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A biomechanical and ergonomic evaluation of patient transferring tasks: bed to wheelchair and wheelchair to bed

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Keywords: Patient transferring devices; Mechanical hoists; Compressive force; Back stress, comfort and security ratings.

A laboratory study was conducted in an effort to reduce back stress for nursing personnel while performing the patient handling tasks of transferring the patient from bed to wheelchair and wheelchair to bed. These patient handling tasks were studied using five manual techniques and three hoist-assisted techniques. The manual techniques involved one-person and two-person transfers. One manual technique involved a two-person lift of the patient under the arms; the others used a rocking and pulling action and included the use of assistive devices (a gait belt using a two-person transfer, a walking belt with handles using a one-person and a two-person transfer, and a patient handling sling with cutout areas to allow for a hand grip (Medesign) for a one-person transfer). The three mechanical hoists were Hoyer, Trans-Aid and Ambulift. Six female nursing students with prior patient transfer experience served both as nurses and as passive patients.

Static biomechanical evaluation showed that pulling techniques, as compared to lifting the patient, required significantly lower hand forces and produced significantly lower erector spinae and compressive forces at the L_5/S_1 disc ($P \geq 0{\cdot}01$). Shear force, trunk moments and the percentage of females who were capable of performing the transfers (based on static strength simulation) also favoured pulling methods. Perceived stress ratings for the shoulder, upper back, lower back and whole body were lower for pulling methods than those for lifting the patient ($P \leq 0{\cdot}01$).

Patients found the pulling techniques, with the exception of when using the gait belt, felt more comfortable and more secure than the lifting method ($P \leq 0{\cdot}01$). However, a number of subjects believed that the patient handling sling (Medesign) and the walking belt with one person making the transfer would not work for those patients who could not bear weight and those who were heavy, contracted or combative. A walking belt with two persons was the preferred manual method. Two out of three hoists (Hoyer lift and Trans-Aid) were perceived by the nurses to be as physically stressful as manual methods. Patients found these two hoists to be more uncomfortable and felt less secure than with three of the five manual methods (one- and two-person walking belts and Medesign). Ambulift was found to be the least stressful, the most comfortable, and the most secure among all eight methods. Pulling techniques and hoists took significantly longer amounts of time to make the transfer than manually lifting the patient ($P \leq 0{\cdot}01$).

The two-person walking belt using a pulling technique and Ambulift are recommended for transferring patients from bed to wheelchair and wheelchair to bed. A large-scale field study is needed to verify these recommendations.

1. Introduction

Back injuries account for approximately one of every five injuries and illnesses in the workplace and a quarter of all workers' compensation indemnity expenditures (Bureau of Labor Statistics 1982). Approximately 19% of the disabling injuries resulting in compensation claims are back injuries (Klein *et al.* 1984). Nursing aides and Licensed Practical Nurses ranked fifth and ninth respectively, based on workers' compensation claims, for back sprains and strains per 100 workers (Klein *et al.* 1984). These and other statistics indicate that nursing personnel (nurses and nursing aides) are as likely to sustain a compensable back injury as are workers in several other occupations widely recognized as heavy load handling occupations such as construction labourers, rubbish collectors and warehouse workers (Jensen 1987).

Also, several studies have concluded that nursing personnel show a relatively high prevalence of low-back pain (Cust *et al.* 1972, Dehlin *et al.* 1976, Raistrick 1981, Videman *et al.* 1984, Harber *et al.* 1985, Arad and Ryan 1986, Owen 1987, Stubbs *et al.* 1983a, 1986). The problem appears to be much more severe in nursing homes than in hospitals (Jensen 1987, Valles-Pankratz 1989). Some nurses believe that low-back pain is an inevitable part of nursing practice (Owen 1987). Researchers have concluded that most of the occupationally related low-back pain in nursing personnel is the result of, or is precipitated by, frequent manual lifting of patients (Ferguson 1970, Dehlin *et al.* 1976, Bell *et al.* 1979, Lloyd *et al.* 1987, Klein *et al.* 1984, Harber *et al.* 1985, 1990, Owen 1985, 1987, Greenwood 1986, Venning *et al.* 1987). High levels of postural stresses (standing, walking, stooping) are also a cause of concern (Baty and Stubbs 1987).

A few studies have found high levels of biomechanical stress from patient lifting and transferring tasks (Stubbs *et al.* 1983b, Gagnon *et al.* 1986, Torma-Krajewski 1986). Indeed, Lloyd *et al.* (1987) and the Standard Association of Australia (1982) recommended that safe and efficient patient transfer practices be based on biomechanical evaluations to reduce the stress on the spine. Others have concluded that the primary approach for reducing low-back pain should be reducing back stresses to nursing personnel (Bell 1984, Videman *et al.* 1984, Harber *et al.* 1985, Stubbs *et al.* 1986, Owen 1987, Jensen 1989, 1990).

Often nursing personnel, and nursing aides in particular, lift and move patients whose weights range from 37 kg to over 100 kg (Carlson 1989). These weights are considerably greater than the static strength of the 50th percentile of the female population at elbow height (about 20 kg) (US Department of Health and Human Services 1981). Also, the maximum weight acceptable to the same population at knuckle height, assuming a compact load (box width = 34 cm), is about 17 kg (Snook 1989). In the case of patient lifting, the shape of the load is awkward for lifting as the human body cannot be considered a compact mass and is without convenient handholds. Some patients can be combative, heavily contracted and/or uncooperative (Carlson 1989). In addition, patients are unpredictable and may suddenly resist movement. Often optimum body postures cannot be assumed due to space limitations, equipment interference and unadjustable beds, chairs and commodes, etc.

Most of the recommendations in the nursing literature deal with proper lifting techniques, body mechanics and back care (Hollis and Waddington 1975, Iveson-Iveson 1979, MacMillan 1979, Owen 1980, Raistrick 1981, Fletcher 1981, Scholey 1984, Greenwood 1986, Takala and Kukkonen 1987). However, there is a lack of consensus on proper lifting techniques. Often methods acceptable in one health institution are not considered appropriate in others (Standard Association of Australia 1982). While there is intuitive appeal and widespread use of such techniques, efficiency has not been demonstrated in nursing practice. For example, Dehlin *et al.* (1976), Buckle (1982), Stubbs *et al.* (1983b) and Owen (1985) found no relationship between different kinds of lifting techniques and the incidence of low-back symptoms. Based on a comprehensive study of low-back pain among nursing personnel, Stubbs *et al.* (1986) could not recommend any one lifting technique including the Australian (shoulder) lift.

