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A comprehensive analysis of low-back disorder risk and spinal loading during the transferring and repositioning of patients using different techniques

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Although patient handlers suffer from low-back injuries at an alarming rate worldwide, there has been limited research quantifying the risk for the specific tasks performed by the patient handlers. The current study used both a comprehensive evaluation system (low-back disorder risk model) and theoretical model (biomechanical spinal loading model) to evaluate risk of LBD of 17 participants (12 experienced and five inexperienced) performing several patient handling tasks. Eight of the participants were female and nine were male. Several patient transfers were evaluated as well as repositioning of the patient in bed; these were performed with one and two people. The patient transfers were between bed and wheelchair (fixed and removable arms) and between commode chair and hospital chair. A 'standard' patient (a 50 kg co-operative female; non-weight bearing but had use of upper body) was used in all patient handling tasks. Overall, patient handling was found to be an extremely hazardous job that had substantial risk of causing a low-back injury whether with one or two patient handlers. The greatest risk was associated with the one-person transferring techniques with the actual task being performed having a limited effect. The repositioning techniques were found to have significant risk of LBD associated with them with the single hook method having the highest LBD risk and spinal loads that exceeded the tolerance limits (worst patient handling job). The two-person draw sheet repositioning technique had the lowest LBD risk and spinal loads but still had relatively high spinal loads and LBD risk. Thus, even the safest of tasks (of the tasks evaluated in this study) had significant risk. Additionally, the current study represented a 'best' case scenario since the patient was relatively light and co-operative. Thus, patient handling in real situations such as in a nursing home, would be expected to be worse. Therefore, to have an impact on LBD, it is necessary to provide mechanical lift assist devices.

1. Introduction

While LBD affects the population as a whole, patient handlers have been particularly susceptible to LBD problems. Within the nursing profession, Jensen (1987) found that nurses' aides had the highest incidence of disabling back injuries in the USA. The incidence rate for nurses' aides was higher than the more traditional heavy physical occupations such as construction workers and garbage collectors. In addition to nurses' aides, both the licensed practical nurses and registered nurses had incidence rates similar to that of construction workers and garbage collectors. Klein

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et al. (1984) found that the nurses' aides accounted for 3.6 worker compensation claims due to back injuries per 100 workers, which was higher than for material handlers (3.4) and construction workers (2.8). Between 1992 and 1994, patient handlers in nursing homes had the fifth highest incidence rates in the State of Washington (13.77 cases per 100 full time workers) (Washington State Department of Labor and Industries 1996). Fuortes *et al.* (1994) found that nurses' aides were more than three times as likely to suffer a low-back injury compared to registered nurses. Garg and Owen (1992) estimated the incidence rate of LBD to be 83 per 200 000 work-hours for nursing personnel in the USA. Workers in the nursing home portion of the health care sector have had increasingly higher back injury rates, which is most likely a result of the high proportion of nursing aides (Personick 1990).

Patient transfers have been found to be the task that is associated with most low-back injuries suffered by nursing aides (Videman *et al.* 1984, Harber *et al.* 1985, Venning *et al.* 1987, Stobbe *et al.* 1988, Estryn-Behar *et al.* 1990, Owen *et al.* 1992, Fuortes *et al.* 1994, Smedley *et al.* 1995, Yassi *et al.* 1995, Knibbe and Friele 1996). Among the more frequently reported tasks are adjusting the patient in bed (31.7%), transferring the patient from bed to wheelchair or vice versa (21.6%), and chair to toilet (2.2%) (Knibbe and Friele 1996). Similarly, Vasiliadou *et al.* (1995) found that moving patients in bed and transferring patients out of bed were responsible for 29% and 24% of the low-back injuries, respectively. Furthermore, Owen *et al.* (1992) and Garg and Owen (1992) found that patient transfers were perceived to be the most stressful tasks that nurses' aides performed while repositioning the patient in bed had the next highest perceived stress.

While LBD has been associated with the tasks performed by the patient handlers, few researchers have evaluated the various tasks performed by patient handlers biomechanically. Garg *et al.* (1991a, b) evaluated transferring patients from bed to wheelchair (and vice versa) and from wheelchair to shower chair (and vice versa). Similarly, Garg and Owen (1994) evaluated patient transfers from wheelchair to toilet and vice versa. These studies used static estimations of the compressive loads on the spine to evaluate one-person versus two-person lifting. These authors found that pulling the patient with either one or two patient handlers had lower compression loads than when lifting the patients with two people. The pulling methods required the patients to be able to support their own weight, a situation that is not always common place in nursing homes and chronic care facilities. Furthermore, Owen *et al.* (1992) found that the compression forces were substantial during the transferring of patients (bed to/from wheelchair and toilet to/from wheelchair), loads on average being more than 3600 N. The repositioning of the patient in bed was found to be drastically lower, only 107 N.

Garg and Owen (1992) found the values of the static computed compression loads for patient transfers were 4751 N, considerably higher than recommended spinal tolerances (NIOSH 1981). Thus, these results indicate that the transferring of patients would be associated with significant risk of LBD if no intervention was introduced. Winkelmolen *et al.* (1994) evaluated various lifting techniques through the two-dimensional static model. In general, all the lifting techniques evaluated had substantial static compressive load (greater than 3315 N). These authors also only evaluated two-person transfers.

All of the previous biomechanical evaluations of patient transfer methods used static loading models that neglect the effects of motion on the internal loads. This may under-predict compression by as much as 22.5 to 60% (Marras and Sommerich

1991a). This under-prediction occurs due to a lack of consideration for the dynamic loading and coactive nature of the multiple muscle system. Granata and Marras (1995b) found that neglecting coactivity in a spinal load model could underpredict shear loads by 70% and compression loads by 45%. The lack of coactivity accountability would represent a non-realistic situation in the evaluation of tasks that are as complex as transferring patients for two reasons. First, it would be expected that individual patient handlers would use different methods resulting in different muscle activity patterns. Next, when the force level approaches the limits of the extensor muscles (erector spinae muscles), other trunk muscles (internal obliques) must begin to exert in order to generate the additional force. The lifting of patients would probably require the recruiting of muscles other than the primary extensors. Therefore, the estimation of the spinal loads would only be realistic when predicted by a model that considers coactivity. Another problem associated with the models used to evaluate patient handling is the estimation of the external moment. Since the patient can be partially supported by the bed and other hospital furniture, the actual moment lifted would be unknown. However, the calibrated EMG-assisted model would allow these moments to be predicted by using the muscle activities and known muscle parameters (muscle moment arm, cross-sectional area, etc.).

Hence, the objectives of the study were to identify the nature and range of low-back spinal forces and risk of low-back disorder associated with the various patient handling tasks and patient handling techniques that are commonly used in patient care facilities. Specifically, the tasks previously identified as problematic were evaluated. These included the transferring of patients between hospital furniture (bed and wheelchair, commode chair and hospital room chair) as well as the repositioning of the patient in bed. These transfers were performed by either one person or two people. The two-person transfers were executed using either a hook or gait belt technique.

