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Biomechanical evaluation of assistive devices for transferring residents

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Abstract

This is the first of two articles to report a biomechanical evaluation and psychophysical assessment of nine battery-powered lifts, a sliding board, a walking belt, and a baseline manual method for transferring nursing home residents from a bed to a chair. The objectives of the biomechanical evaluation were: (1) to investigate the effects of transfer method and resident weight on the biomechanical stress to nursing assistants performing the transferring task, and (2) to identify resident-transferring methods that could reduce the biomechanical stress to the nursing assistants. Nine nursing assistants served as test subjects; two elderly persons participated as residents. A four-camera motion analysis system, two force platforms, and a three-dimensional biomechanical model were used to measure biomechanical load. The results indicate that transfer method and resident weight affect a nursing assistant's low-back loading. The basket-sling and overhead lift devices significantly reduced the nursing assistants' back-compressive forces during the preparation phase of a resident transfer. In addition, the use of basket-sling, overhead, and stand-up lifts removed about two-thirds of the exposure to low-back stress (lifting activities per transfer) as compared to the baseline manual method. Thus, the use of these devices reduces biomechanical stress, and thereby will decrease the occurrence of resident-handling-related low-back injuries. Furthermore, lifting device maneuvering forces were found to be significantly different and a number of design/use problems were identified with various assistive devices. The second article will detail the psychophysical assessment of the same resident-transferring methods. Published by Elsevier Science Ltd.

Keywords: Patient-handling devices; Biomechanical evaluation; Back injury

1. Introduction

Nursing personnel have both high prevalence rates of back pain and high incidence rates of workers' compensation claims for back injuries (Klein *et al*, 1984; Biering-Sorensen, 1985; Leighton and Reilly, 1995). Between 1980 and 1992, the injury and illness rate for nursing home workers increased from 10.7 to 18.2 per 100 workers among the nation's 1,506,000 nursing aides, orderlies, and attendants (US Department of Labor, Bureau of Labor Statistics, 1994). According to 1994 Bureau of Labor Statistics data, nursing home workers face the third highest rate of occupational injury and illness (221,000 cases in 1994) among all US industries. The risk of back injury to nursing personnel, particularly in nursing home environments, has also been found to be high in other studies (Jensen, 1987; Jensen *et al*, 1989; Stobbe *et al*, 1988; Owen and Garg, 1989, Guo *et al*, 1995).

A significant portion of these back injuries can be attributed to events that occur during the handling and lifting of residents (Jensen *et al*, 1989; Leighton and Reilly, 1995). Stobbe *et al* (1988) used four statistical procedures to test the possible relationship between frequency of patient lifting and risk of having at least one episode of back pain. The survival analysis by Stobbe *et al* indicated that infrequent lifters survived longer than frequent lifters, i.e. worked for a longer time without back

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injury. Those nurses exposed to frequent patient lifting were more likely to have reported a back injury than those who infrequently lifted patients. In addition, the study showed that the longer a nurse was exposed to patient-handling tasks, the more likely she/he would be injured.

Kumar (1990) reached a similar conclusion when he studied the cumulative spinal compressive load (a combination of the lifting frequency, the years of lifting exposure, and the posture-related lifting forces) in health care personnel. He found that both cumulative spinal compressive load and cumulative generic load were predictive of low-back pain. He also found that the longer a person worked in patient-handling activities, the more likely they were to experience low-back pain.

Other studies have also shown that most of the occupationally related low-back pain in nursing professionals is the result of frequent manual lifting of patients (Bell *et al*, 1979; Harber *et al*, 1985; Venning *et al*, 1987; Jensen *et al*, 1989; Owen, 1987; Owen *et al*, 1992). Transferring residents from toilet to wheelchair and from wheelchair to toilet, and moving residents from chair to bed and bed to chair have been identified as the top four of 16 problematic tasks among patient/resident-handling tasks (Owen *et al*, 1992).

Several researchers have suggested that the use of assistive devices could reduce back stress for nursing personnel performing resident-handling tasks (Harber *et al*, 1985; Jensen, 1985; Venning *et al*, 1987; Owen and Garg, 1989; Stobbe *et al*, 1988). However, in a laboratory study of six assistive devices, Garg *et al*. (1991) found that two assistive devices were helpful and four were not helpful in reducing nursing personnel' back stress. During the last 6 years, many new assistive devices have become commercially available due to technological advances in the devices. Moreover, the advancement of motion measurement technologies in recent years has allowed researchers to more accurately study human motions, postures, and other physical requirements while using different resident-transferring methods. A comprehensive evaluation of these resident-transferring methods would be valuable to the health-care industry.