Patient transferring methods can generally be classified into four main categories: (i) manual lifting methods (shoulder lift, through-arm lift, orthodox lift, drag lift, axillary hold, etc.); (ii) use of assistive devices such as belts, slings and draw-sheets to lift and carry patients (walking belt, gait-belt, Medesign, lift sheet, etc.); (iii) mechanically, electrically or hydraulically powered hoists (Hoyer lift, Trans-Aid, Medi-Lifter, Molift, Ambulift, etc.); and (iv) other devices such as a turntable, roller, trapeze, slide board, inflatable cushion, etc. In general, there is a paucity of data about the availability, use and acceptance of patient handling devices (Owen 1988). Manual lifting is the most common method of transferring patients (Bell *et al.* 1979).

Bell *et al.* (1979) concluded that priority should be given to a detailed investigation of the problems of patient transfer tasks. Owen and Garg (1989) reported that wheelchair to bed and bed to wheelchair transfers were ranked in the top four on a list of 16 patient handling task categories for perceived physical stresses by the nursing aides. These patient transfers received an average low-back stress rating of more than 14 on the Borg scale.

The objective of this study was to perform biomechanical and ergonomic evaluations of five different manual methods using slings and belts, and three different mechanical hoists for transferring patients from bed to wheelchair and wheelchair to bed. It is believed that this research can provide a manual method based on pulling, rather than lifting and carrying the patient, that would result in substantially lower stresses to the nursing personnel without compromising the safety and comfort of the patient. Similarly, a hoist can be recommended which would be more acceptable to the nursing personnel based on physical stresses and ease of operation and to the patients based on safety and comfort. It is believed that prevention can be successful by introducing more efficient handling methods which involve less stress on the nurse's back.

2. Method

2.1. *Subjects*

Six female paid volunteers participated as subjects. They were all nursing students with at least one year of experience in patient handling tasks. They served as both nurses and patients. When serving as patients, they were instructed to act as passive patient models and not to assist in supporting their own body weight. Their mean age, height and body weight were 22·5 years (σ=0·8, range=21 to 23), 165·3 cm (σ=6·3, range=157 to 175) and 63·3 kg (σ=10·8, range=54 to 79·5), respectively. They were all judged to be in good physical health and claimed never to have had any musculoskeletal or cardiovascular problems.

2.2. *Patient handling devices*

A literature search and questionnaire were completed to ascertain the assistive devices available and presently in use for these patient handling tasks (Owen 1988). The most commonly used assistive devices were gait belt and Hoyer lift; these were therefore included in this study. The gait belt is 5 cm wide and of varying length, has an adjustable belt-like loop closure, and has no handles (figure 1). The Hoyer lift has an adjustable base, has a handle requiring a manual pumping action for raising and lowering the patient, and has a transfer sling that attaches through hooks, chains, and metal bars (figure 1).

Figure 1. The most commonly used assistive devices gait belt (top left) and Hoyer lift (top right) and the manual lifting technique (bottom right) used in a nursing home for transferring patients from bed to wheelchair and wheelchair to bed.

Through observation in a large nursing home Carlson (1989) found the technique most often used for transferring patients in and out of bed was a manual lifting technique. This involved assisting or lifting the patient from a lying to a sitting position on the side of the bed. The nursing aides then grasped the patient under the axillae, lifted and carried the patient to the wheelchair (figure 1). This technique was also used in the study.

A preliminary study was then conducted by the first two authors and two nurses (research assistants) to test the feasibility of using additional assistive devices. Based on those study results, a walking belt with handles, a patient handling sling (Medesign) and two additional hoists (Trans-Aid and Ambulift) were selected for study. The walking belt (figure 2) is 12·5 cm wide and of varying lengths, has handles on each side, has a velcro closure and two quick-release buckles so the belt can be fastened around the patient. (Upon request of the authors, the company replaced the closure buckles with quick-release buckles to reduce fastening and tightening time.) The Medesign is made of flexible polymer, is 20·5 cm wide and 51 cm long. At each end there is a cutout for allowing a hand grip, and it does not fasten around the patient (figure 2). The Trans-Aid hoist has no adjustable base, the crank for raising and lowering the patient is in the horizontal plane, and the sling attaches by hooks and dangling chains (figure 3). The Ambulift hoist has a semi-adjustable base, a crank located in the vertical plane, and the lift-up sling attaches by loops and hooks (figure 3).

2.3. *Transferring patients from bed to wheelchair—walking belt, gait belt and Medesign*

A bed was lowered to the mean bed height found in nursing homes (bed height = 65 cm, wheelchair height = 48 cm), and the wheels were locked. A

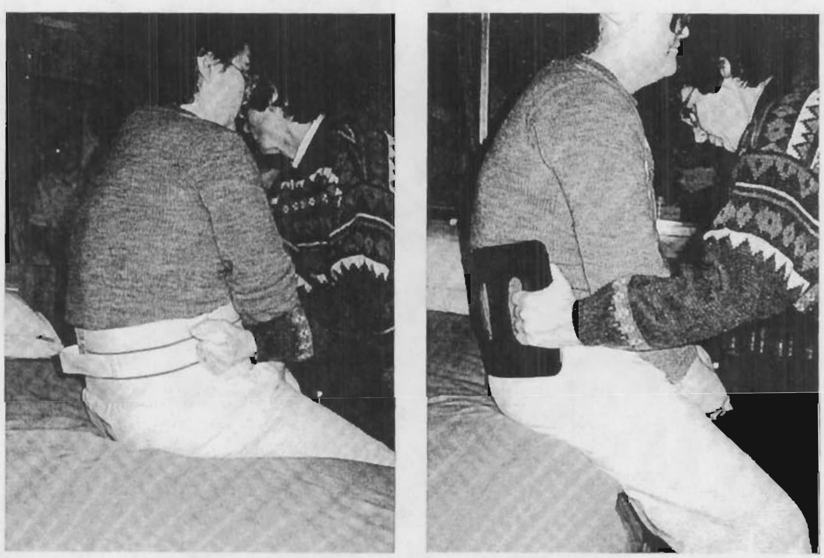

Figure 2. The walking belt (left) and Medesign (right) with one-person for transferring patients from bed to wheelchair and wheelchair to bed.