2. Methods

2.1. *Subjects*

A total of 17 participants (12 experienced and five inexperienced) volunteered to perform the patient transferring tasks. The inexperienced participants consisted of two females and three males while gender breakdown for the experienced participants was six females and six males. None of the participants were experiencing low-back pain. The experienced participants were current patient handlers at a large local long-term care complex. Their job experience ranged from 9 months to 21 years. The mean (SD) age, weight, and height for the experienced participants were 32.6 (7.4) years, 77.3 (24.5) kg, and 173.4 (13.1) cm, respectively, while for the inexperienced participants these were 24.0 (3.5) years, 65.9 (5.7) kg, and 172.2 (9.2) cm, respectively. The inexperienced participants were college student volunteers. The participants were paired as they volunteered for the study and no attempt was made to match height or gender.

2.2. *Study design*

The experimental tasks in this study consisted of patient handling performed under various conditions that are common in patient care facilities. Subjects were asked to simply lift a 'patient' using different patient handling techniques as they would in their work environment. In general, the most routinely performed tasks were evaluated in this study. The study consisted of two portions. First, the participants performed patient transfers using one of three transfer techniques while performing six different tasks (table 1). Notice, two types of wheelchairs were evaluated, one with fixed arms and one with removable arms where one arm was removed. It was hypothesized that the removal of the wheelchair arm would reduce the LBD risk and spinal loads by eliminating any obstruction to the transfer. The bed remained at a constant height throughout the study (58 cm). Each task was analysed by separating the lifting and lowering phases of the task (hereafter referred to as sub-tasks) by including a time marker administrated by one of the experimenters. The evaluation of the sub-tasks allowed for the gathering of more detailed information about the risk of the various transfer tasks. Thus, the experiment evaluated various combinations of the transfer techniques, transfer tasks, and the various sub-tasks (lifting versus lowering) (table 1). Figure 1 shows the three transfer techniques while transferring the 'standard' patient from the bed to the wheelchair.

The second portion of the study consisted of repositioning the 'standard' patient in the bed. Four different techniques were used to reposition the patient. These were the manual one-person hook method, manual two-person hook method, manual two-person using draw sheet, and manual two-person lifting under the thigh and shoulders. Again, for the manual two-person methods, the participants performed the lifts on both the left and right side of the 'standard' patient. Figure 2 shows the four techniques for repositioning the 'standard' patient on the bed.

2.3. *The 'standard' patient*

The 'standard' patient was a 50 kg female who served as the patient for the entire study. The 'standard' patient maintained a standard level of dependency, one who has total dependency (non-weight bearing) but capable of arm support and can follow basic instructions. The use of a 'standard' patient reduced the risk of injury due to unexpected loading conditions that commonly occur in an actual nursing home setting. Additionally, having a 'medium' size female reduced the chances of

Table 1. Description of the study conditions for the transferring of the patient.

		Transfer task					
Trasfer method	Side of the body that patient handler lifted	Bed to wheel-chair with arms	Wheel-chair with arms to bed	Bed to wheel-chair with one arm removed	Wheel-chair with one arm removed to bed	Commode chair to hospital room chair	Hospital room chair to commode chair
One-person hug	Centre	*	*	*	*	*	*
Two-person hook and toss	Right	*	*	*	*	*	*
Two-person hook and toss	Left	*	*	*	*	*	*
Two-person gait belt	Right	*	*	*	*	*	*
Two-person gait belt	Left	*	*	*	*	*	*

*Indicates that the patient handlers used the indicated transfer method to move the patient between the specified hospital furniture.

fatigue due to performing the numerous lifts during the study. Thus, the results of this study would be considered a 'best case' scenario.

2.4. *Dependent measures*

The dependent variables were categorized into two separate groups. First, the 'probability of membership in the high risk low-back disorder group' (hereafter referred to as 'LBD risk') was evaluated for each combination of the independent variables. The LBD risk was an index that incorporated various kinematic and workplace variables through logistic regression methods (Marras *et al*. 1993, 1995). Five variables, collectively, were found to be the best predictor of high-risk group membership. These were maximum sagittal flexion position, lift rate, maximum external moment, maximum lateral velocity, and average twisting velocity.

Second, spinal loading and predicted spinal supported moments were evaluated using an EMG-assisted biomechanical model that has been developed at the

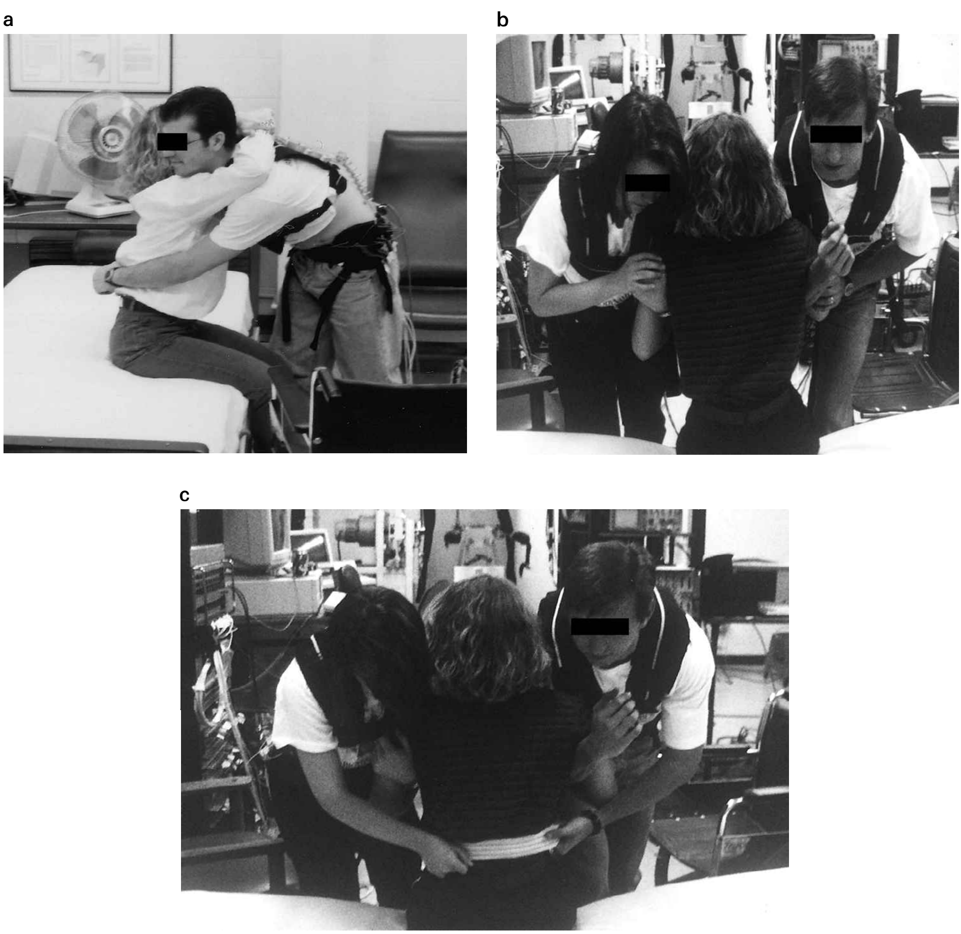

Figure 1. Subjects performing the three transfer techniques: (a) Manual one-person hug method, (b) Manual two-person hook and toss method, (c) Manual two-person gait belt method, while transferring the 'standard' patient from the bed to the wheelchair.