The objective of this study was to evaluate the effects of resident-transfer method and resident weight, on the biomechanical stress to nursing assistants performing a bed-to-chair transferring task, and thus to identify methods that could reduce the biomechanical stress to the nursing assistants. The bed-to-chair transfer task was defined as transferring a resident from a supine position (i.e. lying on the back on a bed) to an upright position in a chair. It was hypothesized that resident-transferring method and resident weight will affect the biomechanical load on a nursing assistant's low back during resident-transferring activities, and that assistive devices will reduce the L_5/S_1 compressive forces as compared to the baseline manual method. In addition, it was hypothesized that different assistive devices will not function equally and will require different levels of forces to operate or to position residents.

A psychophysical stress assessment of the same resident-transferring methods was also conducted in this study. The results of the psychophysical assessment portion of the study are presented in a companion paper (Zhuang *et al*, 1998).

2. Materials and methods

2.1. Subjects

There were two types of subjects in this study: nursing assistants and residents. Nine nursing assistants (two males and seven females) were recruited from local nursing homes. The nursing assistant selection criteria were that they must: (1) perform resident-handling tasks as part of their work activity; (2) be willing to undergo tests for static arm lifting strength and torso/leg lifting strength; (3) have no history of back injury or pain within the last year or chronic episodic back pain that was symptomatic within the last 3 years; and (4) have passed a medical screening exam. The nursing assistants' mean age, height, and body weight were 45.8 years (range = 20–69 years), 168 cm (range = 157–183 cm), and 76.2 kg (range = 45.5–132.3 kg), respectively. Mean experience as a nursing assistant was 33.2 months (range = 2–71 months).

Nursing assistants were trained in the proper use of the assistive devices by the manufacturers' representatives. The initial training was reinforced prior to each session with a review of the manufacturers' written instructions and video tapes. Prior to performing each transfer, the nursing assistants practiced the technique with feedback from the researchers. Each nursing assistant spent about 50 h on training and data collection.

Two elderly female volunteers, who were not nursing homes residents, served as residents for the study. Female volunteers were selected because most nursing home residents are female. In addition, conversations with nursing home personnel indicated that females were generally more difficult to transfer. Elderly subjects were selected because nursing home residents are generally elderly. One volunteer resident was 51 years old, 152 cm tall, and weighed 58.2 kg. The other was 67 years old, 160 cm tall, and weighed 77.3 kg. Both passed a medical screening exam.

2.2. Transfer methods

Twelve transfer methods [nine battery-powered lifts, a sliding board, a walking belt, and a manual transfer (i.e. no assistive device)] were evaluated in the study. These methods were classified into six categories: (1) baseline manual technique (no device), (2) walking belt, (3) sliding board, (4) stand-up lift (four brands), (5) overhead lift, (6) basket-sling lift (four brands). The selection criteria for the lifting devices were: (1) the device was designed for commercial rather than home use; (2) the device could be lowered to lift residents in a seated or lying position from the floor; and (3) the device could be equipped with scales to weigh totally dependent residents. All methods were evaluated using the same standardized task. The major activities of each category are summarized in Table 1.

The manual-transfer method required two nursing assistants to slowly lift and rotate the resident to assume a sitting position on the edge of the bed (Fig. 1). Both assistants then helped the resident to stand, pivot, back up to the chair, and sit down.

The walking belt has handles, is approximately 10-cm wide, and is wrapped around the resident's abdomen–hip area to provide a grip during the transfer (Fig. 2). With the walking belt, the nursing assistants assisted the resident to a sitting position on the side of the bed (as described above). The walking belt was snugly fastened around the resident's lower abdomen–hip area. The resident was helped to a standing position, pivoted and backed up to a chair, and seated into the chair.

The sliding board (Fig. 3) is 102 cm long, 30 cm wide with a 1.3-cm-thick seat which slides on a 2.5-cm-thick

Fig. 1. Baseline manual transfer method.