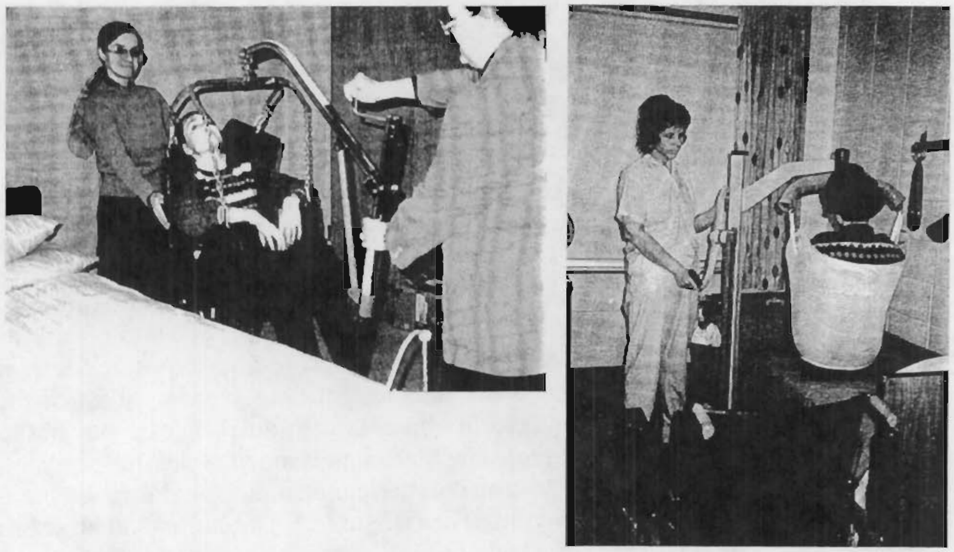

Figure 3. The Trans-Aid and Ambulift hoists for transferring patients from bed to wheelchair and wheelchair to bed.

Figure 4. Two-person walking belt with handles for transferring patients from bed to wheelchair and wheelchair to bed.

walking belt was placed snugly around the patient's lower abdomen/hips. A wheelchair was placed at a slight angle about 0·3 m from the bed to allow room for two nurses during transfer. The pedals were moved up to avoid interference with feet and the wheelchair was locked. A patient was assisted or lifted from a lying to a sitting position on the side of the bed (sitting and feet dangling). The nurses stood facing the patient (as close as possible) with feet far apart, one foot facing the patient and the other foot in the direction of the move (towards the wheelchair) to avoid twisting while transferring. They were instructed to bend their knees and keep their backs straight (if possible), and to grasp the handle of the walking belt with one hand and place the other hand on the arm of the wheelchair to stabilise it during the transfer (figure 4). In synchronization, using a gentle rocking motion to utilize momentum, the nurses *pulled* the patient toward themselves, shifted their weight to the foot facing the direction of the move (wheelchair), pivoted to avoid twisting, and moved the patient to the wheelchair. The walking belt was removed, foot pedals were put down and the patient's feet were positioned. The nurses were instructed, 'Pull with your hand and not your back. Do not lift'.

The procedures used with the gait belt and Medesign were similar to the above. Both one- and two-person transfers were made with the walking belt, two-person transfers with the gait belt and one-person transfers with the Medesign. When only one nurse made the transfer, the wheelchair was placed against the bed and one knee was placed between the knees of the patient and against the bed. When using the Medesign lifting method, the nurses preferred a one-person transfer as they were concerned that the belt might slip during a two-person transfer, as it could not be fastened to the patient.

2.4. *Transferring patient from bed to wheelchair—manual lifting method*

The two nurses stood near the patient facing each other. They grasped the patient under the axillae with one arm near the elbow. They lifted the patient off the bed and carried the patient to the wheelchair (figure 1).

2.5. *Transferring patient from bed to wheelchair—mechanical hoists*

These transfers were studied using two nurses. The sling of the Ambulift was placed under the patient with the separated areas at the bottom. Sling loops were hooked to the Ambulift hooks, and the patient's knees were flexed. One nurse cranked the Ambulift to raise the patient off the bed while the other supported the patient's legs until they were off the bed. One nurse pushed the Ambulift away from the bed while the other positioned the wheelchair under the patient. The patient was guided upright into the wheelchair, the Ambulift was cranked to lower the patient into it, the sling was removed, foot pedals were put down, and the patient's feet were positioned. The above procedure was also used with Trans-Aid and Hoyer lifts. The three hoists differed in terms of stability, types of sling used, patient posture while being transferred, and the hand motion and body posture required of the nurse to raise or lower the patient.

2.6. *Transferring patient from wheelchair to bed*

The procedures used for transferring patients from wheelchair to bed were very similar to those used for transferring from bed to wheelchair. For manual lifting and two-person pulling tasks, the wheels of the wheelchair were not locked. Rather, the nurses used one hand to push the wheelchair away from the work area to avoid interference with the patient transfer.

2.7. *Procedure*

All six subjects served as both patients and nurses. Experimental procedures and data collection forms were explained to the subjects. Each patient transfer procedure was demonstrated. Before any data were collected, the subjects were asked to try the procedure several times until they felt comfortable with it. For two-person transfers nurses were selected at random. The five manual techniques were studied first and then the three hoists. A given patient transfer technique was selected at random and all six subjects completed that technique. After completing a given patient transfer the nurses were asked to rate the physical stresses for shoulder, upper back, lower back and whole body on a nine point scale (Webb 1983, Blache *et al.* 1987). They were also required to place a check mark under conditions where they felt the method would not work (patient can bear weight, patient cannot bear weight, heavy patient, combative patient, contracted patient and patient with equipment attached). The patients were asked to rate how comfortable they felt and how secure they felt on a seven point Likert scale (0=extremely comfortable and 7=extremely uncomfortable; 0=extremely secure and 7=extremely insecure). After completion of all five manual techniques, the nurses were asked to rank the five methods based on overall preference (1=most preferred and 5=least preferred). Each transfer was timed and videotaped. The same procedure was repeated for wheelchair to bed transfers using manual techniques followed by bed to wheelchair and wheelchair to bed transfers using the three mechanical hoists.

2.8. *Biomechanical evaluations*

After completion of each manual patient tranferring task, the subjects were asked to assume the initial posture at the beginning of motion, and body angles were measured. These angles were later verified from videotapes. Pulling forces were measured by attaching a hand force dynamometer to the belt or sling. A static biomechanical model (Garg and Chaffin 1975) was used to simulate the task and estimate erector spinae force, compressive and shear forces at the L_5/S_1 disc, task produced moments on the L_5/S_1 disc in three directions and the percentage of the female population that would be capable of performing the task based on static strength.

Generally, all six subjects worked together during each data collection session which lasted for about 2 h per day. Data were collected twice a week for about six months. All data (both biomechanical measures and various ratings by the subjects) for manual patient transfer techniques were subjected to an analysis of variance (for example, 2 tasks × 5 methods × 4 body parts × 6 nurses for stress rating). Similarly, various ratings for the three hoists were analysed separately (2 tasks × 3 hoists × 4 body parts × 6 subjects).

3. Results

Biomechanical evaluations, ratings of perceived stresses from nurses, comfort and security ratings from patients, patient conditions for which nurses believed a transfer method would not work, overall method preference, and transfer times are summarized in tables 1 to 7.

3.1. *Biomechanical evaluations*

Trunk flexion, lateral bending and rotation angles for all five manual techniques

Table 1. Summary of biomechanical analysis of five different manual methods for transferring patients from bed to wheelchair (mean, s.d. and range).