Biodynamics Laboratory over the past 12 years (Marras and Reilly 1988, Reilly and Marras 1989, Marras and Sommerich 1991a, b, Granata and Marras 1993, 1995a, b, Mirka and Marras 1993, Marras and Granata 1995, 1997, Davis *et al.* 1998). The model has been validated under forward trunk bending motions (Marras and Sommerich 1991a, b, Granata and Marras 1993, 1995a, b), trunk twisting motions (Marras and Granata 1995), lateral bending motions (Marras and Granata 1997), and lowering tasks (Davis *et al.* 1998). The spinal loads estimated in this study were the maximum values of compression force, anterior–posterior shear and lateral shear forces on the lower-back at the lumbosacral joint (L5/S1).

2.5. *Apparatus*

The Lumbar Motion Monitor (LMM) was used to collect the trunk motion variables. The LMM is essentially an exoskeleton of the spine in the form of a triaxial electrogoniometer that measures instantaneous three-dimensional position, velocity, and acceleration of the trunk. The design of the LMM allowed the data to be collected with minimal obstruction to the participant's movements. For more information on the design, accuracy, and application of the LMM, refer to Marras *et al.* (1992).

Electromyographic (EMG) activity was collected through the use of bi-polar electrodes spaced approximately 3 cm apart at the 10 major trunk muscle sites. The

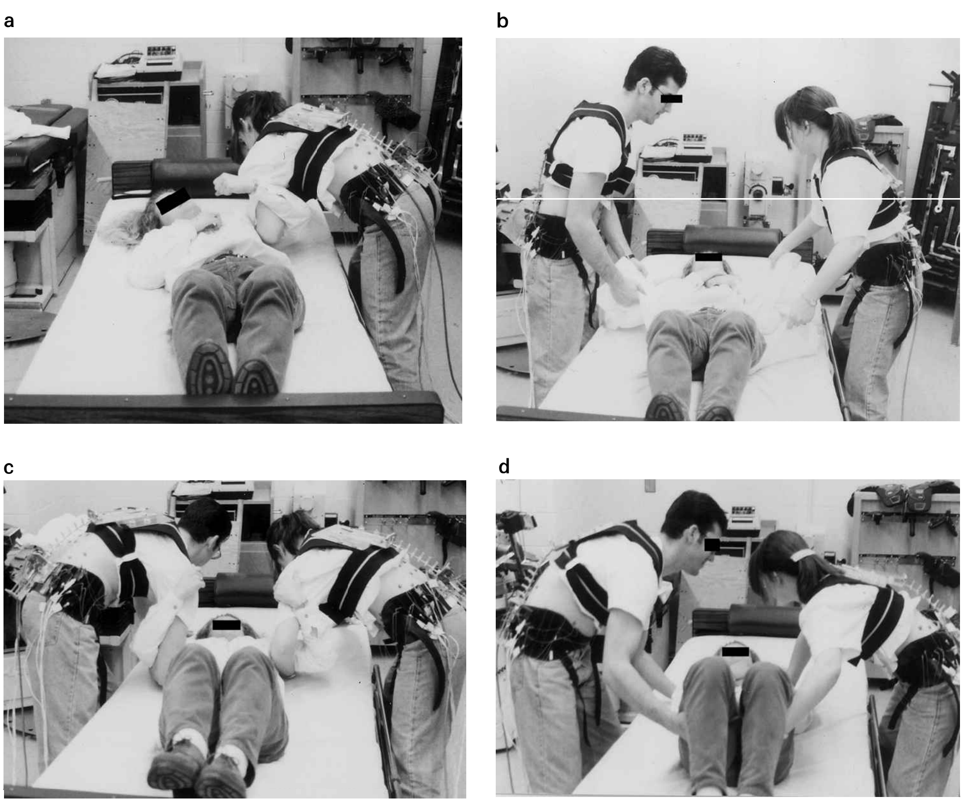

Figure 2. Subjects performing the four repositioning techniques: (a) Manual one-person hook method, (b) Manual two-person draw sheet method, (c) Manual two-person hook method, (d) Manual two-person thigh and shoulder method.

10 muscles of interest were: right and left erector spinae; right and left latissimus dorsi; right and left internal obliques; right and left external obliques; and right and left rectus abdominis. Standard locations of electrode placement for these muscles are described in Mirka and Marras (1993). The EMG-assisted biomechanical model used to estimate spinal loading requires calibration exertions using a force plate (Bertec 4060A, Worthington, OH) and an L_5/S_1 locator (Fathallah *et al.* 1997).

All signals from the aforementioned equipment were collected simultaneously through customized Windows™-based software developed in the Biodynamics Laboratory. The signals were collected at 100 Hz and recorded on a 486 portable computer via an analogue-to-digital board.

2.6. *Procedure*

Upon arriving at the Biodynamics Laboratory, participants were given a brief description of the study and tasks that they were asked to perform. Next, anthropometric measurements were taken. Subjects read and signed a consent form. The participants performed both portions of the study on the same day (patient transfers first, repositioning of patient second). The order of the transfer tasks in the first part of the study was randomized within a given transfer technique condition. Similarly, in the second part of the study, the order of the repositioning techniques was randomized.

The surface electrodes were applied using standard placement procedures to sample the muscles of interest (NIOSH 1992). The participant then was placed into a structure that allowed maximum exertions to be performed in six directions, while participants performed the static exertions. These maxima were performed to allow all subsequent EMG data to be normalized (Mirka and Marras 1993). After each maximum exertion, 2 min of rest was given to reduce the effects of fatigue (Caldwell *et al.* 1974).

Before starting the first set of lifting conditions, the participant completed a set of calibration lifts. Using methods developed by Fathallah *et al.* (1997), the participant-specific muscle gain was determined. The magnitude of the muscle gain represents the force output of the muscle per cross-sectional unit area for that particular participant. This gain factor was then used to calculate the internal moments and forces for the experimental task to allow the participants to move without being restricted to a force plate.

After completing the set of calibrations, the participants performed the various combinations of transfer techniques and transfer tasks (in random order). Simple instructions were provided about the transfer technique but the participants were allowed to alter the technique to fit personal preference. The bed, wheelchairs (with and without arms), commode chair and hospital room chair were all of standard design that is typically found and used in a hospital or nursing home setting. Thus, the laboratory simulation represented a ‘realistic’ task as much as possible. Upon completion of the transferring tasks, the patient handlers completed the repositioning conditions that were also done in random order.

2.7. *Data analyses*

The kinematic data and external moments were used to calculate probability of high-risk group membership (LBD risk) based on a multiple logistic regression equation developed by Marras *et al.* (1993). Since external moment estimation is problematic in team lifting and in situations where the patient’s body weight might be partially supported by the various hospital furniture, the trunk moment predicted by the EMG-assisted model served as the 'best' representative of the maximum moment. A pilot study that estimated the maximum moment using the method of Marras *et al.* (1993) indicated that these estimates were reasonable.

