

An ergonomic comparison between mechanical and manual patient transfer techniques

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Abstract. Multiple studies have concluded that manual patient transfer and repositioning techniques are a significant cause of low back injuries. The objective of this study was to compare the low back stresses resulting from the use of two different mechanical patient transfer assist devices with the use of traditional manual transfer techniques. The mechanical transfer systems used were the Barton Patient Transfer System and a Sling-Suspension Lift similar to a “Hoyer Lift”. The back compressive forces derived using the Michigan 3D Static Strength Model (Version 4.0) and electromyography (EMG) of the muscles of the low back were compared. This study found that the mechanical assist devices placed less stress on the low back and were more desirable to use than the traditional manual techniques. The Barton System was found to be, in general, less hazardous and more preferred than the Sling Suspension Lift.

1. Background and introduction

Low back pain is a serious problem among hospital personnel, and in particular the nursing staff. The nursing profession has been shown to be one of the most at risk occupations for low back pain [2,3,5,6,8,10]. Klein found that practical nurses had 3.3 low back pain related claims per 100 workers and nursing aides had 3.6 claims per 100 workers. These claim rates are approximately the same as the rates for material handlers (3.4), lumberman (3.3) and construction laborers (2.8) [8]. Nurses have a low back pain point prevalence of 15%, a period prevalence of 40–50% and a lifetime prevalence of 35–80% [6]. The prevalence and fre-

quency of low back pain and injury have resulted in decreased productivity and lost time from work. The Ontario Hospital Association found that, among all hospital nursing personnel, back injury accounted for more than 40% of all time-lost claims [13].

Many studies have concluded that manual patient handling is one of the primary causes for the high prevalence of low back pain among nurses and nurse aides [1,2,4,7]. Smedley et al. [11] performed a study on manual handling techniques and the risk of low back pain in nurses. They found that patient repositioning and patient transfers from bed to chair were associated with increased risk of low back pain [4]. The hazard associated with the lifts and transfers is not only a function of the weight of the patient but is a combination of many other factors including the patient’s size, shape, deformities, low limb function, balance and co-ordination [1,4,5]. Also, the nurse may be in situations where the lifting posture is awkward, the lift is jerky or accelerated or the space available is constricted [1,5].

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The risk associated with manual transfers and repositioning may be a result of a lack of training in the proper lifting techniques. It has been found, however, that the traditional approach of training in proper lifting and handling techniques alone are of little, or no, long-term benefit [6]. Wachs and Parker [14] studied the lifting behaviors of 178 nurses and found that only 2% of these nurses followed the prescribed lifting behavior. They suggested that nurses be taught the principle of body mechanics specific to patient transfer (vs. lifting and carrying a box, for example) and that the nurses' understanding of these principles be evaluated. They also suggested that the use of prescribed lifting behavior be recognized in performance evaluations.

Marras et al. [9] quantified the hazards of manual patient transfers and repositioning and found that there is a significant risk when manually transferring patients and that manual patient handling should be considered an extremely risky task. As a result of these findings, Marras et al. recommended the use of mechanical lifting devices. Many of these mechanical devices, however, have not been evaluated to determine if they are effective in reducing the physical hazards associated with patient handling.

2. Objectives

The objective of this study is to compare the low back stresses resulting from the use of two different mechanical patient transfer assist devices with the low back stresses during the use of traditional manual transfer techniques. The mechanical transfer systems being used are the Barton Patient Transfer System and a Sling Suspension Lift.

3. Material and methods

3.1. Subjects

Six subjects were recruited to participate in this study. Four of the subjects were female and two were male. The average age, height, and weight of the subjects were 29.2 years ($\sigma = 9.9$ years), 66.6 inches ($\sigma = 3.1$ inches) and 147.7 lbs. ($\sigma = 34.8$ lbs.) respectively. None of the subjects claimed to be experiencing low back pain. All of the subjects had been formally trained in patient transfer and repositioning techniques and perform such duties regularly as a part of their job. The subjects were paid ten dollars per hour for their participation in this study.

3.2. Standard patient

In an attempt to minimize the stresses placed on the subjects, a 120 lb., 66 inch, female patient was used as a standard patient. The use of a relatively small patient was intended to decrease the risk of fatigue or injury to the subjects during the study. The utilization of the same patient for all of the transfer techniques also standardized the amount of assistance that the patient provided.

3.3. Study procedure

The objective of this study is to compare the back compressive forces on nursing personnel during various manual and mechanically assisted transfer and repositioning tasks in order to determine if the use of a mechanical transfer device is less hazardous than the use of traditional, manual transfer techniques. This was accomplished by comparing the back compressive forces derived from the data collected using the Michigan 3D Static Strength Prediction Program [12] and electromyography (EMG) of the muscles of the low back.