Variable	Manual lifting (2 person)	Gait belt (2 person)	Walking belt (2 person)	Walking belt (1 person)	Medesign (1 person)
Trunk flexion angle (°)	46 ± 11 30–55	48 ± 3 45–50	53 ± 12 40–60	50 ± 10 40–60	47 ± 15 30–60
Trunk lateral bending (°)	15 ± 4 10–20	5 ± 0 5–5	0 ± 0 0–0	8 ± 6 5–15	3 ± 3 0–6
Trunk rotation angle (°)	0 ± 0 0–0	0 ± 0 0–0	0 ± 0 0–0	0 ± 0 0–0	3 ± 5 0–10
Hand force (N)	312 ± 54 263–392	114 ± 21 98–138	116 ± 9 107–125	196 ± 18 178–214	240 ± 23 214–254
% Capable females	41 ± 21 14–61	53 ± 5 49–59	92 ± 2 91–95	54 ± 17 42–74	52 ± 21 36–76
Trunk flexion moment (Nm)	171 ± 11 155–181	93 ± 6 87–100	86 ± 4 81–90	89 ± 11 77–98	92 ± 20 72–111
Lateral bending moment (Nm)	104 ± 19 81–120	10 ± 6 4–15	13 ± 13 5–28	13 ± 12 5–28	6 ± 3 4–9
Rotation moment (Nm)	41 ± 14 21–51	29 ± 5 26–35	4 ± 2 2–26	4 ± 2 2–6	3 ± 1 2–4
Erector spinae force (N)	3415 ± 229 308–3613	1848 ± 129 1736–1989	1710 ± 89 1642–1802	1787 ± 216 1544–1958	1845 ± 391 1437–2216
Compressive force (N)	4376 ± 165 4223–4557	1998 ± 109 1905–2118	1928 ± 78 1865–2015	1881 ± 347 1526–2221	1896 ± 524 1353–2399
Shear force (N)	711 ± 129 521–805	488 ± 48 458–543	455 ± 43 409–494	380 ± 34 343–409	396 ± 47 347–441

Table 2. Summary of biomechanical analysis of five different manual methods for transferring patients from wheelchair to bed (mean, s.d. and range).

Variable	Manual lifting (2 person)	Gait belt (2 person)	Walking belt (2 person)	Walking belt (1 person)	Medesign (1 person)
Trunk flexion angle (°)	39 ± 7 30–50	40 ± 0 40–40	38 ± 4 30–40	33 ± 4 30–40	36 ± 6 30–45
Trunk lateral bending (°)	14 ± 6 10–25	10 ± 4 5–15	14 ± 2 10–15	10 ± 3 5–15	0 ± 0 0–0
Trunk rotation angle (°)	0 ± 0 0–0	0 ± 0 0–0	0 ± 0 0–0	0 ± 0 0–0	0 ± 0 0–0
Hand force (N)	312 ± 54 263–392	127 ± 12 116–138	125 ± 18 107–156	277 ± 28 254–312	277 ± 23 254–312
% Capable females	49 ± 3 45–53	77 ± 9 67–90	84 ± 11 70–98	59 ± 17 36–88	53 ± 9 42–64
Trunk flexion moment (Nm)	168 ± 21 143–207	89 ± 5 85–97	86 ± 5 76–91	118 ± 17 102–149	157 ± 19 122–172
Lateral bending moment (Nm)	109 ± 22 85–145	17 ± 12 4–35	19 ± 12 6–40	27 ± 8 16–40	0 ± 0 0–0
Rotating moment (Nm)	38 ± 8 23–45	41 ± 6 31–47	38 ± 8 28–52	6 ± 3 2–10	0 ± 0 0–0
Erector spinae force (N)	3363 ± 414 2901–4143	1776 ± 94 1700–1940	1709 ± 100 1517–1811	2353 ± 338 2034–2968	3134 ± 376 2439–3435
Compressive force (N)	4395 ± 339 4027–4979	2027 ± 181 1851–2345	1968 ± 180 1695–2243	2733 ± 359 2385–3315	3339 ± 429 2518–3662
Shear force (N)	640 ± 75 534–752	570 ± 37 507–610	547 ± 48 481–627	502 ± 46 432–561	448 ± 23 445–516

were about the same (tables 1 and 2). Trunk flexion angles were about 50° and 40° for bed to wheelchair and wheelchair to bed transfers, respectively. The trunk lateral bending angle was about 10° and there was practically no axial rotation involved (tables 1 and 2). As expected, pulling the patients required a substantially lower force than lifting the patients ($P \leq 0 \cdot 01$). Even pulling the patient with one nurse required less force than lifting the patient with two nurses (tables 1 and 2). The mean forces required to pull the patients ranged from 36% to 77% of the mean force required to lift the patients for bed to wheelchair transfers and from 40% to 89% for wheelchair to bed transfers. Based on static strength simulations, 92% and 84% of female workers would be capable of pulling the patients from bed to wheelchair and wheelchair to bed, respectively, with the two-person walking belt as compared to 41% and 49% with the manual lifting technique (tables 1 and 2). Trunk flexion and lateral bending moments were also greater for the manual lifting method than those for the pulling techniques. Trunk rotation moments were fairly small for all five manual methods. Estimated erector spinae muscle forces and compressive forces at the L_5/S_1 disc for both one- and two-person pulling techniques were about 53% (range = 50% to 54%) and 44% (range = 43% to 46%) of those for manual lifting for bed to wheelchair transfers (table 1). The small differences in compressive and erector spinae forces between one- and two-person transfers show the importance of body weight and posture when small forces are being applied. For wheelchair to bed transfers (table 2), these ratios were about the same for two-person pulling techniques (52% for erector spinae forces and 45% for compressive forces). However, for one-person pulling techniques (walking belt and Medesign), these ratios were substantially higher (70% and 93% for erector spinae force and 62% and 76% for compressive force, respectively). Shear forces at the L_5/S_1 disc for pulling techniques were 53% to 69% of the shear force for manual lifting for bed to wheelchair transfers and 70% to 89% for wheelchair to bed transfers (tables 1 and 2). For bed to wheelchair transfers (table 1), there was no significant difference between one- and two-person pulling techniques in erector spinae and compressive forces ($P > 0 \cdot 05$) even though one-person transfers required larger pulling forces ($P \leq 0 \cdot 01$). For wheelchair to bed transfers (table 2), one-person pulling transfers required significantly greater pulling forces (more than two times for the walking belt) and resulted in significantly greater erector spinae and compressive forces (38% and 39% for walking belt) as compared to two-person pulling transfers ($P \leq 0 \cdot 01$).