The raw EMG signals were pre-amplified, high-pass filtered at 30 Hz, low-pass filtered at 1000 Hz, rectified, and integrated via a 20 ms sliding window hardware filter. The EMG and kinematic data were imported into the EMG-assisted model to calculate spinal forces and moments on the lumbosacral joint (L5/S1).

Univariate descriptive statistics were performed to determine the mean and standard deviations for each of the combinations of the independent variables that were of interest. The dependent measures were evaluated for the various transfer techniques and transfer tasks using the Fisher's least significant difference (LSD) multiple pairwise comparisons method. The various multiple comparisons were tested using an error term that accounted for participant variability due to the nested design (participant nested in the various effects). These error terms were computed by multiple analysis of variance (ANOVA) procedures that allowed the overall experimental error to be partitioned to the individual effects.

3. Results

3.1. *Transfer technique*

The probability of 'high' risk group membership (LBD risk) and three-dimensional spinal loads that were produced during the transfer techniques for the lifting and lowering phases are summarized in table 2. During both the lifting and lowering phases of the tasks, the single person hug method resulted in about 10% higher LBD risk, 300 to 400 N greater lateral shear force, and 1300 to 1700 N larger compression force than any of the two-person transferring techniques. During both phases of the transfer, the LBD risk and compression force for the left side two-person hook method was found to be significantly greater than any of the right side techniques (hook and gait belt). There was no significant difference between the left side transfer techniques.

Slightly different results were found for anterior-posterior (A-P) shear forces during the lifting and lowering phases of the tasks. The only difference in A-P shear force between the single person transfers (highest) and any of the two-person techniques involved the two-person hook method (lowest) when on the right side of the patient. There were no statistically significant differences between any of the two-person transferring techniques for A-P shear, as well as no difference in A-P shear was found for transfers that had the patient handlers on the left side and the single person transfers. Thus, the use of a gait belt for the two-person lifts would seem to reduce the loading only for the person that would be on the right side of the patient, while the person on the left side would have loading equivalent to the single person transfer.

3.2. *Transfer task*

The means (standard deviations) for LBD risk and three-dimensional spinal loads for the various transfer tasks that occurred during the lifting and lowering phases of the transfers are displayed in tables 3 and 4 for both the one-person and two-person transfers. Notice, the two-person transfer tasks had LBD risk values, lateral shear, and compression forces that were lower than the one-person transfers for all tasks for both the lifting and lowering phases. The trends found across the various transferring tasks, relative to the spine tolerance for compression are illustrated in figure 3, which shows the mean peak compression forces as a function of transfer

Table 2. Means (SD) of the probability of 'high' risk group membership and three-dimensional spinal loads as a function of transfer technique for the lifting and lowering phases of the tasks.

Transfer technique		Probability of 'high' risk group membership	Spinal loads: Maximum lateral shear force (N)	Spinal loads: Maximum A-P shear force (N)	Spinal loads: Maximum compression force (N)
			Lifting phase		
One-person					
	Hug	91.1 (18.5)^{C}	1060.7 (697.6)^{B}	908.5 (555.9)^{B}	6336.3 (2044)^{C}
Two-person					
Left side lifter	Hook	83.3 (23.0)^{B}	731.7 (442.6)^{A}	955.6 (436.5)^{B}	4948.2 (1598.6)^{B}
	Gait belt	82.1 (20.7)^{B}	702.6 (495.1)^{A}	916.7 (549.1)^{B}	4895.5 (1633.1)^{B}
Right side lifter	Hook	79.1 (24.1)^{A}	697.1 (435.8)^{A}	892.8 (495.6)^{A}	4455.8 (1539.9)^{A}
	Gait belt	79.0 (21.7)^{A}	664.2 (461.5)^{A}	985.7 (567.6)^{B}	4600.9 (1437.6)^{AB}
			Lowering phase		
One-person					
	Hug	90.5 (18)^{B}	1127.9 (621.6)^{B}	1111.69 (614.6)^{C}	6007.9 (1859.2)^{C}
Two-person					
Left side lifter	Hook	81.1 (24)^{A}	845.2 (489.0)^{A}	1020.8 (503.0)^{C}	4713.4 (1640.1)^{B}
	Gait belt	80.9 (22)^{A}	781.4 (506.1)^{A}	1005.4 (523.8)^{C}	4597.5 (1454.9)^{AB}
Right side lifter	Hook	77.1 (27)^{A}	830.4 (463.9)^{A}	935.6 (478.9)^{A}	4314.1 (1694.4)^{A}
	Gait belt	78.7 (24)^{A}	815.5 (469.8)^{A}	1097.4 (487.6)^{B}	4571.8 (1529.7)^{AB}

Different alpha characters indicate significant differences at $p = 0.05$.

tasks and number of people performing the transfers during the lifting phase of the transferring tasks. For the lifting phase of the one-person transfers, there was only minor differences in LBD risk between all transfer tasks, with lifting from the hospital chair having the highest LBD risk (96%) and compression force (6717 N). Lifting from the hospital chair also had the highest LBD risk and compression associated with it for the lifting phase of the two-person transfers (87% and 5178 N, respectively). The lowering of the patient to the hospital chair from the commode chair was also found to have the highest LBD risk and compression values.

During the lifting phase, no statistically significant differences in lateral shear force were found between the two-person transfer tasks but there were lateral shear differences between the various one-person transfer tasks. The only differences in lateral shear force during the lowering phase was found between the two-person transfers. The one-person transfers exceeded the two-person transfers by 245 to 557 N when lifting the patient and by 75 to 348 N during the lowering phase.

Table 3. Means (SDs) of the probability of 'high' risk group membership and three-dimensional spinal loads as a function of transfer task for the lifting phase of the tasks.

Transfer task	One-person transfers	Two-person transfers
Probability of 'high' risk group membership		
Lift from bed to wheelchair without an arm	91.4 (17.8)^{D}	81.3 (22.8)^{A}
Lift from wheelchair without an arm to bed	89.5 (21.2)^{DE}	82.3 (22.1)^{A}
Lift from bed to wheelchair	93.8 (12.6)^{D}	78.4 (23.5)^{AB}
Lift from wheelchair to bed	87.3 (22.4)^{DE}	79.4 (24.3)^{A}
Lift from hospital chair to commode chair	95.9 (8.7)^{F}	87.1 (16.7)^{C}
Lift from commode chair to hospital chair	88.8 (24.3)^{DE}	76.9 (23.8)^{B}
Lateral shear forces (N)		
Lift from bed to wheelchair without an arm	906.5 (625.5)^{B}	661.4 (389.1)^{A}
Lift from wheelchair without an arm to bed	1106.6 (531.4)^{C}	816.5 (590.5)^{A}
Lift from bed to wheelchair	935.8 (636.0)^{BC}	631.2 (383.6)^{A}
Lift from wheelchair to bed	1282.3 (874.0)^{C}	725.9 (456.2)^{A}
Lift from hospital chair to commode chair	1004.6 (773.2)^{BC}	696.7 (455.8)^{A}
Lift from commode chair to hospital chair	1134.0 (733.9)^{C}	662.1 (436.7)^{A}
Anterior-posterior shear forces (N)		
Lift from bed to wheelchair without an arm	874.6 (635.3)^{AB}	949.3 (553.8)^{B}
Lift from wheelchair without an arm to bed	775.8 (521.0)^{A}	963.6 (466.2)^{B}
Lift from bed to wheelchair	1115.9 (629.3)^{C}	964.6 (517.6)^{B}
Lift from wheelchair to bed	925.3 (520.1)^{B}	913.0 (450.8)^{B}
Lift from hospital chair to commode chair	990.0 (502.3)^{BC}	913.7 (544.7)^{B}
Lift from commode chair to hospital chair	776.2 (506.4)^{A}	921.7 (508.5)^{B}
Compression forces (N)		
Lift from bed to wheelchair without an arm	6420.6 (2165.4)^{D}	4760.1 (1541.1)^{B}
Lift from wheelchair without an arm to bed	6141.2 (2058.8)^{D}	4810.3 (1614.9)^{B}
Lift from bed to wheelchair	6408.3 (1947.2)^{D}	4578.1 (1601.5)^{AB}
Lift from wheelchair to bed	5964.0 (2161.3)^{D}	4556.6 (1574.0)^{AB}
Lift from hospital chair to commode chair	6717.6 (1562.6)^{E}	5178.1 (1509.3)^{C}
Lift from commode chair to hospital chair	6383.4 (2242.5)^{D}	4463.0 (1474.8)^{A}