The subjects were videotaped using three cameras to record two lateral views and one anterior/posterior view, while they performed the various transfers and repositioning tasks. This videotaped data was then used to identify the most stressful postures associated with each task. The postural data was entered into the model along with the force magnitude and force vector data to estimate a back compressive force value. The back compressive force calculated using the Michigan 3D model will be termed $F_{c_{mod}}$.

The subjects also wore EMG electrodes on both their right and left erector spinae while performing the transfer and repositioning tasks. The EMG activity was sampled at 30 Hertz and was smoothed using an 11 point moving average. The data was then converted into back compressive force values using a calibration relationship between the EMG values and the back compressive forces. Data were collected during two calibration trials in which the subjects first held an 8.8 lb. weight with both hands at arm's length at 0° and 45° of hip flexion and then repeated the process with a 14.3 lb. weight. Each data point represented the back compressive force determined from the Michigan 3D model and the recorded EMG value. A line-of-best-fit was then established to be the calibration curve. The average R^2 between the EMG and the back compressive force was 0.863 with a range of 0.634 to 0.988. The back

compressive force determined from the EMG data was then used to determine the most stressful 1/3-second of the lift. The back compressive force derived from the EMG data corresponding to the average most stressful 1/3-second during the entire transfer will be termed F_{CEMG} .

After performing the different tasks, the subjects were asked to compare the different techniques using a numerical rating system. The following questions were asked.

1. Was this technique easy to use?
(1 = difficult, 3 = no significant problem, 5 = very easy)
2. How much physical effort did this technique require?
(1 = a great deal of effort, 3 = somewhat stressful but could perform several times per day, 5 = minimal effort)
3. Was this technique comfortable to use?
(1 = uncomfortable, 5 = very comfortable)
4. Do you feel that this technique is safe for nursing personnel to perform?
(1 = unsafe, 5 = completely safe, little, if any chance of injury to personnel)
5. Do you feel that this technique is safe for the patient?
(1 = unsafe, 5 = completely safe, little, if any chance of injury to the patient)
6. Would you use this method in your work environment?
(1 = no, 5 = yes)
7. Which of the techniques do you prefer?

Upon comparing the techniques, the subjects were asked to list any comments they had concerning the various techniques.

3.4. Mechanical assist devices

3.4.1. Barton System

The Barton System transfer and repositioning process is one that is designed to be performed by a single person. The system consists of the Barton Bar and the bed/chair, referred to as the Barton in this study (see Fig. 1). The telescoping, light-weight metal bar is designed to rest in the cradle of the two bracket adapters that are either clamped onto the bed to which the patient is being transferred (during bed to bed transfers) or clamped onto the head of the bed (during patient repositioning). Sliding metal bales are attached to the bar. The nylon straps are attached to these bales with

Velcro. With the bar resting on the brackets, the nylon straps are attached to the bed sheet on which the patient is lying using sheet clips. The person performing the techniques then rotates the Barton bar using the crank that is stored in either end of the Barton Bar when it is not being used. As the bar is rotated, the nylon straps wrap around the Barton Bar. This pulls the sheet and therefore slides the patient into position.

The Barton can also be converted from a bed to a chair and vice versa with a patient sitting on it. A single nurse can transform the Barton from a bed to a chair through the use of the brake release squeeze bar located under the head of the Barton. The nurse then securely tightens the belt around the patient's waist and extends the footrest. The nurse then squeezes the brake release bar and either gently lifts or lowers the head of the bed. The pneumatic device allows the movement of the head of the bed to be slow and smooth. The brake release bar can be released when the desired angle of the head of the bed is achieved and the position of the Barton will be locked in place.

3.4.2. Sling Suspension lift

Sling Suspension lifts consist of a pneumatic crane on wheels and a nylon sling with eyelets in the four corners (see Fig. 2). Upon positioning the patient in the sling and widening the crane's base of support, the crane boom is lowered. The hooks, attached to the boom, are hooked onto the sling through the eyelets. The person performing the transfer then uses the pneumatic crank to raise the patient up. The crane is then positioned over the bed or chair to which the patient is being transferred, and the pneumatic switch is released and the patient is lowered.

3.5. Patient transfer techniques

Fourteen different patient transfer techniques were divided into four transfer categories: bed to bed transfers, bed to chair transfers, chair to bed transfers and repositioning techniques. For each category, the patient transfer techniques most likely to be used in the field were analyzed. The following techniques were analyzed for each category.

1. Bed to Bed
 - a. Barton
 - b. Two-Person Draw Sheet
2. Bed to Chair
 - a. Barton
 - b. Two-Person Hook
 - c. Sling Suspension Lift
 - d. One-Person Hug



Fig. 1. Bed to Bed Transfer using the Barton System.



Fig. 2. Bed to Chair Transfer using the Sling Suspension lift.