Table 1
The major activities of each resident-transferring method category

Categories	Major activities	Data collected
Baseline manual method (two nursing assistants)	1. Lifting torso or legs of the resident	FP
	2. Helping the resident to reach a standing position	FP
	3. Helping the resident move around to the chair	*
	4. Lowering the resident into the chair	**
Walking belt (two nursing assistants)	1. Lifting torso or legs of the resident	FP
	2. Pulling the resident to reach a standing position	FP
	3. Lowering the resident into the chair	**
	4. Fastening and removing the walking belt	*
Sliding board (one nursing assistant)	1. Rotating the resident to a sitting position	FP
	2. Placing the board under the resident	*
	3. Gliding the resident across the board	F
	4. Pulling the board out from under the resident	*
Basket-sling lift (four brands) (one nursing assistant)	1. Rolling the resident away from or toward the assistant	FP
	2. Placing, connecting, and removing the basket-sling	*
	3. Pushing and turning the lift	F
	4. Pulling the resident to an upright position in the chair	F
Overhead lift (one nursing assistant)	1. Rolling the resident away from or toward the assistant	FP
	2. Placing, connecting, and removing the basket-sling	*
	3. Pushing and turning the lift	F
	4. Pulling the resident to an upright position in the chair	F
Stand-up lift (four brands) (one nursing assistant)	1. Rotating the resident to a sitting position	FP
	2. Positioning the resident's feet on the footrest	*
	3. Placing, connecting, and removing the sling	*
	4. Pushing and turning the lift	F

FP = biomechanical evaluation (i.e. measurement of both hand force and posture).
F = measurement of hand force only.
* = no measurement; no major back stress involved.
** = no measurement of hand force or posture.

Fig. 2. Walking belt.

Fig. 3. Sliding board.

Fig. 4. A basket-sling lift.

Fig. 5. An overhead lift.

board, and weighs 2.9 kg. One nursing assistant slowly and smoothly lifted and rotated the resident to a sitting position on the edge of the bed. The nursing assistant placed the seat under the resident, fasten a belt around the resident's waist, and glided the resident slowly across the board into the chair.

The basket-sling lifts are wheeled devices with battery-powered lifting arms. The resident is placed in a basket sling, centred over the device base, and gently raised. Fig. 4 shows one of the four devices evaluated in this study. The transfer method required one nursing assistant to roll the resident (in the bed) onto her side, fold the sling in half, place it behind the resident's back, connect the sling straps to the lift, lift the resident, move her to the chair, and lower her into it.

Overhead lifts have battery-powered lifts with basket-slings attached to a ceiling-mounted track that can be moved to access any part of a room or building. In this laboratory, the track was installed over the bed and chair to perform the resident-transferring task. One overhead lift (Fig. 5) was tested. The transfer procedure for this lift was the same as the basket-sling lift.

Stand-up lifts are similar to the basket-sling lifts except that the resident is standing rather than sitting. Here again, a nursing assistant assisted the resident to a sitting position on the side of the bed. The stand-up lift was brought to the resident, the resident's feet were positioned on the footrest, a belt-sling was placed under the arms and around the resident's back, and the support arms were raised to elevate the resident to a near-standing position with the feet being supported on the footrest. The device was positioned in front of the chair and the resident was seated. Fig. 6 shows one of the four devices evaluated in the study.

2.3. Experimental design

The experimental design was an $a \times b \times c$ split-plot design, where $a = 9$ nursing assistants, $b = 2$ residents/weight levels, and $c = 5$ activity–category combinations, with two replications at each factor level combination. The specific activity–category combinations are presented in the first and second rows in Table 2. Generally speaking, each of the six resident-transferring category methods includes four major activities (Table 1). This study focussed on the first activity (i.e. lifting/rolling/rotating the resident to prepare for a transfer) because it is the most strenuous one of the four activities.

Fig. 6. A stand-up lift.

The nine nursing assistants were organized into five pairs; the fifth pair was formed with the ninth nursing assistant and one of the first eight. The method presentation order was randomized for each resident/nursing assistant combination in each test session.