Different alpha characters indicate significant difference at $p = 0.05$.

The peak A-P shear forces exceeded 775 N when lifting the patient from any of the furniture and 980 N when lowering the patient for one- and two-person transfers. For the one-person transfers, the only differences in A-P shear force occurred during the lifting phase of the transfer task where lifting of the patient from bed to wheelchair with both arms resulted in the highest A-P shear forces (1115 N) and lifting from wheelchair without an arm to bed resulted in the lowest (775 N). There was no difference in A-P shear force between any of the various transferring tasks for two-person transfers when lifting and lowering the patient to the various hospital furniture.

3.3. *Repositioning technique*

Table 5 shows the LBD risk and spinal loads for the one- and two-person repositioning techniques. The one-person hook method resulted in the highest LBD risk values and three-dimensional loads while the best method to reposition the

Table 4. Means (SDs) of the probability of 'high' risk group membership and three-dimensional spinal loads as a function of transfer task for the lowering phase of the tasks.

Transfer task	One-person transfers	Two-person transfers
Probability of 'high' risk group membership		
Lower to wheelchair without an arm from bed	88.0 (23.7)^{E}	78.6 (24.3)^{AB}
Lower to bed from wheelchair without an arm	92.7 (15.9)^{F}	80.0 (25.0)^{B}
Lower to wheelchair from bed	86.5 (22.1)^{D}	76.4 (24.8)^{A}
Lower to bed from wheelchair	90.9 (15.4)^{E}	80.6 (24.8)^{B}
Lower to commode chair from hospital chair	91.4 (15.9)^{E}	79.1 (26.1)^{B}
Lower to hospital chair from commode chair	93.5 (15.8)^{F}	82.2 (22.5)^{C}
Lateral shear forces (N)		
Lower to wheelchair without an arm from bed	1176.8 (891.0)^{D}	754.0 (144.9)^{AB}
Lower to bed from wheelchair without an arm	1256.2 (778.8)^{D}	908.6 (589.4)^{C}
Lower to wheelchair from bed	1066.8 (490.0)^{D}	639.1 (351.6)^{A}
Lower to bed from wheelchair	1017.0 (370.9)^{D}	942.5 (508.3)^{C}
Lower to commode chair from hospital chair	1146.8 (587.5)^{D}	833.4 (507.3)^{B}
Lower to hospital chair from commode chair	1104.1 (526.6)^{D}	834.1 (425.6)^{B}
Anterior-posterior shear forces (N)		
Lower to wheelchair without an arm from bed	1031.8 (681.7)^{A}	986.8 (496.8)^{A}
Lower to bed from wheelchair without an arm	1089.7 (615.6)^{A}	1032.9 (472.1)^{A}
Lower to wheelchair from bed	1180.8 (716.7)^{A}	1020.7 (503.4)^{A}
Lower to bed from wheelchair	1108.7 (544.5)^{A}	1049.4 (511.4)^{A}
Lower to commode chair from hospital chair	1137.1 (587.5)^{A}	1018.4 (544.9)^{A}
Lower to hospital chair from commode chair	1122.0 (536.0)^{A}	982.6 (484.6)^{A}
Compression forces (N)		
Lower to wheelchair without an arm from bed	5895.4 (1998.1)^{D}	4483.2 (1661.7)^{B}
Lower to bed from wheelchair without an arm	6457.2 (1930.6)^{E}	4663.3 (1719.2)^{B}
Lower to wheelchair from bed	5424.0 (2133.8)^{C}	4245.2 (1378.7)^{A}
Lower to bed from wheelchair	5744.0 (1728.5)^{CD}	4630.7 (1656.2)^{B}
Lower to commode chair from hospital chair	6062.3 (1669.7)^{D}	4645.7 (1450.8)^{B}
Lower to hospital chair from commode chair	6464.7 (1698.0)^{E}	4630.6 (1621.4)^{B}

Different alpha characters indicate significant difference at $p = 0.05$.

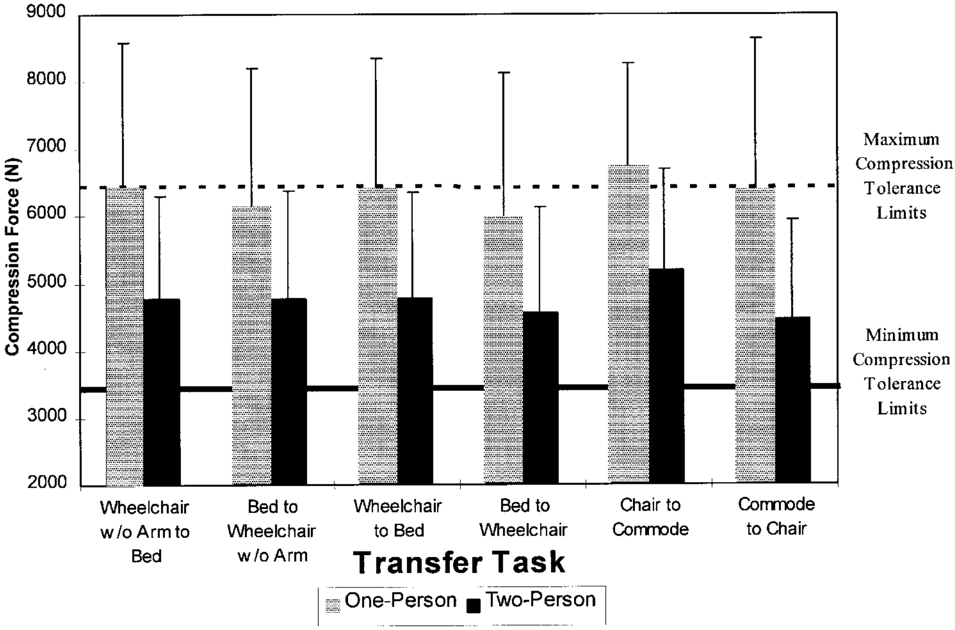

Figure 3. Maximum compression force as a function of transfer task for the lifting phase of the transfers.

patient in bed was when two patient handlers used the draw sheet. The other two person techniques (hook and thigh and shoulder methods) were found to have LBD risk, lateral shear force and compression force values that were above the draw sheet technique and below the single person hug repositioning technique.

