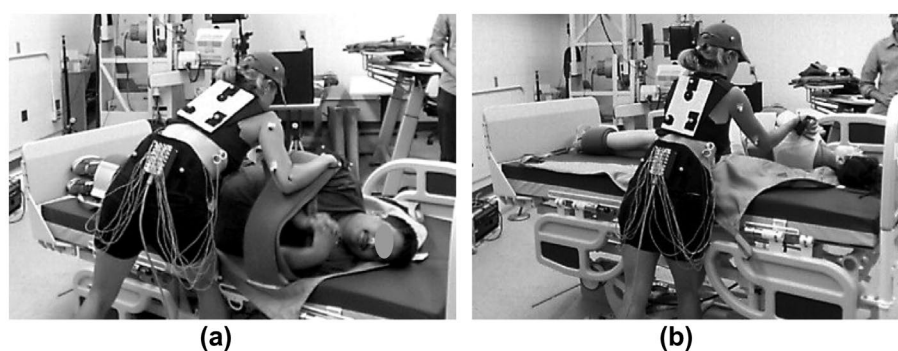
Figure 1. The experimental set-up showing instrumented participant performing the sling insertion task on a heavier patient at the lowest bed height (a) and on the lighter patient at the highest bed height (b).

exertions required to calibrate the biomechanical model to each specific subject (Dufour, Marras, and Knapik 2013).

Data from the EMG system, kinetic data from force plates and motion capture data from the tracking system are channelled using a PCI-6031E Data Acquisition System (National Instruments, Austin, TX, USA) by a Customised Laboratory Information Management System developed at the OSU Biodynamics Laboratory.

Procedure

After obtaining informed consent, anthropometric measures were obtained from the subject to prepare for the calibration of the model. Surface EMG electrodes were applied to the subject's trunk muscles after skin preparation. Impedance was measured across the bipolar electrodes at each trunk muscle site to ensure adequate electrode sensitivity. Tracking markers were put on the subject at different anatomical locations. The subjects were then asked to perform a series of calibration exertions while standing on the force plates. These data were used to calibrate the open-loop biomechanical model. All participants were shown videos that demonstrated the sling insertion and removal techniques that they were asked to use. The specific techniques demonstrated in the video were based upon worksite observations in a rehabilitation hospital and a local nursing home. The subjects were given opportunity to practice the sling application and removal using the demonstrated techniques. The patient weight conditions and the sling application techniques were counterbalanced between different subjects and the bed height conditions were randomised between sessions. Figure 1 shows an instrumented participant working with the heavier and lighter patient at the lowest and highest bed heights.

Data analysis

The raw EMG data collected during the experiments were pre-amplified, low-pass filtered at 1000Hz, high-pass filtered at 15 Hz and then passed through a 20-ms sliding window filter. The data were further smoothened using a Hanning smoothing filter. The dynamic EMG signal was used by the model to compute dynamic muscle forces. The model produced estimated peak compression and shear forces at the superior and inferior endplate for each disc level between L2/L3 and L5/S1. For each disc level, the superior and inferior endplate forces were compared and whichever was greater was used in the subsequent statistical analyses.

The initial statistical analysis involved use of a multivariate ANOVA (MANOVA) analysis to evaluate the main effects and interactions looking collectively at the data across disc levels. The Wilks-Lambda statistic has been used as a test criterion for identifying significances of main effects and any relevant interactions. Any interactions of significance were further evaluated by univariate analysis of variance using post hoc analysis to check for any significant differences between different levels of a variable. A post hoc REGWQ test was conducted to verify for significant differences between the different pairs of bed height conditions. A significance level of 0.05 was chosen for all the analyses.

Results

Model performance

The biomechanical model's performance during the calibration process was assessed using the R-squared correlation and the normalised Average Absolute Error (AAE) mentioned earlier. The average R-squared correlation across the different sessions was 0.85 (SD = 0.07) and the AAE averaged across the different sessions was 0.087 (SD = 0.03).

Multivariate analysis

Table 1 shows the p-values from the MANOVA test evaluating the independent variables and their interactions collectively across the multiple disc levels. This analysis

Table 1. *p*-values for the Wilks' Lambda criterion from multivariate ANOVA for the main effects and subsequent interactions.

Task	Factor	Compression	A/P shear	Lateral shear
Application	Weight	<0.001	<0.001	<0.001
	Height	<0.001	<0.001	0.004
	Method	NS	<0.001	0.002
	Weight*Height	NS	NS	NS
	Height*Method	NS	0.017	0.019
	Weight*Method	NS	NS	NS
	Weight*Height*Method	NS	NS	NS
Removal	Weight	<0.001	<0.001	<0.001
	Height	<0.001	<0.001	0.022
	Method	<0.001	<0.001	NS
	Weight*Height	NS	NS	0.024
	Height*Method	NS	0.020	NS
	Weight*Method	NS	NS	NS
	Weight*Height*Method	NS	NS	NS

Table 2. *p*-values for univariate ANOVA analyses at the different vertebral disc endplate levels for effects where the MANOVA showed significant differences.