2.4. Measurement techniques

A three-dimensional motion analysis system, the Peak® Performance System, was used to register the body postures and joint angles of the nursing assistants. Twelve reflective markers were placed on the left and right side of the wrist, elbow, shoulder, hip, knee, and ankle. Four cameras were placed on fixtures mounted in each corner of the lab at approximately right angles to one another and centered upon the same point (Fig. 7). The cameras were time-synchronized and placed about 5.3 m from the subject and 2.2 m above the floor. This camera arrangement allowed at least two cameras to constantly track the markers.

Two Kistler® force platforms were positioned side by side so that the ground-reaction forces of the two nursing

Table 2
Summary of biomechanical measures for lifting/rolling/rotating the resident to prepare for a transfer

Variables	Baseline manual and walking belt (two-person)		Basket-sling lift and overhead lift (one-person)		Stand-up lift and sliding board (one-person)
	Lifting torso ($n = 20$)[A]	Lifting legs ($n = 20$)	Rolling toward ($n = 36$)	Rolling away ($n = 36$)	Rotating resident ($n = 36$)
Both Residents					
Trunk flexion angle (°)	43 ± 5[B]	38 ± 11	35 ± 6	37 ± 9	42 ± 9
	35–50[C]	20–62	25–50	17–55	26–57
Trunk lateral bending (°)	12 ± 6	10 ± 7	5 ± 5	7 ± 5	21 ± 9
	4–26	0–21	0–15	0–15	3–38
Trunk rotation angle (°)	10 ± 5	12 ± 7	7 ± 5	9 ± 5	20 ± 10
	0–20	0–25	0–20	2–17	1–37
Hand force (N)	139 ± 28	174 ± 42	83 ± 21	102 ± 25	194 ± 58
	89–173	113–262	44–120	54–147	58–315
% Capable	78 ± 22	84 ± 13	84 ± 15	87 ± 13	74 ± 16
	26–95	53–97	38–97	44–96	41–97
Back-compressive force (N)	3487 ± 614	3150 ± 482	2951 ± 503	2698 ± 582	3454 ± 571
	2391–4999	2298–4089	2094–4367	1804–4745	2436–4618
Group label[D]	A	B	C	D	A
Heavier Resident					
Back-compressive force (N)	3676 ± 572	3216 ± 517	3081 ± 531	2786 ± 708	3635 ± 639
	2977–4999	2298–3085	2407–4367	1881–4745	2436–4618
Group label	A	B	B	C	A
Lighter Resident					
Back-compressive force (N)	3299 ± 625	3085 ± 462	2822 ± 452	2610 ± 424	3273 ± 439
	2391–4397	2585–3806	2094–3904	1804–3438	2470–3990
Group label	A	A	B	B	A

[A]Number of observations (5 nursing assistants × 2 residents × 2 replications).
[B]Mean (43) and standard deviation (5) of n observations.
[C]Range.
[D]Mean compressive forces with the same letter (A–D) are not significantly different ($p > 0.01$).