3. Chair to Bed

- a. Barton
- b. Two-Person Hook
- c. Sling Suspension Lift
- d. One-Person Hug

4. Repositioning

- a. Barton

b. Two-Person Hook

c. Two-Person Draw Sheet

d. One-Person Hug

3.5.1. Bed to bed transfers

3.5.1.1 Barton System

The Barton Bar was placed on two brackets that are positioned on the side of the Barton System farthest

from the patient. This transfer is designed to be performed by a single person and is shown in Fig. 1. The four straps that are attached to the bar were then attached to the sheet. The crank was then pulled out of the center of the bar and cranked until the patient was transferred. This transfer is designed to be performed by a single person and is shown in Fig. 1. Each subject performed this transfer once.

3.5.1.2 Two-person draw sheet

The patient's bed was positioned directly next to the bed onto which the patient was to be transferred. The subjects lifted and slid the patient to the second bed using the underlying sheet. A standard hospital bed and the Barton were used to represent the two beds (see Fig. 3). Each subject performed this lift twice: once moving the patient away from him/her and once moving the patient toward him/her.

3.5.2. Bed to chair transfers

3.5.2.1 Barton System

With the patient already lying on the Barton, a single subject securely buckled the patient onto the Barton and extended the Barton Footrest. The subject then squeezed the brake release handle under the head of the bed and lifted up until the Barton was transformed from a bed to a "chair". Each subject performed this transfer once.

3.5.2.2 Two-person hook

A wheelchair was placed next to the bed on which the patient was sitting. With one subject on either side of the patient, the subjects bent and placed their forearms under the axilla of the seated patient and lifted her from the bed to a wheelchair (see Fig. 4). Each subject performed this lift twice, once while lifting on the side of the patient closest to the wheelchair and once while lifting on the side of the patient furthest from the wheelchair.

3.5.2.3 Sling Suspension lift

The sling was placed under the patient by rolling her onto her right side and then onto her left side. Chains from the Sling Suspension lift's boom were attached to the eyelets in the sling. The subject then cranked the patient up until the patient cleared the bed, positioned the suspended patient over the wheelchair and finally lowered the patient into the wheelchair. This is similar to Fig. 2. Each subject performed this transfer once.

3.5.2.4 One-person hug

With the patient seated on the edge of the bed, the subject grasped the patient around the waist at the same time the patient would hug the subject around the neck. The patient was then lifted off of the bed and lowered into a wheelchair (see Fig. 5). Each subject performed this transfer once.

3.5.3. Chair to bed transfer

3.5.3.1 Barton System

With the patient sitting upright in the chair form of the Barton System, the subject squeezed the brake release bar and lowered the head of the Barton until it was in its "bed" form. Each subject performed this transfer once.

3.5.3.2 Two-person hook

With one subject on either side of the patient seated in a wheelchair, the subject bent and placed their forearms under the patient's axilla and lifted the patient from the wheelchair to the bed. This is similar to Fig. 4. Each subject performed this transfer twice, once on either side of the patient.

3.5.3.3 Sling Suspension lift

With the sling already underneath the patient, the subject raised the patient up out of the wheelchair, positioned the suspended patient over the bed and lowered her onto the bed. This is similar to Fig. 2. It was assumed that a Sling Suspension assistive transfer device was previously used to transfer the patient into the chair and therefore, the sling would already be underneath the patient when it was time to transfer the patient out of the chair. (If this were not the case there would be additional back stress during the placement of the sling under the subject.) Each subject performed this transfer once.

3.5.3.4 One-person hug

With the patient seated in a wheelchair, the subject grasped the patient around the waist and the patient grasped the subject around the neck. The patient was then lifted up out of the wheelchair and onto the bed. This is similar to Fig. 5. Each subject performed this transfer once.



Fig. 3. Bed to bed transfer using the two-person draw sheet technique.



Fig. 4. Bed to chair transfer using the two-person hook technique.

3.5.4. Repositioning techniques

3.5.4.1 Barton System

The Barton Bar was placed on two brackets attached to the head of the bed. The two straps connected to the bar were then attached to the sheet using sheet clips. After pulling the crank out of the center of the bar, the subject cranked the Barton Bar in order to reposition

the patient approximately 12 inches closer to the head of the bed. This is similar to Fig. 1 except the Barton begins at the head of the bed instead of at the side. Each subject performed this transfer once.

3.5.4.2 Two-person hook

With one subject on either side of the reclined patient, the subjects bent and placed their forearms under the



Fig. 5. Bed to chair transfer using the one-person hug technique.

patient's axilla. The subjects then lifted and dragged the patient approximately 12 inches closer to the head of the bed (see Fig. 6). Each person performed this repositioning task twice, once on either side of the patient.