Task	Factor	Compression	A/P shear	Lateral shear
Application	Weight	All < 0.001	All < 0.0001	L2/L3 < 0.001 L3/L4 < 0.001 L4/L5 = 0.004 L5/S1 = 0.002
	Height	All < 0.001	L2/L3 = 0.037 L3/L4 < 0.001 L4/L5 < 0.001 L5/S1 < 0.001	L2/L3 = 0.007 L3/L4 = 0.007 L4/L5 = 0.004
	Method	–	L2/L3 = 0.019 L3/L4 < 0.001	L2/L3 = 0.006 L3/L4 = 0.027
	Height*Method	–	L2/L3 < 0.005	NS
Removal	Weight	All < 0.001	All < 0.001	All < 0.001
	Height	All < 0.001	L2/L3 = 0.050 L3/L4 < 0.001 L4/L5 < 0.001 L5/S1 < 0.001	L5/S1 = 0.016
	Method	All < 0.001	L2/L3 = 0.012 L3/L4 < 0.001 L4/L5 < 0.001 L5/S1 < 0.001	NS
	Weight*Height	–	–	L5/S1 = 0.019
	Height*Method	–	L2/L3 = 0.005	NS

shows that for the sling application task the compression, anterior shear and lateral shear forces were affected by the patient weight and the bed height. Additionally, anterior and lateral shear forces were dependent upon the method used and the interaction between patient weight and the height of the bed.

The sling removal task showed significant changes in compression and the A/P shear due to patient weight, bed height and method used. Lateral shear was affected by the patient weight and the bed height but not the work method. Only the A/P shear was affected by the combination of method and bed height, and only the lateral shear was affected by the combination of patient weight and bed height (Table 2).

Effects of patient weight

Figure 2 shows the spine compression and shear forces predicted by the model as a function of vertebral level and patient weight. Univariate analyses showed significantly higher compression, A/P shear and lateral shear forces across all vertebral levels with the higher patient weight during sling application and sling removal. For both sling application and removal compression, forces were 800–1000 N higher at all disc levels for the heavier patient (Figure 2(a) and (b)). The highest increase in the A/P shear force due to the heavier patient, approximately 400 N, occurred at the L5/S1 level during both sling application and removal (Figure 2(c) and (d)). For the rest of the lumbar vertebral levels, the differences in A/P shear forces due to the increased patient weight were between 150 and 200 N for the sling application task and between 50 and 100 N for the sling removal task. The heavier patient weight also generated consistently higher lateral shear loads (Figure 2(e) and (f)), with increased differences between the patient weight conditions with more for the superior disc levels.
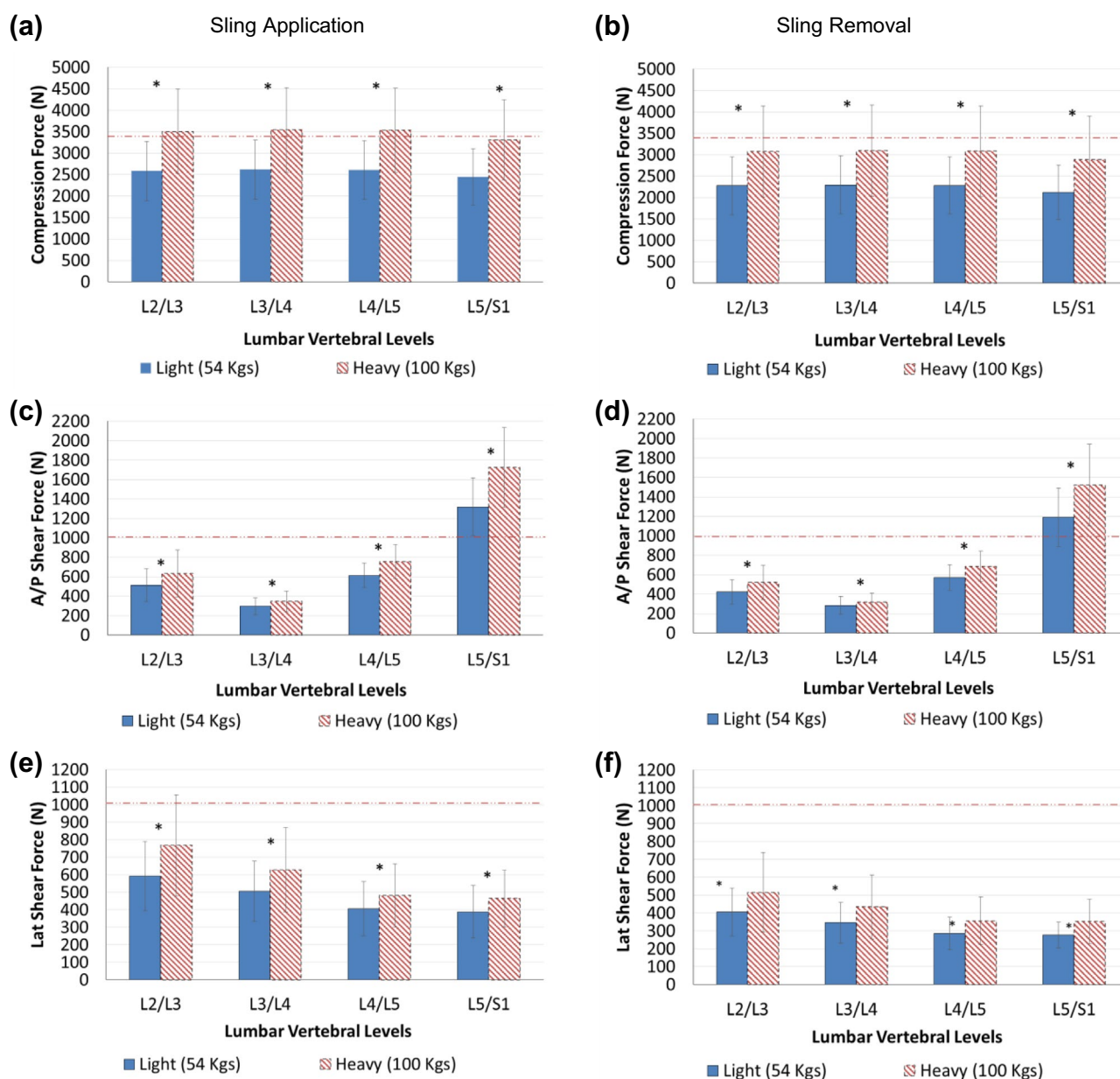
(a) Sling Application