There were no significant differences between bed to wheelchair and wheelchair to bed transfers in required hand forces, erector spinae forces and compressive forces for manual lifting and two-person pulling techniques ($P > 0 \cdot 05$). However, for one-person pulling techniques, these forces were considerably higher for wheelchair to bed transfers than those for bed to wheelchair transfers ($P \leq 0 \cdot 01$). Hand, erector spinae and compressive forces for wheelchair to bed transfers were 41%, 32% and 45% higher for the one-person walking belt and 15%, 70% and 76% higher for Medesign than those for bed to wheelchair transfers. Shear forces for all four pulling techniques were 13% to 32% higher for wheelchair to bed transfers than those for the bed to wheelchair transfers. A 17 cm height difference between the bed and wheelchair and the tendency of the patient to slouch in the wheelchair may partially account for some of the observed differences.

Table 3. Stress ratings for five manual techniques and the three hoists (on a scale of 0=no stress to 9=extremely stressfull.

Task	Body part	Manual lifting (2)*	Gait belt (2)	Walking belt (2)	Walking belt (1)	Medesign (1)	Hoyer lift (2)	Trans-Aid (2)	Ambulift (2)
Bed to chair	Shoulder	5·3 ± 1·6 2·0–7·2	3·5 ± 1·4 1·0–5·5	3·3 ± 1·3 1·5–5·6	2·3 ± 0·7 1·5–3·4	3·6 ± 1·8 2·0–6·2	5·3 ± 2·0 1·8–8·9	3·4 ± 1·3 1·9–6·1	2·0 ± 0·7 0·7–3·2
	Upper back	4·6 ± 2·1 2·0–8·4	3·5 ± 1·5 1·0–5·9	3·0 ± 1·2 2·0–5·5	2·7 ± 1·0 1·0–4·0	3·8 ± 1·7 2·0–6·2	4·2 ± 1·5 1·8–6·0	2·7 ± 1·3 1·0–6·0	1·9 ± 1·0 0·6–4·0
	Lower back	4·6 ± 1·8 1·6–6·8	3·6 ± 1·4 1·0–5·5	3·3 ± 1·4 1·5–5·1	3·1 ± 1·5 1·0–5·0	4·1 ± 2·3 1·0–7·0	3·8 ± 2·2 1·0–7·0	2·4 ± 1·7 0·6–5·8	1·5 ± 1·3 0·0–3·9
	Whole body	5·1 ± 1·5 2·0–7·2	3·8 ± 1·5 1·0–5·6	3·2 ± 1·2 1·8–5·2	2·9 ± 1·2 1·2–4·2	3·7 ± 1·8 1·4–6·0	4·1 ± 1·8 1·3–7·7	2·5 ± 1·5 0·6–4·7	1·3 ± 0·7 0·3–2·8
Chair to bed	Shoulder	5·2 ± 1·2 4·0–7·6	4·7 ± 1·6 2·0–7·6	3·5 ± 1·3 1·0–5·2	3·2 ± 1·1 1·5–5·0	3·9 ± 1·5 1·5–6·3	5·4 ± 2·0 2·0–9·0	5·0 ± 1·5 3·0–9·0	2·1 ± 1·0 1·0–4·4
	Upper back	5·1 ± 1·6 3·0–8·6	4·4 ± 1·6 1·7–7·2	2·9 ± 1·1 1·0–4·2	3·6 ± 1·3 1·5–5·0	4·1 ± 1·9 1·5–6·8	4·3 ± 1·3 2·4–6·0	4·1 ± 1·6 1·5–8·1	1·7 ± 1·1 0·2–4·8
	Lower back	4·2 ± 0·9 3·0–6·0	4·5 ± 1·8 1·5–6·2	2·3 ± 1·8 0·0–5·3	3·1 ± 1·8 1·0–6·0	4·3 ± 2·0 1·0–6·2	4·1 ± 2·0 1·2–6·1	3·1 ± 1·8 1·0–6·0	1·1 ± 0·7 0·0–2·3
	Whole body	4·9 ± 0·7 4·0–6·0	4·7 ± 1·5 1·8–7·1	3·2 ± 1·1 1·0–4·9	3·5 ± 1·5 1·3–5·8	4·2 ± 1·5 1·2–5·8	4·4 ± 1·5 1·6–6·2	3·8 ± 2·0 2·0–8·9	1·2 ± 0·8 0·0–2·8

*Indicates number of nurses employed for patient transfer.

3.2. *Stress ratings*

Although different tasks, techniques, body parts and nurses all have statistically significant effects on stress ratings ($P \leq 0.01$), differences in perceived stress between various tasks and body parts were not very pronounced (table 3). In general, the shoulder was the body part most stressed for the five manual techniques (except Medesign) and the three hoists (table 3). In the case of Medesign, the lower back was the body part most stressed. Among the five manual techniques, manually lifting the patient was perceived to be the most stressful technique (mean rating = 5·3 for shoulder, about 'definitely stressed') for both bed to wheelchair and wheelchair to bed transfers. One- and two-person walking belt techniques were perceived to be the least stressful for bed to wheelchair and wheelchair to bed transfers, respectively. Among the three hoists, the Hoyer lift with a mean rating of about 5·3 for shoulder stress was perceived to be the most stressful and the Ambulift with a mean rating of 2 ('just noticeable') was perceived to be the least stressful both for bed to wheelchair and wheelchair to bed transfers. In general, wheelchair to bed transfers were perceived to be a little more stressful than bed to wheelchair transfers (probably because the wheelchair was lower than the bed).

Among all five manual methods and the three hoists, Ambulift was perceived to be the least stressful. However, it is interesting to note that the other two mechanical hoists (Hoyer lift and Trans-Aid) were perceived as being as stressful as or more stressful than some of the manual methods, even though the hoists required relatively small forces to operate and push them. For example, the mean ratings of perceived stresses at the shoulder for the Hoyer lift and Trans-Aid were 5·4 and 5·0 for transferring from wheelchair to bed as compared to 5·2 for the manual lifting method, the most stressful manual technique (table 3).

3.3. *Patient comfort and security ratings*

Out of five manual techniques, lifting and the gait belt were rated as very uncomfortable while the walking belt with one- and two-person transfers and Medesign were rated as very comfortable by the patients (table 4). Among the three mechanical hoists, the Hoyer lift was rated as very uncomfortable (mean rating = 5·3 for wheelchair to bed), Trans-Aid as neither comfortable nor uncomfortable and Ambulift as very comfortable. Among all manual techniques and mechanical hoists for bed to wheelchair transfers, Ambulift was found to be the most comfortable followed by the walking belt with one person, walking belt with two persons and Medesign. For wheelchair to bed transfers, walking belts with one and two persons, Medesign and Ambulift were about equally comfortable. Overall, subjects found the eight techniques studied to be somewhat more comfortable for bed to wheelchair transfers (mean rating = 2·8) than for wheelchair to bed transfers (mean rating = 3·4).