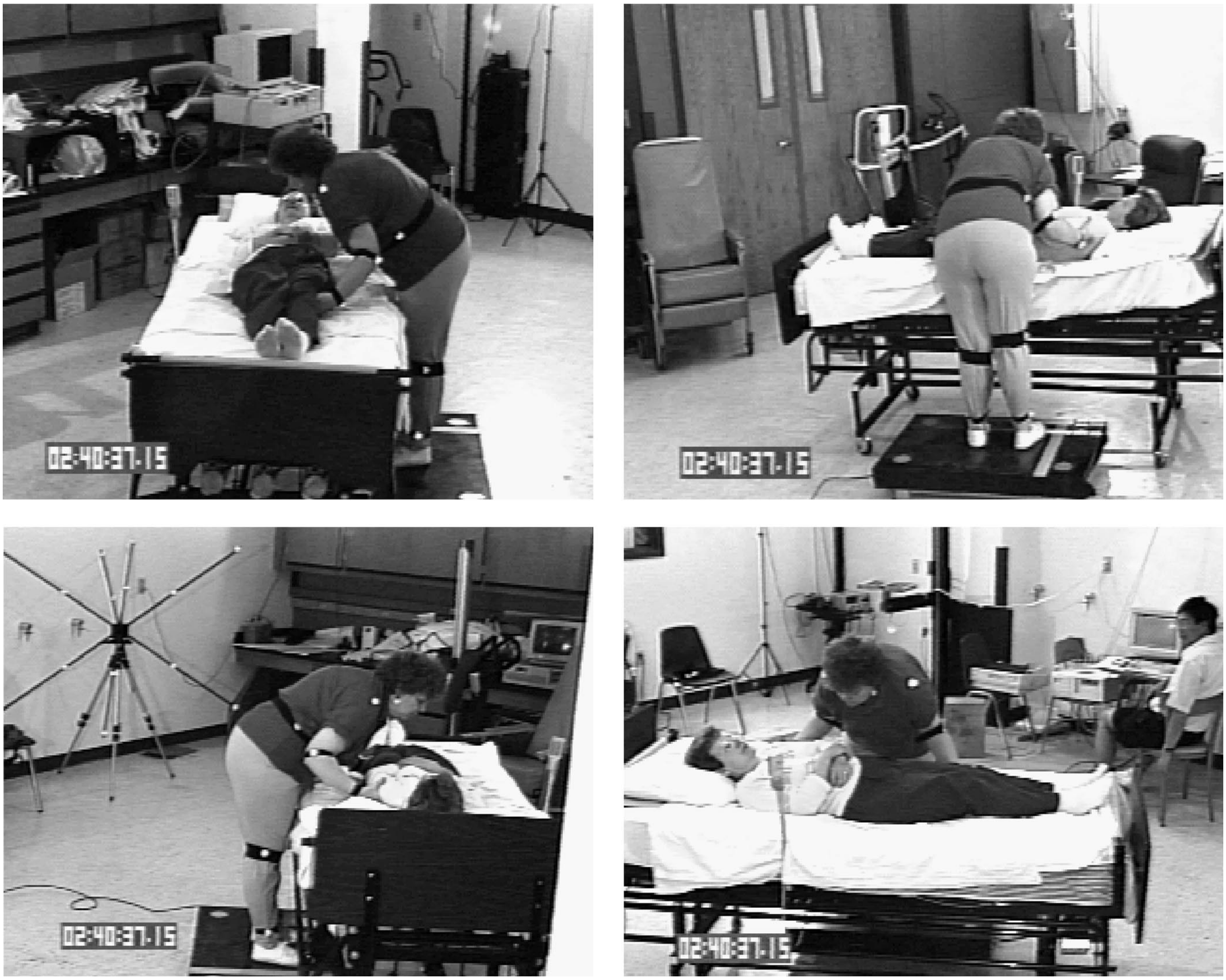

Fig. 7. Motion measurement of a nursing assistant rolling the resident using a four-camera system.

assistants could be determined during each resident transfer. The force platforms were time-synchronized with the motion-analysis system. Only one force platform was used when only one nursing assistant performed the transfer. The measured ground-reaction forces and hand-motion directions captured on the video tapes were used to estimate the magnitude and direction of the nursing assistants' hand forces when performing the transfer task.

A three-dimensional biomechanical model (University of Michigan, 1993) was used to estimate the L_5/S_1 compressive force and the percent of the population with sufficient strength capability to perform the task. Body posture, hand-force magnitude and direction, and the nursing assistants' anthropometric data were the input parameters. It should be noted that the percent not capable (100% minus percent capable) are considered to be at increased risk of musculoskeletal injury due to their inadequate strength to perform the task (NIOSH, 1981 and 1994).

2.5. Data collection procedures

Nursing assistants practiced the method, then the markers were placed. The resident-transferring activities shown in Table 1 were then performed. The nursing assistants' postures and hand forces were recorded with the cameras and force platforms. Then, the nursing assistants stood on a force platform and pushed/turned each device with a resident in the sling. This procedure was used to quantify the device's maneuvering force. The sliding board hand forces were measured in the same way. The hand forces required to pull a resident in a basket-sling to an upright position in a chair were also measured in this manner.

2.6. Statistical analysis

Statistical analyses of data were performed by using Statistical Analysis System (SAS) software (SAS Institute Inc., 1989) and linear models for the split-plot designs. Duncan's Multiple Range Tests (Montgomery, 1984) were performed to compare means and detect significant differences between means. The back-compressive forces for each nursing assistant for each transfer with the baseline manual and walking-belt methods were dependent on each other. A significance level of 0.01 was used because of the co-dependence of the two data points for each nursing assistant when they performed a transfer together. For other dependent variables, a significance level of 0.05 was used for statistical tests.