(b) Sling Removal

(c)

(d)

(e)

(f)

Figure 2. The averaged peak spine compression, A/P shear and lateral shear forces as a function of vertebral level, patient weight and task (sling application vs. removal). An '*' next to the bars indicates significant differences ($p < .05$) due to patient weight. Dashed lines represent recommended tolerance limits for these measures. (a) Compression sling application, (b) Compression sling removal, (c) A/P shear sling application, (d) A/P shear sling removal, (e) Lateral shear sling application, and (f) Lateral shear sling removal.

Effects of bed height

There were several significant differences between the bed height conditions for the means of the peak compression, A/P shear and lateral shear forces which occurred during the sling application and removal tasks. For the compression forces, each incremental increase bed height tested resulted in statistically significant decreases in the compression force at all disc levels in both the sling application and removal tasks (Figure 3(a) and (b)). With each change in the bed height level, compression forces changed by 300–400 N for the sling application task and by 500–600 N for the sling removal task.

During sling application, means of the A/P shear force peaks were significantly reduced at the knuckle (71 cm) height bed as compared with the 56-cm bed height for all disc levels except L2/L3 and further reduced when the bed height was further increased to 93 cm (Figure 3(c)). Similar trends were seen for the A/P shear forces during sling removal (Figure 3(d)).