While the single person hook technique had the highest A-P shear forces, the draw sheet method did not have the lowest A-P shear forces (figure 4). No differences were found in A-P shear forces for the two-person techniques when the patient handlers were on the left side of the patient (approximately 830 N). However, when the patient handlers were on the right side of the patient, the hook method had the lowest A-P shear forces (720 N) while the thigh and shoulder technique had the highest (937 N).

4. Discussion

4.1. *Transfer techniques*

Patient transfers were found to be a hazardous activity, regardless of whether only one person was moving the patient. This was confirmed by both assessment tools. The LBD risk model indicated that all the lifting techniques had a high probability of being in the high-risk group (above 76%). Marras *et al.* (1997a) found that a probability above 60% almost always ensures that the job was a high-risk job (97% of the jobs with LBD risk value above 0.6 were 'high' risk jobs). Therefore, none of the lifting techniques would be considered safe to use in a hospital setting for either one or two-patient handlers. The largest difference in LBD risk was between the single transfer method and both the two-person methods indicating that the actual method of transfer was less a factor of determining who was at risk than how many were actually performing the transfers.

Table 5. Means (SD) of the probability of 'high' risk group membership and three-dimensional spinal loads as a function of repositioning technique.

Repositioning technique		Probability of 'high' risk group membership	Maximum lateral shear force (N)	Maximum A-P shear force (N)	Maximum compression force (N)
One-person					
	Hook	97.8 (7.0)^{C}	1088.4 (676.6)^{C}	1202.3 (459.7)^{D}	9171.9 (2729.4)^{D}
Two-person					
Left side	Hook	90.8 (13.2)^{BC}	607.1 (382.5)^{B}	825.3 (808.6)^{B}	6068.8 (1990.7)^{B}
	Thigh and shoulder	96.1 (4.8)^{C}	646.0 (327.2)^{B}	828.8 (584.9)^{B}	6479.0 (1545.7)^{C}
	Draw sheet	72.0 (24.6)^{A}	414.2 (214.9)^{A}	847.3 (296.0)^{B}	3902.5 (1273.6)^{A}
Right side	Hook	88.3 (17.1)^{B}	502.8 (184.7)^{B}	721.6 (272.8)^{A}	5655.3 (1960.3)^{B}
	Thigh and shoulder	94.9 (6.7)^{C}	608.6 (282.1)^{B}	936.9 (459.8)^{C}	6570.3 (2062.1)^{C}
	Draw sheet	67.6 (26.9)^{A}	495.0 (235.3)^{A}	898.0 (287.1)^{C}	3819.7 (1400.2)^{A}

Different alpha characers indicate significant difference at $p = 0.05$.

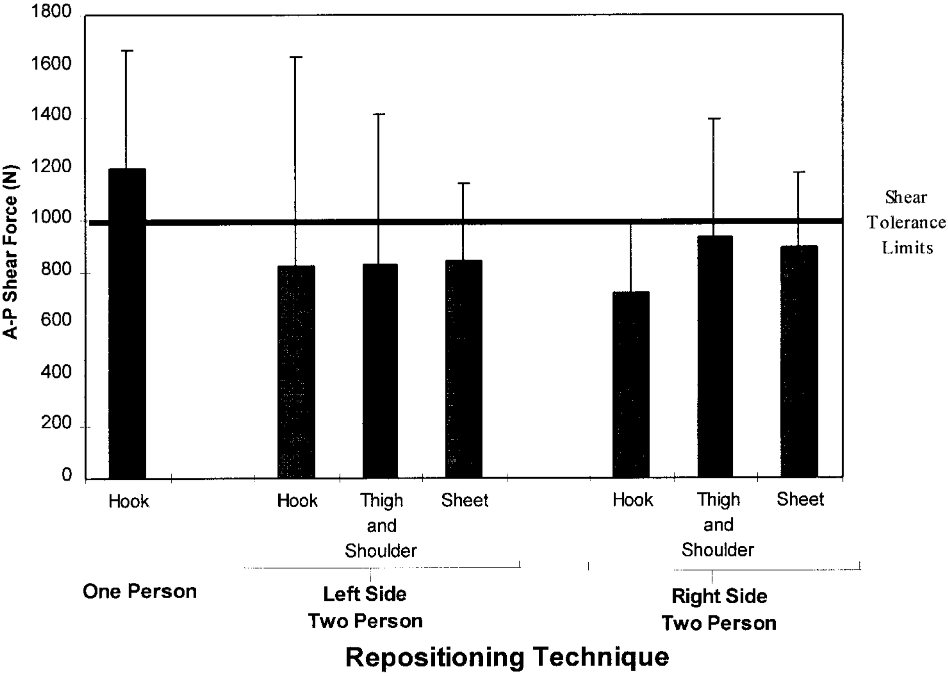

Figure 4. Maximum anterior-posterior shear force as a function of repositioning technique.

The EMG-assisted spine loading model confirmed the findings of the risk model by revealing that all the transferring techniques had loads that approached or exceeded the spine tolerances at which people start to have injuries. Furthermore, for both the lowering and lifting phases of the transfer tasks, the LBD risk values and compression forces provide an identical picture of the overall risk associated with the various transfer tasks, in that, all the patient transfer tasks would be considered harmful, especially when only one-person is performing the transfer. It was found that 52% of the one-person transfers exceeded the maximum recommended limit indicating that many individuals may start to experience some type of low-back injury (microfractures to the endplates) (NIOSH 1981). While the two-person techniques produced lower loads, these transfers still approached or exceeded the spine load limits. Roughly 15% to 20% of the two-person transfers resulted in compression forces above the 6400 N tolerance limit.

It is interesting to note that the single-person transfers had higher lateral shear forces than the two-person transfers. A possible explanation for this might be that patient handlers tend to move their feet more during the two-person lifts, thus, reducing the motions that influence lateral shear forces. During the single-person transfers, the patient handlers tended to swing the patient between the various hospital furniture, producing more lateral shear force.

Furthermore, conventional wisdom indicates that combined loadings should be considered when evaluating spinal loading. The literature is rich with studies indicating that disc strain increases greatly with lateral loading and with increases in loading in all three dimensions (Lin *et al.* 1978, Schultz *et al.* 1979, Broberg 1983, Shirazi-Adl 1989, 1991, Shirazi-Adl and Drouin 1987, Shirazi-Adl *et al.* 1986). Additionally, shear forces greater than 1000 N have been found to cause damage (tears) to the annulus fibrosis (Farfan 1988, McGill 1996). Since many of the transfers exceeded more than one tolerance limit, patient handlers who transfer patients alone might be at an even more extreme risk of some type of disc and/or spine injury. Additionally, many of the two-person transfers may also make the patient handler susceptible to similar back injuries. It is apparent that none of the current transfer techniques sufficiently protect the patient handlers who commonly perform patient transfers. This might explain the high prevalence and incidence rates commonly found for nursing personnel.