3. Results

3.1. Low-back loading while lifting/rolling/rotating the resident to prepare for a transfer

Trunk flexion, lateral bending, and rotation angles, hand force, back-compressive force, and percent of population capable of performing the activity are summarized by activity–category combination in Table 2. The Duncan's grouping of mean back-compressive forces is illustrated with superscript letters in the table. Means with the same superscript letter are not significantly different. The analysis of variance (ANOVA) for back-compressive force is shown in Table 3. A plot of the residual values showed that the data are normally and randomly distributed. The ANOVA results show the statistical significance of main effects of nursing assistant subject, resident weight, and transfer method.

During the two-person baseline manual and walking-belt methods, the average back-compressive force (when the resident was rotated to a sitting position on the edge of the bed) was 3487 Newtons (N). The average back-compressive force was 3454 N when a single assistant rotated a resident to the edge of a bed to prepare for a stand-up lift or sliding board transfer. These mean compressive forces exceeded the back-compression criterion limit (3400 N) recommended by the National Institute for Occupational Safety and Health (NIOSH, 1981 and 1994) and were significantly larger than the mean back-compressive forces generated by other activity–category combinations. Thus, the use of basket-sling and overhead lifts significantly reduced the nursing assistants' back-compressive forces during this resident-transferring preparation stage.

Table 3
Analysis of variance for back-compressive force

Sources of variation	Degree of freedom	Mean square	F-ratio	P-value
Whole plot				
Nursing assistant (S)	8	2,907,561	47.6	0.0001
Resident weight (W)	1	2,549,269	41.7	0.0001
$S \times W$	8	212,602	3.5	0.0019
Subplot				
Method (M)	4	3,331,165	54.5	0.0001
$S \times M$	26	3,97,139	6.5	0.0001
$W \times M$	4	75,131	1.2	0.3058
$S \times W \times M$	22	85,626	1.4	0.1430
Errors	74	61,112		
Total	147			

The biomechanical data were also analyzed to determine the effect of resident weight: the average back-compressive force was greater when transferring the heavier resident, and the average percent of population capable significantly smaller when transferring the heavier resident (Table 2).

3.2. Hand force requirement while pushing/turning lift devices

The pushing and turning forces are summarized by device and resident in Table 4. The overhead lift had a significantly smaller mean pushing force (24 N) than the other devices. The largest mean pushing forces (44 and 43 N) were almost twice those of the overhead lift. Basket-sling lifts required significantly larger pushing forces to operate than other lift devices. The average force required to push the lifts was significantly greater for the heavier resident than the lighter one.

The sliding board required a mean force of 81 N which was significantly larger than the mean turning forces associated with the lift devices. There were no statistical differences in mean turning forces among the basket-sling and stand-up lifts.

3.3. Hand force requirement while pulling a resident in a sling to an upright position

The pulling forces are summarized by device and resident in Table 5. The sling handle pulling forces varied from 121 to 174 N. Only the highest and lowest pulling forces were significantly different from the other devices' pulling forces. The average pulling force was significantly greater for the heavier resident (Table 5). Clearly, resident weight is an important factor in determining the physical stress on the nursing assistant during patient handling.

4. Discussion

4.1. Low-back loading while lifting/rolling/rotating the resident to prepare for a transfer

In this study, the task was to transfer a resident from a supine position on a bed to an upright position in

Table 4
Resident/device maneuvering forces by transfer method

Method	Both residents: Mean[A] $n = 18$ (N)	Group label[B]	Standard deviation	Range	Heavier resident: Mean[C] $n = 9$ (N)	Lighter resident: Mean[C] $n = 9$ (N)
Pushing force						
Basket-sling lift #2	44.0	A	7	32–57	47	56
Basket-sling lift #3	43.1	A	6	35–54	44	42
Basket-sling lift #4	42.1	A,B	7	30–53	45	39
Basket-sling lift #1	38.9	B,C	6	25–55	42	28
Stand-up lift #1	37.2	C,D	7	28–53	39	35
Stand-up lift #4	36.8	C,D	10	15–59	41	32
Stand-up lift #3	35.6	C,D	6	25–44	38	33
Stand-up lift #2	34.7	D	6	25–44	38	32
Overhead lift	24.0	E	6	15–38	25	23
Turning force						
Sliding board	81.3	A	40	38–163	89	74
Basket-sling lift #4	32.4	B	7	20–45	32	32
Basket-sling lift #2	31.3	B	6	23–41	31	31
Stand-up lift #1	30.7	B	7	20–42	32	29
Basket-sling lift #3	30.5	B	8	10–52	31	30
Basket-sling lift #1	29.3	B,C	5	20–39	30	28
Stand-up lift #4	29.2	B,C	6	21–43	29	29
Stand-up lift #2	27.3	B,C	4	20–34	28	27
Stand-up lift #3	26.8	B,C	10	8–47	28	26
Overhead lift	24.5	C	5	16–34	26	23