Relative to the trends encountered for the compression and A/P shear forces, the means of the peak lateral shear forces during the sling application task were significantly lower for the lowest bed height. On average, the
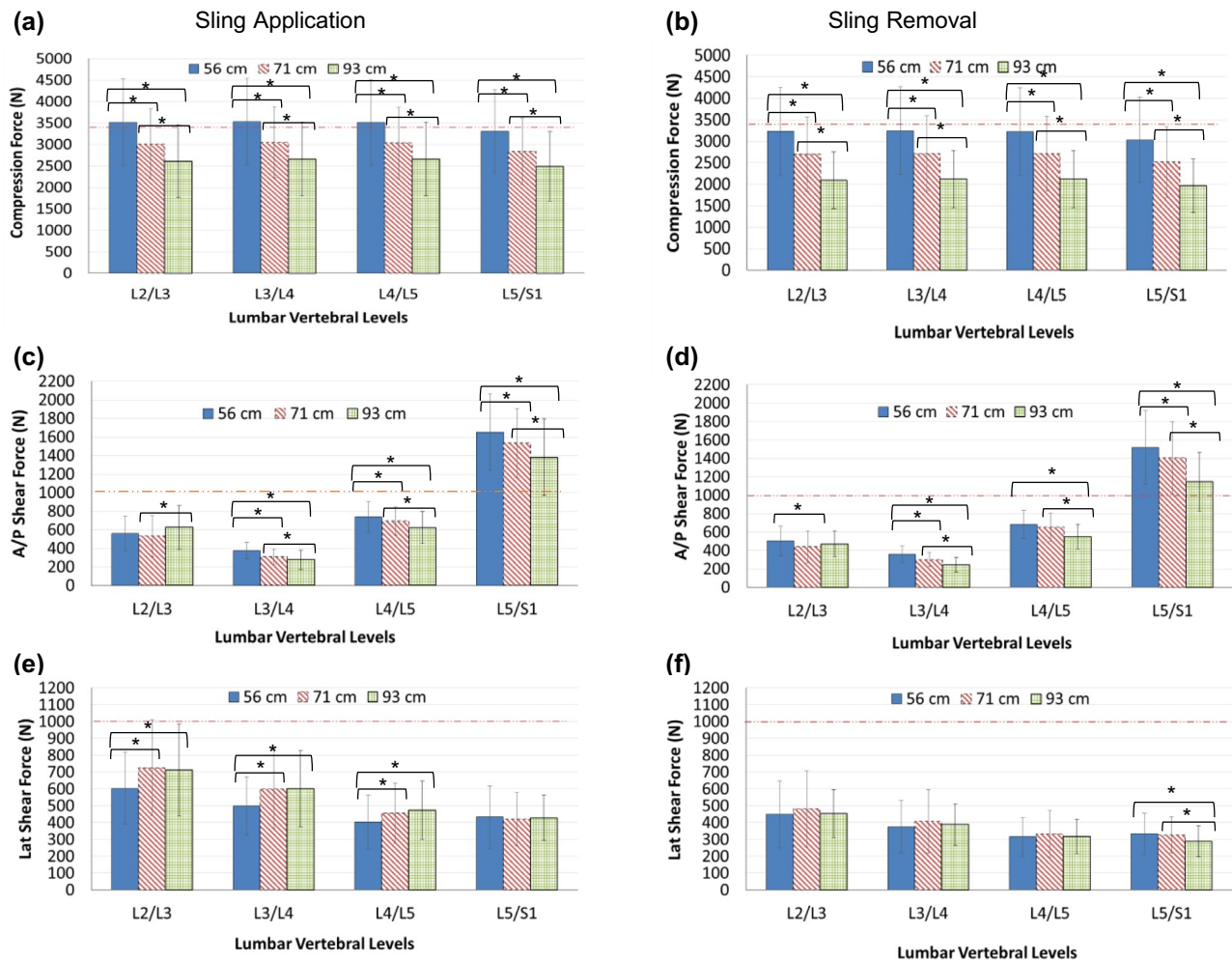
Figure 3. The averaged peak spine compression, A/P shear and lateral shear forces as a function of vertebral level, bed height and task (sling application vs. removal). Dashed lines represent recommended tolerance limits for these measures. Significant differences ($p < .05$) between bed height conditions are noted on the figures. (a) Compression sling application, (b) Compression sling removal, (c) A/P shear sling application, (d) A/P shear sling removal, (e) Lateral shear sling application, and (f) Lateral shear sling removal.

lateral shear only increased by approximately 100 N as bed height increased from 56 cm to the knuckle height for sling application (Figure 3(e)). There were no significant changes between knuckle height and the 93-cm level. However, for sling removal, the 93-cm bed height resulted in the lowest lateral shear force on the L5/S1 disc (Figure 3(f)).

Effects of sling application method

There were no differences in the compression forces as a function of the method used for sling application (Figure 4(a)). The A/P shear forces at the more superior disc levels were lower using the one-sided method during sling application (Figure 4(c)). On average, these differences between methods were less than 100 N. The significant method by bed height interaction for the sling application shows that for the L2/L3 disc level, the anterior shear forces using the

one-sided method were only lower than the two-sided method at 56 cm and knuckle height bed level. As for the lateral shear, the one-sided sling application generated more lateral shear loading in the L2/L3 and L3/L4 disc levels than the two-sided method (Figure 4(e)). This difference was of the order of 100–150 N.