Patients felt extremely secure with Ambulift and very secure with one- and two-patient walking belts. Overall, Trans-Aid and Medesign were rated as marginally secure. The gait belt was rated as neither secure nor insecure. Patients felt very insecrue with the Hoyer lift and the manual lifting technique. Overall, they felt a little more secure from bed to wheelchair transfers than from wheelchair to bed transfers. Both techniques and tasks were found to have statistically significant effects on patient comfort and security ratings ($P \leq 0.01$).

Table 4. Summary of comfort and security ratings from the patients for the five manual techniques and the three hoists.

Task	Variable	Manual lifting (2)*	Gait belt (2)	Walking belt (2)	Walking belt (1)	Medesign (1)	Hoyer lift (2)	Trans-Aid (2)	Ambulift (2)
Bed to chair	Comfort rating**	4·8 ± 1·6 2·0–6·5	4·8 ± 0·7 3·7–5·9	1·5 ± 0·6 1·0–2·5	1·2 ± 0·9 0·4–2·5	2·2 ± 0·7 1·3–2·9	4·0 ± 1·6 1·4–5·7	3·0 ± 1·9 0·3–6·0	0·6 ± 0·5 0·0–1·0
	Security rating***	3·8 ± 1·9 1·0–6·6	3·3 ± 1·5 1·0–4·8	1·3 ± 0·5 0·6–2·1	1·4 ± 0·8 0·8–3·0	3·2 ± 1·8 0·5–5·1	4·0 ± 0·7 3·0–4·7	2·5 ± 1·7 0·3–5·0	0·4 ± 0·6 0·1–1·6
Chair to bed	Comfort rating**	4·3 ± 0·9 2·9–5·0	5·5 ± 0·6 5·0–6·4	1·9 ± 0·7 0·6–2·8	2·0 ± 0·6 1·3–3·0	2·2 ± 0·7 1·0–2·8	5·3 ± 0·6 4·6–6·1	3·9 ± 1·0 2·7–5·0	2·0 ± 2·0 0·0–4·8
	Security rating***	3·7 ± 1·8 1·0–5·5	3·3 ± 1·0 2·0–4·0	2·5 ± 1·0 1·3–4·0	2·4 ± 1·8 1·0–5·8	2·5 ± 1·4 1·0–4·6	5·9 ± 1·2 3·7–7·0	3·4 ± 1·9 1·2–6·0	0·5 ± 0·8 0·0–1·6

*Indicates number of nurses employed for patient transfer.
**On a scale of 0 to 7 with 0 = extremely comfortable and 7 = extremely uncomfortable.
***On a scale of 0 to 7 with 0 = extremely secure and 7 = extremely insecure.

Table 5. Percentage of nurses believing manual transfer methods studied will not work for different patient conditions.

		Percentage of nurses believing method will not work				
Task	Patient condition	Manual lift (2)*	Gait belt (2)	Walking belt (2)	Walking belt (1)	Medesign (1)
Bed to chair	Patient can bear weight	17	0	0	0	0
	Patient cannot bear weight	17	33	0	50	100
	Heavy patient	17	50	0	67	67
	Combative patient	0	17	0	67	67
	Contracted patient	0	50	17	83	100
	Patient with equipment	0	0	0	33	50
Chair to bed	Patient can bear weight	0	0	0	0	0
	Patient cannot bear weight	0	33	0	17	100
	Heavy patient	17	50	0	33	67
	Combative patient	17	17	0	50	83
	Contracted patient	0	17	0	67	100
	Patient with equipment	17	0	0	17	33

*Indicates number of nurses employed for the transfer

Table 6. Summary of nurses' method preferences for manual transfers (1 = most preferred and 5 = least preferred).

	Method preference for					
	Bed to wheelchair			Wheelchair to bed		
Technique	Mean	s.d.	Range	Mean	s.d.	Range
Manual lifting (2)	4·5	0·8	3–5	4·0	1·1	2–5
Gait belt (2)	3·3	1·2	2–5	4·2	0·8	3–5
Walking belt (2)	1·0	0·0	1–1	1·0	0·0	1–1
Walking belt (1)	2·5	0·8	2–4	2·3	0·5	2–3
Medesign (1)	3·7	0·8	3–5	3·5	1·2	2–5

3.4. *Patient characteristics and nurses method/preference*

Practically all subjects believed that a walking belt with two persons would work for different types of patients (table 5). For each type of transfer and each patient characteristic, at least five of our six subjects believed the two-person lift technique would work. For heavy patients the only method that all subjects agreed was feasible was the walking belt with two nurses.

Overall, the nurses liked the walking belt with two persons the most (mean rating = 1, table 6). The walking belt with one person was second in overall preference. Two-person manual lifting was the least preferred method for bed to wheelchair transfer and the gait belt for wheelchair to bed transfer.

Table 7. Summary of transfer times in seconds.

	Transfer time(s) for					
	Bed to wheelchair			Wheelchair to bed		
Technique	Mean	s.d.	Range	Mean	s.d.	Range
Manual lift (2)*	17·8	2·1	14·7–21·6	14·0	1·6	12·2–15·1
Gait belt (2)	57·5	15·0	37·1–72·3	41·4	4·5	35·1–49·3
Walking belt (2)	67·3	7·3	58·0–80·5	63·4	4·9	58·5–68·9
Walking belt (1)	61·2	3·5	55·4–65·7	56·1	8·7	48·1–72·7
Medesign (1)	30·4	2·9	26·5–34·2	31·3	6·9	24·0–47·0
Hoyer lift (2)	124·5	4·2	120·1–132·3	170·0	18·2	147·8–197·8
Trans-Aid (2)	170·8	9·5	159·7–187·5	198·1	23·4	158·1–231·6
Ambulift (2)	149·0	31·2	126·0–203·8	130·4	8·5	121·6–143·3

*Indicates number of nurses employed for the transfer.

Table 8. Qualitative summary of different patient transfer methods.

Criteria	Manual lift (2)	Gait Belt (2)	Walking Belt (2)	Walking Belt (1)	Medesign (1)	Hoyer Lift (2)	Trans-Aid (2)	Ambulift (2)
Biomechanical stresses	N	Y	Y	Y	Y	—	—	—
Perceived Stresses	N	N	Y	Y	N	N	N	Y
Patient security	N	N	Y	Y	N	N	N	Y
Patient comfort	N	N	Y	Y	Y	N	N	Y
Patient characteristics	N	N	Y	N	N	—	—	—
Method preference	N	N	Y	Y	N	—	—	—
Transfer time	Y	N	N	N	Y	N	N	N
Favourable comments	N	N	Y	Y	N	N	N	Y

N: relatively high stresses, unfavourable ratings or large transfer times
Y: relatively low stresses, favourable ratings or small transfer time

3.5. *Transfer time*

The two-person manual lift took the least amount of time and mechanical hoists took the longest times, both for bed to wheelchair and wheelchair to bed transfers (table 7). Medesign took the second lowest time. In general, patient transfers with the gait belt and one- and two-person walking belts took about 1 min as compared to about 16 s for manual lifting and 2–3 min for mechanical hoists.