[A]The mean maneuvering force was associated with the activities of pushing or turning the lift to the chair while the resident was supported in the sling, and sliding the resident across the sliding board.
[B]Mean pushing or turning forces with the same letter (A–E) are not significantly different ($p > 0.05$).
[C]Mean pushing or turning forces for each resident.

a chair. The baseline manual transfer and the walking-belt methods both required rotating the resident to a sitting position on the edge of the bed before transfer. The average back-compressive force was 3487 N for the nursing assistant lifting the resident's torso (while working with another nurse to rotate the resident to a sitting position on the edge of the bed), with the maximum value exceeding 4900 N. The 1981 and revised NIOSH lifting guidelines (1981, 1994) use 3400 (N) as the back-compression criterion. Clearly, nursing personnel are exposed to excessive biomechanical stress when performing resident transfers without using any assistive device.

One interesting observation from this study is that more than 10% of the measured back-compressive forces for each activity/category combination exceeded the NIOSH criterion limit of 3400 N (1981, 1994). This implies that transferring residents from bed to chair is very stressful for some people (especially those who are overweight) even when assistive devices are used.

This study revealed that the average back-compressive force associated with the use of basket-sling and overhead lifts was 2951 N when the nursing assistants rolled residents toward themselves and 2698 N when rolling residents away from themselves. Rolling a resident either toward or away is considered to be the most stressful action performed when using basket-slings or overhead lifts. However, these forces were about 15 and 23%, respectively, smaller than the force (3487 N) associated with the baseline manual transfer. Thus, the basket-sling and overhead lifts significantly reduced the biomechanical load on the nursing assistants' backs during resident transfers. Given that manual resident transfers are not always done with two nursing assistants in nursing homes, the advantage of using a basket-sling or an overhead lift could be even greater in practice than that found in this laboratory.

The manufacturers of the basket-sling and overhead lifts recommend that nursing personnel either roll the resident away from themselves (push) or toward themselves (pull) before placing the sling under the resident. This study's results demonstrate that nursing assistants should roll the resident away from themselves using a pushing motion before placing the sling under the resident. When nursing personnel push the resident away from themselves, their hands are positioned close to their bodies, while pulling is done with the hands far from their bodies. In addition, pushing decreases back extensor

Table 5
Forces required to pull a handle on the back of the slings for the basket-sling and overhead lifts to position the resident in an upright position

Method	Mean[A] (N)	Group label[B]	Standard deviation	Range
Both residents ($n = 18$)				
Basket-sling lift #1	174	A	60	53–263
Overhead lift	152	B	49	53–240
Basket-sling lift #4	145	B	45	80–240
Basket-sling lift #2	143	B	40	85–209
Basket-sling lift #3	121	C	45	36–196
Heavier resident ($n = 9$)				
Basket-sling lift #1	191	A	67	67–263
Basket-sling lift #2	171	A	35	120–209
Overhead Lift	163	A,B	52	67–240
Basket-sling lift #4	152	A,B	45	93–214
Basket-sling lift #3	122	B	48	49–196
Average of all lifts	160			
Lighter resident ($n = 9$)				
Basket-sling lift #1	157	A	49	53–214
Overhead lift	140	A,B	45	53–209
Basket-sling lift #4	137	A,B	45	80–240
Basket-sling lift #3	121	B	41	36–174
Basket-sling lift #2	114	B	21	85–147
Average of all lifts	134			

[A]The pulling force was associated with the activity of pulling a handle on the back of the sling while lowering the resident into the chair in an upright position.
[B]Mean pulling forces with the same letter (A–C) are not significantly different ($p > 0.05$).

action while pulling increases it. These factors result in lower back-compressive forces for pushing.