For sling removal, the one-sided method yielded lower compression and A/P forces at all lumbar disc levels (Figures 4(b) and (d)). On average, the magnitude of the difference in compression force was approximately 300 N and approximately 100 N for the A/P shear force, except for L5/S1. The method by bed height interaction indicates that lower anterior shear forces were only found for the one-sided method at the L2/L3 disc level when the bed height was 56 cm or at knuckle height (average 71 cm). The method used during the sling removal task did not affect the magnitude of the lateral shear forces at any of the disc levels (Figure 4(f)).
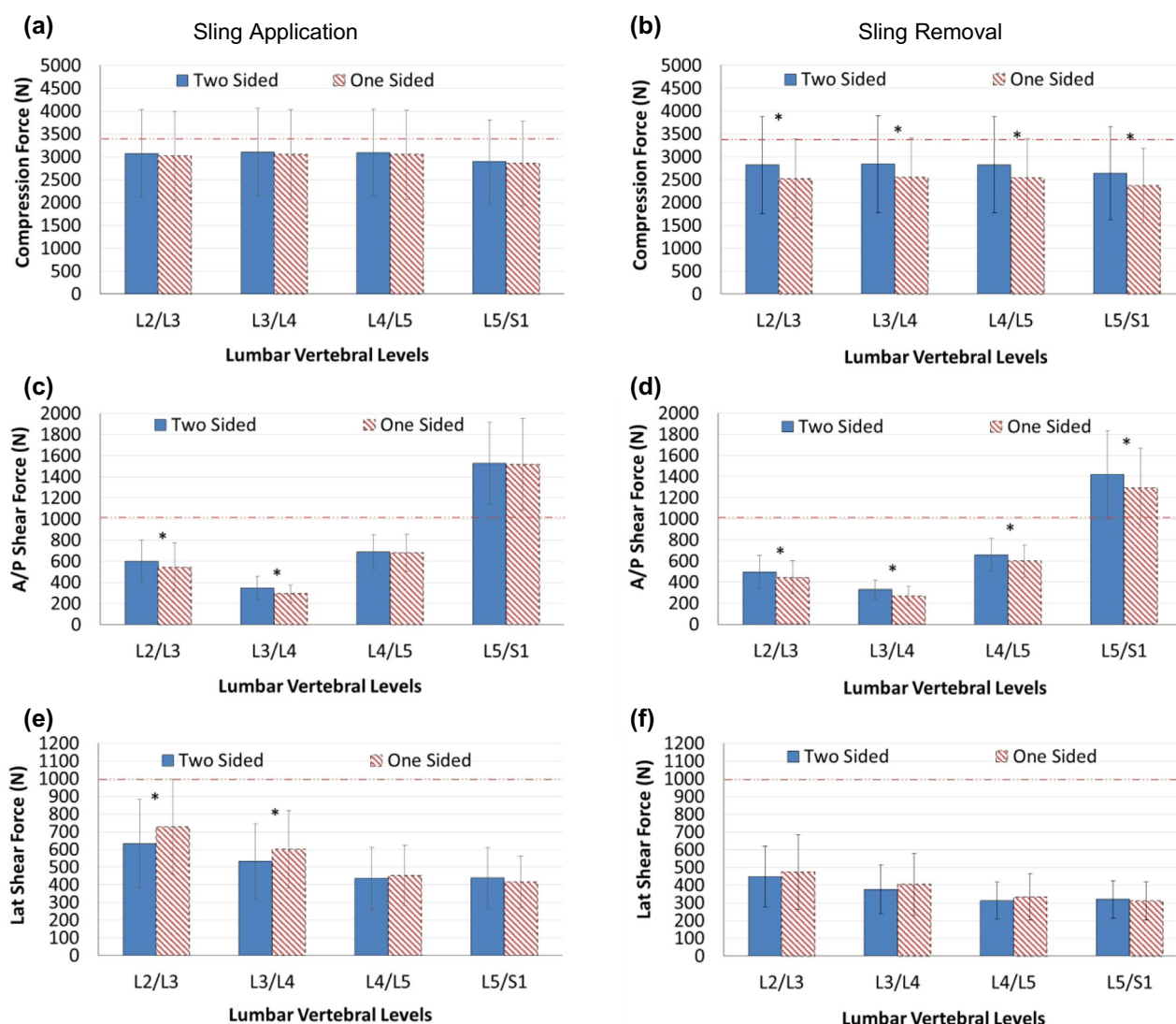
Figure 4. The averaged peak spine compression, A/P shear, and lateral shear forces as a function of vertebral level, method used (one sided vs. two sided), and task (sling application vs. removal). An '*' above the bars indicates significant differences ($p < .05$) due to the method. Dashed lines represent recommended tolerance limits for these measures. (a) Compression sling application, (b) Compression sling removal, (c) A/P shear sling application, (d) A/P shear sling removal, (e) Lateral shear sling application, and (f) Lateral shear sling removal.