Since no other studies have evaluated the transferring of patients with both one- and two-person techniques, there are no direct comparisons between the present study and previous research. Typically, the previous studies found that transferring patients resulted in about 3600 to 4750 N of static compressive force (Garg and Owen 1992, Owen *et al.* 1992, Winkelmolen *et al.* 1994). In the present study, the compressive loads were higher than those estimated by the other authors. The difference between this study and the previous studies would be explained by the use of a dynamic spinal loading model that incorporated muscle coactivity as well as different sized patients.

Several other interesting spinal loading trends were present. First, some differences in compression forces were observed between the left and right side transfers. Typically, the compression forces were lower when the patient handlers lifted on the right side of the patient as compared to the left side of the patient. Several of the participants indicated that they had a 'preferred' side during the various transfers, although all participants performed the transfers on both sides of the patient. Other research (Marras and Davis 1998) has found that there were different loading patterns when participants lifted from locations to the right of the sagittal plane as compared to lifting from locations to the left of the sagittal plane. These authors found that the spinal load differences could be attributed to differences in muscle cross-sectional area, trunk and hip kinematics, and muscle activity patterns.

Second, the lowering phase of the transfers had slightly higher shear forces than the lifting phase. Thus, the patient handler may be slightly more at risk while lowering the patient. Davis *et al.* (1998) found that the lowering strength was more than 50% greater than lifting, but the compression forces were higher during lowering exertions (approaching spinal load tolerance) while the A-P shear forces were smaller. In the experiment of Davis *et al.* (1998), the participants were at higher risk during the lowering tasks since the compressive loads were the only forces to approach the tolerance limits. In the present study, the weights that were transferred (patient weight) were much greater than in the study by Davis *et al.* (1998) which may have led to the slightly different results. The participants also performed the lifting and lowering task with their hips and pelvis locked into position. Additionally, the task performed was sagittally symmetric which produces limited lateral shear forces. This might explain why there were differences in lateral shear force between lifting and lowering phases in this study.

Third, the spinal loads for the two-person transferring techniques were not equivalent to half of the loads produced during single-person transfers as was assumed in many of the previous biomechanical evaluations. Marras *et al.* (1997) found that two-person lifts resulted in only lower compressive loads during sagittally symmetric lifts and when the lifts became asymmetric, the difference was non-existent. Lateral shear forces during the two-person lifts actually were higher when the lift became more asymmetric. Differences in the results between the two studies might be explained by the fact that the single person transferred drastically more weight than corresponding two-person transfers in the current study. The findings that the two-person spinal loads were not equal to half of the one-person loads is also confirmed by other researchers (Karwowski and Mital 1986, Karwowski 1988, Karwowski and Pongpatanasuegsa 1988, Rice *et al.* 1995, Sharp *et al.* 1995).

4.2. *Transferring task*

The LBD risk model indicated that all transferring tasks would be considered to have a high probability of being high-risk (above 76%). The lack of difference between the various tasks was independent of the number of people performing the transfers with the one-person transfers being greater than the two-person transfers. Again, it is important to note that the number of people performing the transfer affected the level of LBD risk more than the actual task being performed.

All the tasks for the one-person transfers approached or exceeded the shear tolerance limits for both lateral and A-P shear forces (19 to 60% exceeding shear tolerance limits). Additionally, the compression forces for the one-person transfers exceeded 3400 N and approached 6400 N for all transfer tasks. The percentage of single-person transfer tasks that exceeded the compression limits (6400 N) ranged from 25 to 68%. The complete classification of the spinal loading benchmarks for the *lifting phase* of the various transfer tasks is provided in table 6. Similar results were found for the *lowering phase*. Thus, since all spinal loads approached the tolerance limits, transferring the patient with one-person could be considered extremely hazardous, independent of the transferring task. While most of the time, the two-person transfer tasks resulted in shear loads that approached the tolerance limits, on average, there were still many transfers that exceeded these limits (19 to 46%). Also, the compressive loads during these tasks were above the 3400 N limit and 20% of the tasks were above the 6400 N limit. This indicates that some people may be at risk of vertebral endplate microfractures even during the two-person transfers. Therefore, as with LBD risk, the number of patient handlers used during the lift affected the spinal loads more than what task was being performed; however, all transfer tasks might be considered 'risky'.

Although there was no difference in the loads between the various transferring tasks, it was apparent that each task resulted in significant risk of injury. Both the exposure and loading assessment have shown that patient handling is a risky task. Other authors have found that nurses have perceived transferring tasks as the most stressful tasks performed by nursing personnel (Garg and Owen 1992, Owen *et al.* 1992). The current results also support the data that many of the injuries to patient handlers happen during patient transfers (Videman *et al.* 1984, Venning *et al.* 1987, Stobbe *et al.* 1988, Estryn-Behar *et al.* 1990, Owen *et al.* 1992, Fuortes *et al.* 1994, Yassi *et al.* 1995, Knibbe and Friele 1996).

4.3. *Repositioning technique*

Several interesting results were found when evaluating the LBD risk associated with the repositioning of the patient. First, the single-person hook method was found to have the highest probability of risk of LBD, well above 90%. Second, both the hook and thigh and shoulder two-person methods were found to have LBD risk values

Table 6. Summary of the percentage of spinal loads observed within critical benchmark zones as a function of transfer task for the lifting phase of the tasks.

	Maximum lateral shear forces		Maximum anterior-posterior shear force		Maximum compression force		
Transfer task	< 1000N	> 1000N	< 1000N	> 1000N	< 3400N	> 3400N < 6400N	> 6400N
One-person transfers							
Lift from bed to wheelchair without an arm	70.00	30.00	75.00	25.00	10.00	35.00	55.00
Lift from wheelchair without arm to bed	55.00	45.00	65.00	35.00	10.00	55.00	35.00
Lift from bed to wheelchair	65.00	35.00	45.00	55.00	5.00	40.00	55.00
Lift from wheelchair to bed	40.00	60.00	60.00	40.00	10.00	50.00	40.00
Lift from hospital chair to commode chair	68.42	31.58	47.37	52.63	5.26	26.32	68.42
Lift from commode chair to hospital chair	40.00	60.00	75.00	25.00	10.00	30.00	60.00
Two-person transfers							
Lift from bed to wheelchair without an arm	80.00	20.00	63.75	36.25	20.00	66.25	13.75
Lift from wheelchair without arm to bed	70.00	30.00	60.00	40.00	23.75	56.25	20.00
Lift from bed to wheelchair	81.25	18.75	58.75	41.25	26.25	58.75	15.00
Lift from wheelchair to bed	70.51	29.49	62.82	37.18	26.92	56.41	16.67
Lift from hospital chair to commode chair	75.00	25.00	65.00	35.00	12.50	63.75	23.75
Lift from commode chair to hospital chair	81.25	18.75	71.25	28.75	27.50	61.25	11.25

similar to the single-person technique. Finally, the draw sheet method was significantly lower at about 70% probability of 'high' risk group membership but still considered to be 'high' risk.