4. Discussion

Among other considerations there are at least five factors that need to be examined when determining an appropriate manual technique or mechanical device for transferring patients from bed to wheelchair and wheelchair to bed. These are: physical stresses to the nursing personnel, patient characteristics, safety of patients, comfort of patients and time required to make the transfer. Table 8 gives a qualitative summary of the eight different criteria used to evaluate the five different manual techniques and the three different hoists for transferring patients from bed to wheelchair and wheelchair to bed. The two-person walking belt using a gentle rocking and pulling motion and the Ambulift are the only techniques which satisfy all the criteria, except transfer time (table 8). Assuming adequate staffing, these two methods are recommended for transferring patients from bed to wheelchair and wheelchair to bed.

4.1. *Physical stresses to nursing personnel*

Regarding physical stresses to nursing personnel, most studies have dealt with training the nurses and nursing aides in proper body mechanics and appropriate lifting techniques (Hollis and Waddington 1975, Iveson-Iveson 1979, MacMillan 1979, Raistrick 1981, Fletcher 1981, Scholey 1984, Takala and Kukkonen 1987). However, the effectiveness of training with respect to the subsequent risk of experiencing back pain has been questioned by several researchers (Dehlin *et al.* 1976, Lloyd *et al.* 1987, Buckle 1982, Stubbs *et al.* 1983b, Harber *et al.* 1985, Stubbs *et al.* 1986). Further, it is not clear whether these training methods would result in reduced stresses to the spine, though Stubbs *et al.* (1983b) reported that the shoulder (Australian) lift produced the least stress as assessed through intra-abdominal pressure.

Gagnon *et al.* (1986) using three different lifting techniques estimated that the compressive force on the L_5/S_1 disc ranged from 5744 N to 7951 N for assisting a 72·6 kg manikin from a wheelchair with one person. These compressive forces and a value of about 4400 N for two-person manual lifting estimated in this study are much higher than the 3430 N limit (for action limit) recommended by the US Department of Health and Human Services (1981). Torma-Krajewski (1986) reported that most patient lifting tasks are performed at a horizontal distance of 30 to 55 cm from the ankles and a vertical location of 50 to 100 cm and exceed action limits (AL) and/or maximum permissible limits (MPL) recommended by the US Department of Health and Human Services (1981). Further, an optimum body posture for lifting is not always possible due to space limitations and equipment design and their interference with patient transfer. For example, Carlson (1989) reported that in a large nursing home wheelchair and geriatric chair heights ranged from 37·5 to 47·5 cm (mean = 42·5 cm) and the bed height ranged from 55 to 80 cm (mean = 65 cm). In another facility, beds could not be adjusted to lower than 67·5 cm (Torma-Krajewski

1986). These numbers indicate that overall one would have to lift a totally dependent patient by about 22 cm when transferring from wheelchair to bed. When combined with patient weight and horizontal distance, this lifting task may produce high erector spinae and compressive forces as observed in this study.

The objective of this research was to find a method for patient handling other than the manual lifting of patients. Two different options were considered: manual pulling of patients and use of mechanical hoists. The rocking and pulling gave the patient kinetic energy and by controlling this energy the nurses were able to transfer the patient without lifting. This is somewhat similar in principle to the rocking lift suggested by Lloyd *et al.* (1987). In general, all four pulling methods (walking belt with one and two persons, gait belt and Medesign) resulted in significantly lower compressive forces at the L_5/S_1 disc than the 3430 N limit recommended by the US Department of Health and Human Services (1981). Especially in the case of the two-person patient transfer task using the pulling method, the compressive forces were about 2 kN and were substantially lower than the ultimate compressive strength of 3 kN to 12 kN reported by Jäger (1987). The estimated mean erector spinae forces of 1710 N to 1848 N for two-person pulling transfers from the present study are also lower than the 2200 N to 5500 N limit estimated by Farfan (1973). The measured mean pulling forces of 114 N to 127 N for two-person transfers and 196 N to 277 N for one-person transfers from the present study are well within the peak pulling strength of 294 N for the 25th percentile weak female reported by Snook (1978) (maximum pulling force acceptable to 75% of females for a 2·1 m pull at 57 cm height once every 5 min). These biomechanical findings are supported by subjective stress ratings, which showed that both one- and two-person pulling methods of transferring patients were significantly less stressful than the two-person manual lifting method.

4.2. *Mechanical hoist versus manual methods*

It is generally believed that the use of mechanical hoists to transfer patients would significantly reduce physical stresses to nursing personnel, as most hoists require only a relatively small force to operate them (for example, according to the reference material on the device, it takes 5 kg to raise a 90 kg patient with Ambulift). However, several studies have shown that mobile hoists are rarely used (Bell *et al.* 1979, Takala and Kukkonen 1987, Owen 1988). Some of the reasons given for not using mechanical hoists are: lack of access, lack of space, need for maintenance, inadequate staffing, time involved, lack of skill, unstable and unsafe device, difficulty in placing and removing slings, uncomfortable for patient and fearful patients (Owen 1988). However, there is no indication of the physical stresses associated with mechanical hoists.

This study showed that the stress ratings for two out of three hoists were as high as the stress ratings for manually transferring the patients. Indeed, the highest mean stress rating of 5·4 was for the Hoyer lift. Though the force required to operate a hoist may be small, the location of the handle and such tasks as placing and removing the slings from underneath the patient, attaching slings to the hoist, and the motion required to raise and lower the hoist can cause significant postural stresses to the nursing personnel. For example, the Hoyer lift required a jerky pumping action to raise and lower the hoist resulting in several forward and lateral flexions of the trunk. Subjects found it too hard to pump and steer. They also had difficulty in applying the sling and hooking the sling to the hoist due to short leg straps and hooks. The crank for the Trans-Aid hoist was located in the horizontal plane at about shoulder height. Chains were used to connect the sling to the hoist. It was too time consuming to count the chain links for proper patient balance while in a flexed back posture and the subjects had difficulty with the hooks. About two-thirds of the subjects found the Trans-Aid hoist hard to push and steer due to the design of its 'C' base and some had difficulty in applying the sling. For Ambulift, the crank handle was too high (about shoulder height). None of the three hoists could be pushed or manoeuvred on carpeting.

Also, two out of three hoists received fairly low ratings for patient comfort and security. The Hoyer lift was found to have an uncomfortable body posture for the patient (patient is in a half recumbent position). It swayed too much during movement (lateral swing of patients) and the subjects were concerned that the hoist might tip over. Also, some subjects were concerned that the sling hook could tear the patient's skin. In the case of the Trans-Aid hoist, both the cage and the dangling chains were perceived as being dangerous by the patients. The patients suggested they would be more comfortable if they could assume more of an erect sitting posture while in the sling. The subjects also commented that it had too much swing, raising concerns about patient safety.