Comparison with spine tolerance limits

The percentages of the sample that experienced loading which exceeded the tolerance limits of 3400 N for compression force and 1000 N for shear force during the sling application and removal tasks as a function of patient weight and bed height are shown in Figure 5. The compression at L4/L5, the A/P shear at L5/S1 disc levels, and to a much smaller degree, the lateral shear L2/L3 are the locations where these loading components would most likely to exceed the exposure tolerance levels. In particular, during the sling application and removal tasks for the heavier patient at the low bed height, 64% of the subjects experienced loading that exceeded the threshold values

for L4/L5 compression tolerance (Figure 5(a)). All participants exceeded the A/P shear tolerance of 1000 N at the L5/S1 level for the sling application task with the 100-kg patient irrespective of bed height (Figure 5(c)), in at the lowest bed height with the 54-kg patient. Likewise, during sling removal, the A/P shear exceed the 1000 N tolerance threshold for the majority of the participants in all conditions except the 93-cm bed height with the 54-kg patient (Figure 5(d)). Overall, only a small percentage of the participants exceeded the 1000 N threshold for the lateral shear force, which primarily occurred during the sling application task with the 100-kg patient at the knuckle height bed level (Figure 5(e)).
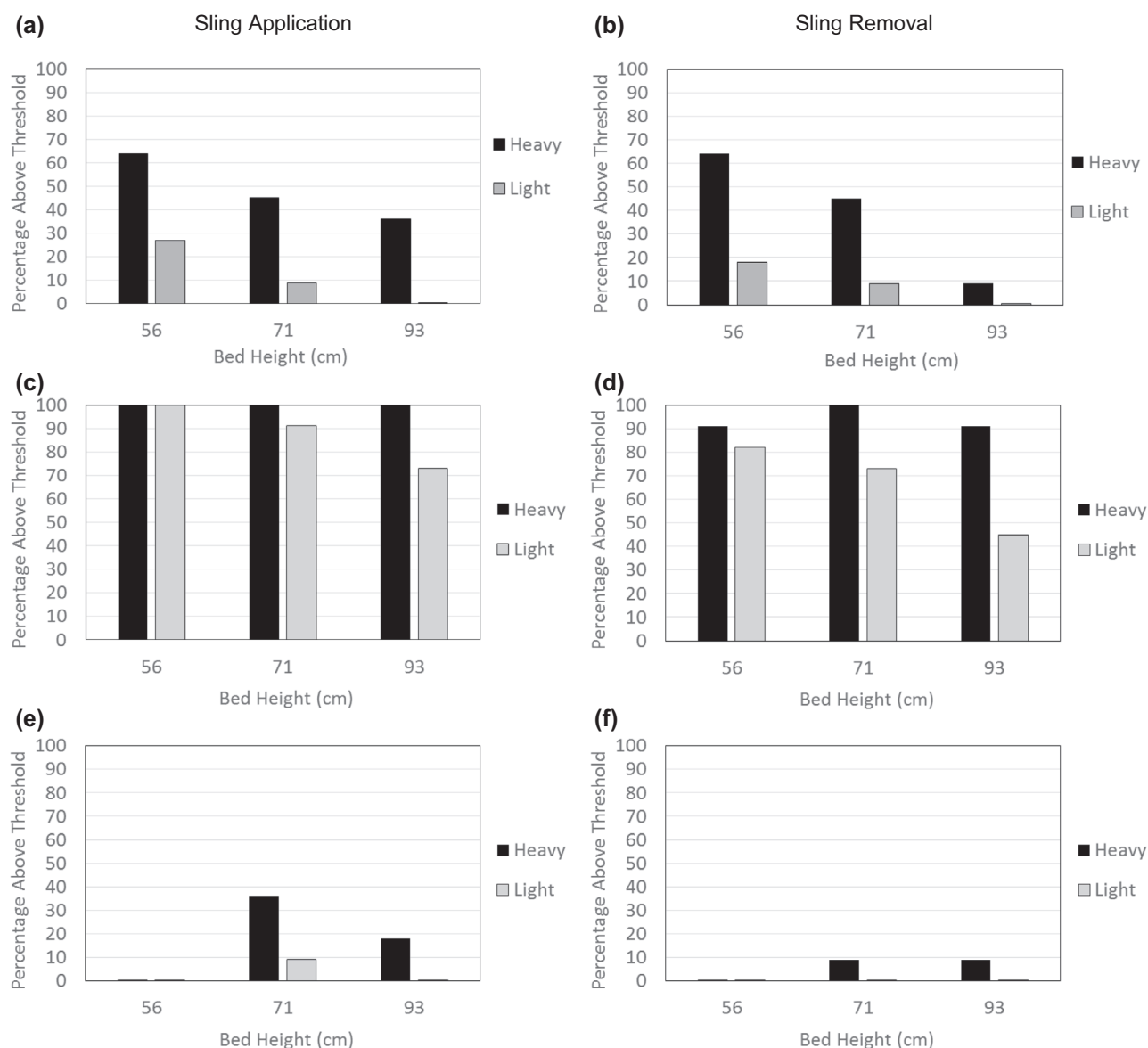
(a) Sling Application

(b) Sling Removal

(c)

(d)

(e)

(f)

Figure 5. The percentage of observations exceeding the compression threshold of 3400 N and the shear force threshold of 1000 N during sling application and removal as a function of the three bed heights and the two patient weights tested. (a) Compression sling application, (b) Compression sling removal, (c) A/P shear sling application, (d) A/P shear sling removal, (e) Lateral shear sling application, and (f) Lateral shear sling removal.