The results from the EMG-assisted spinal load model were even more dramatic in showing the differences between the one- and two-person results. The one-person hook method had 89% of the lifts exceeding the maximum compressive tolerance (see table 7 for complete classification of benchmarks). The two-person draw sheet method was found to have the lowest lateral shear and compressive loads with only 5% of the tasks exceeding the 6400 N compression limit. While the compression loads were lower, these loads would be still considered to be dangerous since they were above the 3400 N limit and in combination with A-P shear forces that approached the tolerance limits. All of the two-person repositioning techniques had A-P shear forces that approached the shear tolerance limits (15 to 40% exceeding shear tolerance limits). Thus, none of the repositioning techniques of the current study were found to be totally safe for the patient handler.

Many authors have found that the repositioning of the patient is one of the most widely reported tasks associated with low-back injuries (Knibbe and Friele 1996, Smedley *et al.* 1995, Vasiliadou *et al.* 1995, Harber *et al.* 1985). Others have found that the nurses perceive the repositioning task as having the second highest physical stress level. The current spinal load and LBD risk results support the findings that repositioning the patient in bed poses a high potential for injury to the patient handlers who perform the tasks. On the other hand, the present results seem to be different from those of Owen *et al.* (1992) who found that repositioning the patient resulted in 107 N of compressive load. In this study, the compressive loads, on average, ranged from 3900 to 9100 N, drastically higher than the loads predicted by Owen *et al.* (1992). The upper limit (9100 N) approaches the highest tolerance limits for compression load at which 90% of the work population would be expected to have vertebral endplate microfractures. One probable explanation of this discrepancy was the accountability of the muscle coactivity and trunk dynamics in the current study. Another possible explanation might be that Owen and associates estimated the amount of weight lifted by the participants (moment), whereas, in the current study, the moment supported by the trunk was estimated by the EMG-assisted model. The use of the EMG-assisted model eliminated the guesswork attributed to not knowing the exact portion of weight being handled by each patient handler.

4.4. *Other considerations*

Much of the differences in the spinal loads for the transferring and repositioning tasks can be explained by the resultant trunk moment. The present data shows that the single-person hug method required the patient handlers to support the largest moment, and thus required the most muscle forces. There were also differences in the resultant trunk moment observed when the patient handlers were on the left side versus the right side of the patient. It was found that all transfers and repositioning tasks had excessive moments, independent of the number of patient handlers, so alternative methods such as mechanical devices and hoists appear to be solutions to reduce the amount of weight being transferred. These alternative methods should be investigated before implementing them as standard practice.

Several limitations of the study must be addressed. First, the 'standard' patient weighed only 50 kg. Typically, patients who are commonly found in the nursing

Table 7. Summary of the percentage of spinal loads observed within critical benchmark zones as a function of repositioning techniques.

Repositioning technique		Maximum lateral shear forces		Maximum anterior-posterior shear force		Maximum compression force		
		< 1000N	> 1000N	< 1000N	> 1000N	< 3400N	> 3400N < 6400N	> 6400N
One-person transfers								
	Hook	65.00	35.00	45.00	55.00	5.26	5.26	89.47
Two-person transfers								
Left side	Hook	85.00	15.00	65.00	35.00	5.00	55.00	40.00
	Thigh and shoulder	85.00	15.00	85.00	15.00	0.00	50.00	50.00
	Draw sheet	100.00	0.00	75.00	25.00	30.00	70.00	0.00
Right side	Hook	95.00	5.00	80.00	20.00	5.00	65.00	30.00
	Thigh and shoulder	90.00	10.00	60.00	40.00	10.00	45.00	45.00
	Draw sheet	85.00	15.00	80.00	20.00	35.00	60.00	5.00

home setting have a wide variety of sizes and shapes. The use of a heavier patient would increase any negative effects of the transfers on the nursing personnel. The one-person transfers and repositions would be especially susceptible where the LBD risk and spinal loading are already extremely high. Under these single-person tasks, the weight of the patient easily exceeds the physical capacity of many of the patient handlers since most are female. Furthermore, the use of one standard patient allowed for controlling unwanted and unexpected loading commonly associated with transfers in an actual nursing home. However, the introduction of unexpected movements by the patient would only be expected to increase the already hazardous tasks. It could have been possible that the ‘standard patient’ did not provide the same level of effort from trial-to-trial in a different experimental design. However, the use of a single person throughout the study who was lifted totally by the patient handlers minimized any possible trial-to-trial variation.

Second, the study was performed under laboratory conditions, not in an actual nursing home environment. However, the study was performed under conditions that simulated a nursing home setting as closely as possible. The furniture used in the study (bed, wheelchair with and without arms, commode chair and hospital chair) were all standard equipment that met hospital and nursing home specifications. Future research should investigate various transfer and repositioning techniques in actual nursing home settings that may be hindered by patient privacy and rights, unco-operative patients, difficult data collection, etc.

Caution must be used when interpreting the LBD risk results since the maximum moment was predicted by the EMG-assisted model and not through the conventional method of tape measure and scale. While the authors feel that the predicted moment was an appropriate estimate of the complex maximum static moment, this estimate might be expected to also contain an element of dynamic moment due to acceleration. However, patient handling is such a slow activity that one expects this dynamic activity to be negligible. The major benefit of the EMG-assisted prediction was that it was consistent for all conditions. Furthermore, the conventional method would have yielded highly questionable moments since there was no way of actually measuring the weight lifted by the participants, especially during the two-person tasks.

Finally, the results of the present study are limited to the transfer techniques, transfer tasks and repositioning techniques that were investigated. These techniques and furniture were chosen because they represent the most commonly used methods and devices. The LBD risk and spinal loads might be drastically altered through the use of other furniture, lifting assist devices, additional people helping to transfer the patient, and other techniques used to grasp and hold the patient. One common method not investigated in the present study was the use of a gait belt during the single-person transfers. Based on the results of the two-person transfers, the gait belt probably would have a limited effect on the spinal loads and LBD risk.

5. Conclusions

The following are the major findings of the study:

- There is significant risk when transferring the patient with either one or two patient handlers. The greatest risk was associated with the one-person transferring techniques.

- The various repositioning techniques were found to have significant risk of LBD associated with them with the single hook method having the highest LBD risk and spinal loads (which exceeded the tolerance limits). The two-person draw sheet technique had the lowest LBD risk and spinal loads but still had relatively high spinal loads and LBD risk.

The results of the study, as a whole, provided evidence that patient handling should be considered to be an extremely 'risky' job. The quantification of the risk of LBD for the various patient handling tasks using two different evaluation methods (LBD risk and spinal loading models) revealed that most tasks performed were hazardous to many individuals. It was found that even the safest of tasks (of the tasks evaluated in this study) had significant risk. Additionally, the current study represented a 'best' case scenario since the patient was co-operative and relatively small. Thus, patient handling in real situations such as in a nursing home, would be expected to be worse. As one can see, patient handling transfers and repositioning tasks are extremely hazardous and require ergonomic intervention to reduce this risk. A possible solution would be to use mechanical lifting devices. However, these devices should be thoroughly evaluated before being implemented.

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