The large differences between the three hoists in stress, comfort and security ratings suggest that one has to be very careful in selecting a hoist. In addition to increased transfer time, it may result in greater stresses to nurses and less comfort and safety of patients as compared to some manual techniques.

4.3. *Patient comfort, safety and characteristics*

Out of the four manual pulling techniques, only the gait belt was rated as very uncomfortable and the patients felt relatively insecure with it. It had a tendency to slip up on the patient and press on the rib cage. Almost all patients complained of discomfort and pain in the rib cage from the belt and/or the nurses' knuckles. In addition, the nurses had difficulty in getting a firm grasp due to lack of handles. They complained of hands getting pinched, and stresses on the hands and wrists. As a result, the nurses felt that this method should not be used with heavy patients, those who could not bear weight, or those who were contracted.

In spite of favourable biomechanical evaluation, stress, comfort and security ratings, the nurses believed that the Medesign sling and the walking belt with one person were suitable for only those patients who could bear weight. Both with the Medesign sling and the one-person walking belt, some nurses felt stress in the arms. The nurses commented that they did not have enough control of the patient because the Medesign sling could not be fastened securely to the patient. In general, the nurses believed that two nurses should be used to transfer those patients who cannot bear weight and those who are heavy, contracted or combative to guard against the possibility that something unexpected could occur during the transfer with one person,

The two-person walking belt was the only manual technique that satisfied four of the five criteria. It had low biomechanical stresses and stress ratings, high patient comfort and security ratings, could be used with patients with different characteristics and was the preferred manual technique. However, it did take about 60 s to transfer patients using the two-person walking belt.

4.4. *Transfer time*

One of the reasons for not using manual and mechanical patient handling devices is that they take too much time (Bell 1984, Owen 1988, Takala and Kukkonen 1987). In this study, it took 124 to 198 s to transfer a patient using a hoist as compared to 120 to 150 s reported by Takala and Kukkonen (1987) and 295 s reported by Bell (1984). The additional time to use an Ambulift as compared to manual lifting of patients was 124 s per transfer and is in agreement with the 90 to 120 s reported by Takala and Kukkonen (1987). However, it is lower than the 275 s reported by Bell (1984). The additional time to use a two-person walking belt, as compared to manual lifting, was 49 s. Carlson (1989) reported that nursing aides working in a team of two made an average of 38 patient transfers per day shift using the manual lifting method. These transfers would require 31 min and 78 min of additional time using a two-person walking belt and Ambulift, respectively. Without adequate staffing, the 78 min of additional time may interfere with various other functions that nursing aides perform (such as dressing patients, feeding patients, making beds, etc.). Therefore, adequate staffing of nursing personnel is a major concern when considering use of patient handling devices and/or hoists to reduce stresses to the spine in those health care facilities where nursing personnel are required to make a large number of patient transfers.

4.5. *Laboratory setting versus actual worksite*

Based on laboratory study, the two-person walking belt using a pulling technique and the Ambulift offer great promise for transferring patients from bed to wheelchair and wheelchair to bed. Although there is no reason to believe that these techniques cannot be used successfully on most patients, caution is needed in extrapolating these results to actual patients, especially when using the walking belt. In spite of the fact that the subjects were instructed to act as passive patients, some of them may have assisted in the transfer. In long-term health care facilities, some patients cannot bear weight at all or are unpredictable in their ability or desire to bear weight. Some patients have very limited physical and mental abilities and are unable to assist (for example, those suffering from Alzheimer's disease) and some can be spastic, rigid, or have contracted joints. Some patients may have an abnormal body shape making it difficult for the belt to fit snugly and some can be resistive or combative or may grab nurses for support. In addition, the weight of the patient to be transferred is definitely a major factor. In this study, the weight ranged from 54 to 79 kg. Although it is difficult to prescribe a weight limit without detailed biomechanical and laboratory evaluations, as a safety precaution it is recommended that only Ambulift should be used for patients who cannot or might not bear weight and weigh more than 70 kg.

The type of wheelchair used and the adjustability of the bed may also influence the recommendations of this study. Geriatric chairs resemble lounge chairs with wheels and are usually lower and deeper than wheelchairs. On the other hand, some beds cannot be adjusted to a low height. This would make wheelchair to bed transfer with a walking belt more difficult and stressful, especially in the case of a totally dependent and heavy patient.

Lastly, nursing personnel are used to a particular patient transferring technique and may be reluctant to learn new techniques due to time pressure and workload, especially when the new techniques take more time and the facility is not adequately staffed. This would require significant education and training on the part of nursing personnel and continuous reminders, encouragement and long-term commitment on the part of administration. A large-scale field study is needed to verify these recommendations.

5. Conclusions

This study showed that for transferring patients from bed to wheelchair and wheelchair to bed, pulling a patient using a sling or belt, as compared to manually lifting a patient, requires lower hand forces and results in significantly lower erector spinae forces, compressive forces at L_5/S_1 and perceived stresses to the nursing personnel, and increased comfort and security of the patient. However, different slings and belts can cause different perceived stresses to nursing personnel and comfort and security levels for patients. The use of a mechanical hoist to transfer a patient, as compared to manual methods, does not necessarily produce reduced stresses to the nursing personnel and/or increased comfort and security to the patients. Therefore, close attention should be paid to various aspects of patient transfer when selecting a mechanical hoist or a manual device. Both mechanical hoists and manual devices take much longer to make a transfer than manually lifting the patient.

Based on nursing personnel and patient considerations, one mechanical hoist and a manual device appear best suited for transferring patients from bed to wheelchair and wheelchair to bed. These are the Ambulift hoist and the two-person walking belt with handles using a rocking motion and pulling technique. The two-person walking belt requires a pulling force of about 120 N and produces an erector spinae force of about 1700 N and a compressive force at the L_5/S_1 disc of less than 2000 N. Subjectively, the Ambulift and the two-person walking belt were rated to produce less than 'just noticeable' and 'noticeable' stresses at the shoulder, upper back, lower back and whole body. The patients felt very comfortable and secure with both methods. The nurses believed that the two-person walking belt could be used for those patients who cannot bear weight, who are heavy, contracted or combative or who have equipment attached. However, it is suggested that only Ambulift should be used for transferring heavy and totally dependent patients.

In spite of very favourable laboratory findings, caution should be used in extrapolating these results to actual worksites. Patient characteristics, adjustability of beds, staffing level, nurses' training and workload, and administrative support need to be considered in using the proposed techniques. Lastly a large-scale field study is needed to confirm the laboratory findings.

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