The average back-compressive force (3454 N) associated with preparing to use a stand-up lift or sliding board exceeded the NIOSH criterion limit (Table 2); the use of the stand-up lift and sliding board may not result in less biomechanical stress to nursing personnel during the preparation phase of resident transfers than the manual method. However, the stand-up lift is designed for assisting partially dependent residents, and with help from residents, nursing assistants may experience less back-compressive forces during the preparation phase than those observed in this study (residents were asked not to assist during any of the study's activities).

After a sling was placed under the resident, the use of the basket-sling and overhead lifts completely eliminated the exposure to low-back stress associated with helping the resident to a standing position and lowering the resident into the chair as required by the manual method. Thus, about two-thirds of the lifting stress exposure (frequency) was removed as compared to a manual-lifting method. When the stand-up lift and sliding board were used for a transfer, the helping and lowering activities associated with the manual method were also eliminated and biomechanical loads on nursing personnel were reduced as well. In addition, nursing personnel's risk of dropping a resident or having a resident fall during the transfer is decreased.

4.2. Hand force requirement while pushing/turning lift devices

This study revealed that the maximum pushing force required to move the lift devices tested was 59 N and the maximum turning force was 52 N. These forces are well within the peak pushing strength of 186 N (maximum pushing force acceptable to 75% of females for a 2.1 m push at 57 cm height) (Snook and Ciriello, 1991). Thus, pushing/turning activities associated with the use of assistive devices are not believed to be a cause of significant overexertion to nursing personnel. However, the design of the wheels, width and length of the lift base, shape of the lift base, and location of the pushing frame were the primary factors that caused significant differences in forces required to push or turn different lifts. An inappropriate pushing frame position may force nursing assistants to use awkward postures which may aggravate an increased risk of musculoskeletal disorder than the pulling, turning, or pushing forces themselves.

4.3. Hand force requirement while pulling a resident in a sling to an upright position

When residents are transferred to a chair by a basket-sling or an overhead lift, they must be placed so that they sit upright. While pulling a resident to an upright position in a chair using basket-sling lifts or the overhead lift, the nursing assistants' postures were approximately neutral. The forces required to pull the sling handle were significantly different. The design of the sling, sling handle, handle position, and frame of the lift are the primary factors that caused the differences in pulling forces among different lifts. The handle on some slings was positioned too low and was not easily grasped, which resulted in an awkward posture while pulling.

5. Summary and conclusions

The task of transferring residents from a bed to a chair in nursing homes involves four major activities. There are a number of sources of low-back stress during resident transferring. During the activity of lifting/rolling/rotating the resident to prepare for a transfer, the average back-compressive forces associated with using the basket-sling and overhead lifts were smaller than the forces associated with the baseline manual method and the NIOSH recommended criterion limit (a positive result for nursing assistants). The authors conclude that the use of basket-sling and overhead lifts significantly reduced the biomechanical load on the nursing assistants' backs during this activity. In addition, the study results suggest that nursing assistants consider rolling the resident away from themselves using a pushing motion instead of rolling the resident toward themselves before placing the sling under the resident.

During the preparation for the stand-up lift and sliding board transfers, the biomechanical stress to nursing personnel was not significantly different from the baseline manual transfer. However, the use of stand-up lift devices as well as basket-sling and overhead lifts completely eliminated the exposure to low-back stress associated with helping the resident to a standing position and lowering the resident into the chair manually. Thus, about two-thirds of the lifting-stress exposure (frequency) was removed. In addition, these methods eliminate the rapid, sometimes jerky movements associated with moving the upright resident from a bed to a chair, and reduce the risk of the resident falling. Based on these results, the use of resident-handling devices is expected to reduce low-back injuries to nursing personnel.

The authors also conclude that maneuvering forces were found to be significantly different among lifting devices. The differences may be associated with the design of the wheels, width and length of the base of the lift, shape of the base, and location of the pushing frame. Significant differences in force required to pull the sling handle were found among different basket-sling lifts. The design of the sling, sling handle, handle position, and frame of the lift may have caused the differences in force required to pull residents to a sitting position. Thus, there is still considerable room for improvement of the assistive devices.

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