Discussion

One of the primary objectives of this study was to quantify the biomechanical loads on the spine in all three directions of loading and compare these measures against the tolerance threshold limits for vertebral endplate damage initiation. Overall, the mean compression at all the lumbar vertebral levels for the sling removal remained under the recommended threshold value of 3400 N. However, with the sling application task, the mean compression value across subjects, with the heavier patient, exceeded the 3400 N threshold level at several vertebral endplate levels. A/P shear loading at the L5/S1 level consistently exceeded the upper threshold limit of 1000 N for shear loading. It

should also be noted that there was considerable variability across this sample of female participants in their estimated spinal loads. The standard deviations shown in the Figures 2–4, and charts presented in Figure 5 show that there were many conditions where the disc tolerance thresholds for compression and shear were exceeded by at least part of the sample. However, the tolerance for the A/P shear forces at the L5/S1 disc level was exceeded under all conditions. In sum, these data signify the risk of initiation of low back pain through endplate damage is possible with the sling application and removal process.

The higher patient weight significantly increased compression, A/P shear and lateral shear loading. This might

be related to the increased demand on the nurse in terms of weight that was to be pushed or pulled while rolling the patient. Further, with the heavier patient there was an increase in the weight that was to be lifted while placing the leg supports of the sling under the patient's legs. Marras, Knapik, and Ferguson (2009) found increased shear loading with increased patient weight when lift systems with loaded slings were pushed. To put these findings regarding patient weight in perspective, the weight of the heavier patient used in the study was only slightly higher than the average US male weight for an adult, 20 years or older, as stipulated by the Centers for Disease Control and Prevention (Fryar, Gu, and Ogden 2012). Given the magnitude of the differences between the 54-kg and the 100-kg patients in this study, a large percentage of the US male patient population could be expected to generate substantially larger spine loads in their care givers during similar sling placement and removal tasks.

The activity of sling application had significantly higher compression, A/P shear and lateral shear loading than the activity of sling removal. This can be attributed to the greater accuracy and thoroughness that the sling application task demands. The nurses had to roll the patients and hold them steadily on their sides with one hand as they spread the sling on the bed with the other hand. The back of the sling needed to be properly spread under the patient while ensuring that the centre of the sling back aligns with the spine of the patients. The tasks demands were also high when the nurse put the leg supports of the sling under the legs of the patient. In contrast, the sling removal required the rolling of the patient only enough to allow the sling to be grabbed and pulled out swiftly, reducing the need for a more sustained exertion of push or pull forces by the nurse. Also with the sling removal, the nurses did not need to lift the legs of the patient to remove the leg supports, which also further reduced exertion demands for the sling removal activity. Thus, it may be advised that the nurses exercise extra awareness during the sling application than the removal with regards to body postures and ergonomics.

When applying the sling, the peak compression, A/P shear and lateral shear forces significantly varied with bed height. Similarly, during sling removal compression and A/P shear varied significantly with changes in bed height. de Looze et al. (1994) also reported decreased time-integrated compression and shear values when rolling patients in bed at self-selected bed heights (which averaged 77.5 cm) as compared with the 'standard' bed height of 71.5 cm. Varying the bed height varied the postural demands on the nurses and modified the ergonomics in terms of reach distance, hand-force application height and the forward external moment on the spine. The largest compression and A/P shear loading, which was observed

at the lowest bed height, could be attributed to increased spine flexion during the sling application and removal tasks. Santaguida et al. (2005) reported that in the sling application activity, spine loading for the nurses happened 'in a manner similar to 45 degree leaning'. There was generally a linear reduction of spine loading magnitude with the stepwise increase in bed height.

The two-sided and one-sided sling application and removal methods differed in two ways. First, the two-sided method replaced the pulling exertion in the one-sided method with an additional pushing task. Second, with the two-sided method the nurses needed to pull the railings up on the first side of the bed and put them down on the second side of the bed before rolling the patient from the other side. This was imperative as it prevented the patients from falling off of the bed during the rolling activity. Observation of the temporal characteristics of loading in this method showed that there were peaks in compression, A/P shear and lateral shear loading as the nurses operated the railings with flexed and laterally bent spine postures. However, this is a specific characteristic of the operation of the bed used in the study, as the handles for the operation of railings were set very low. Further observation of temporal characteristics of the loading in both the sling application methods showed equivalent spine compression and shear forces for both the pushing and pulling tasks involved in rolling the patients. Thus, loading in either method seemed to occur as a systemic effect of the different tasks involved in the methods. Loading estimation for individual tasks within each method was not done in this study. But, this allowed for a realistic replication of the sling application process in the laboratory.

Earlier studies that investigated loading on the spine during patient rolling activities as part of the patient preparation phase published loading measures related to the L5/S1 joint. The compression forces at the L5/S1 joint for patient rolling 'towards' the nurse and 'away' from the nurse were estimated in the ranges of 2094–4367 N and 1804–4745 N, respectively (Zhuang et al. 1999). However, this study utilised a static biomechanical model to arrive at the loading measures. In the present study, the compression forces ranged from 1340 to 4535 N. This range of forces is similar, therein suggesting that there were limited dynamic influences in this task. Skotte (2001), when including the bedside reaction force in the biomechanical model, found lower peak moments at L4/L5 when rolling the patient towards the caregiver versus rolling the patient away from the caregiver. Another study estimated the loading at the L5/S1 joint during the sling application activity to be a compression of only 1400 N (Santaguida et al. 2005). The same authors reported shear loads of only 250–300 N (Santaguida et al. 2005). In contrast, the shear

loads reported in the present study ranged from 200 to 2130 N. This difference in shear loading could be attributed to the model used for the study which has taken into account the geometric orientations of the sampled muscles, therein providing force vectors where the shear forces can accurately be represented (Marras et al. 2001).

Study recommendations

This study evaluated bed heights of 56 cm, knuckle height (mean = 71 cm) and 93 cm. With the exception of the A/P shear loading on the L5/S1 level, the maintenance of bed height at the knuckle level or higher was shown to lower spine loads below the tolerance thresholds. Caboor et al. (2000) noted that when nurses were given an opportunity to adjust bed height, a standard deviation of only 6.4 cm was observed over a pre-set height of 51.5 cm. Further, another study reported a standard recommended height level of 71.5 cm from the floor to the top of the mattress (De Looze et al. 1998). Thus, an objective workplace recommendation can be made for patient beds to be adjusted in height, at least to knuckle height, based on the observations of this study. There is a possibility of greater loading in the shoulders and arms when a bed height of 93 cm is used. However, this was not assessed in this study.

The loading scenario that was seen in this study may be altered when two nursing personnel work cooperatively to apply and remove patient slings. It was not possible to design this study so that the sling application can be compared between a one-nurse method and a method involving two nurses. However, it can be expected that inclusion of a second nurse in the process could potentially reduce the applied forces, depending upon how the team coordinates their activities during this task. Marras et al. (1999) showed that, with a two-person manual transfer, the compression and lateral shear forces were consistently reduced as compared to a one-person transfer process. From an administrative perspective, the allocation of a second nursing personnel for the sling application process may be recommended.

Study limitations

One of the limitations of this study was that all the subjects recruited were female. As such, there was no opportunity to understand the loading scenario for a male spine for the activities being studied. However, since census statistics suggest that only nine per cent of the total nursing personnel are men, the results of this study are reasonably sufficient to represent the general nursing population (U.S. Census Bureau 2013). As mentioned above, another limitation for this study was the utilisation of only one nurse for the sling application/removal tasks. Future research should

need to address the spine loading when two nurses apply and remove slings. Finally, the findings of this study are generalisable to the nursing population within the confines of the conditions employed in this study. The measures obtained may vary depending on the type of sling, bed or other equipment used. However, efforts have been made to design the study to be consistent with pre-study work observations so that the study was representative of the sling application and removal tasks that nurses can expect to encounter.

Conclusion

This study found that the A/P shear at the L5/S1 were greater than the spine tolerance threshold limits of 1000 N suggested in the literature for non-repetitive lifting (Gallagher and Marras 2012). Compression forces exceeded the tolerance threshold of 3400 N (NIOSH 1981) for the heavier patient condition and the lowest bed height condition. The loading along the three dimensions consistently increased with patient weight for both the sling application and removal. Compression and A/P shear showed significant decrease in magnitude as bed height increased, therein suggesting that nurses should be trained to raise the bed to at least knuckle height prior to working with the sling. Changing the method of sling application and removal from a one-sided method to a two-sided method has shown only a slight increase in the compression and A/P shear and a slight decrease in the lateral shear. Thus, this alternative technique cannot be recommended. Finally, given that the loads were generally higher during the sling application, as opposed to its removal, it would be more important for nurses to seek assistance during the application task, particularly with heavy patients.

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