3.5.4.3 Two-person draw sheet

The subjects, one on either side of the supine patient, lifted and slid the patient approximately 12 inches closer to the head of the bed using the underlying sheet. This is similar to Fig. 3 except that both subjects are standing and the direction of movement is toward the head of the bed. Each subject performed this repositioning task twice, once on each side of the patient.

3.5.4.4 One-person hook

The subject bent and placed his or her forearm under the recumbent patient's axilla and lifted and slid the patient approximately 12 inches closer to the head of the bed. This is similar to Fig. 6 except only the subject holding the patient's right arm is moving the patient. Each subject performed this repositioning task once.

4. Results and discussion

4.1. Bed to bed transfers

4.1.1. Barton System

This activity was analyzed by using the Michigan 3D model at two points during the activity: the subject's

posture when the crank was at the top of the cycle and the posture when the crank was at the bottom of the cycle. In general, the $F_{C_{mod}}$ was greater when the crank was at the bottom of the cycle (267.1 lbs., range = 215.1 to 376.8 lbs.). The $F_{C_{EMG}}$ was estimated to be 570.4 lbs. (range = 386.5 to 964.0 lbs.) of back compressive force.

4.1.2. Two-person draw sheet

The Two-Person Draw Sheet (2PDS) bed to bed transfer was analyzed by the Michigan 3D Model in four lift components: the subjects performed this transfer in two separate stages. They would transfer the patient half way, (Lift 1, Lower 1) re-orient themselves and then transfer the patient the remaining distance (Lift 2, Lower 2). During the lift toward the subject, Lift 1 generated the greatest $F_{C_{mod}}$, (average = 664.1 lbs., range = 435.5 to 1025.3 lbs.). This is attributed to the high degree of torso flexion and the high horizontal distance from the subject's low back to the load in the hands. Lift 2 ($F_{C_{mod}}$ average = 447.0 lbs., range = 194.9 to 669.8 lbs.) was the second most stressful lift segment. The opposite pattern was found during the transfers away from the subject. Lower 2 ($F_{C_{mod}}$ average = 739.9 lbs., range = 548.2 to 1124.5 lbs.) and Lower 1 ($F_{C_{mod}}$ average = 665.6 lbs., range = 556.0 to 1124.5 lbs.) were the postures that were responsible for the greatest $F_{C_{mod}}$. The EMG data indicated the greatest $F_{C_{EMG}}$ during the transfers towards the subject



Fig. 6. Repositioning task using the two-person hook technique.

to be 761.5 lbs. (range = 441.9 to 1146.0 lbs.) and the greatest $F_{C_{EMG}}$ during the transfers away from the subject to be 752.2 lbs. (429.7 to 1328.0 lbs.) respectively.

4.1.3. Comparison and discussion

Figure 7 represents the average of the highest compressive force for each subject for bed to bed transfers. When the two bed to bed transfer techniques are compared, it appears that using the Barton System is less stressful than using the two-person draw sheet technique. While that is more evident from the Michigan 3D Model data, the recorded EMG data may be somewhat misleading. The physical activity required to operate the Barton System is mostly limited to the shoulder complex, and the movement of the shoulder may have caused an EMG artifact, resulting in an inflated EMG reading. This study incorporated the use of a small female patient. In actual practice, it can be expected that patients of a considerably large size would need to be transferred. In such a case, it is expected that the back compressive force during the two-person draw sheet would be considerably higher than that determined in this study. The back compressive force resulting from the use of the Barton System, however, would be minimally influenced by the patient's weight.

When the subjects were asked to compare the two bed to bed transfer techniques, all six subjects stated that they preferred the Barton System (see Table 1).

They reported that they felt the Barton System is easier to use, safer for the nursing personnel, safer for the patient, required less physical effort and is more comfortable to use. Four out of six subjects said they were more likely to use the Barton System than the manual technique. The two subjects that stated that they were less likely to use the Barton System indicated they felt that the Barton System might be more time consuming.

4.2. Bed to chair transfers

4.2.1. Barton System

This transfer was analyzed by the Michigan 3D Model at two points during the activity: the posture of the subject squeezing the brake release bar and lowering the head of the Barton from the fully upright position and the posture of the subject when the Barton was fully reclined. The average $F_{c_{mod}}$ resulting from the postures when the Barton was reclined and upright were 431.6 lbs. (range = 287.5 to 603.8 lbs.) and 237.2 lbs. (range = 151.7 to 353.2 lbs.) respectively. The higher average compressive force when the Barton was reclined is due to the back flexion that is required to perform this transfer. The most stressful $F_{C_{EMG}}$ was 522.7 lbs. (range = 225.5 to 1023.5 lbs.).

4.2.2. Two-person hook

Two lift postures were used to analyze this lift: lift and lower. These postures were further differentiated

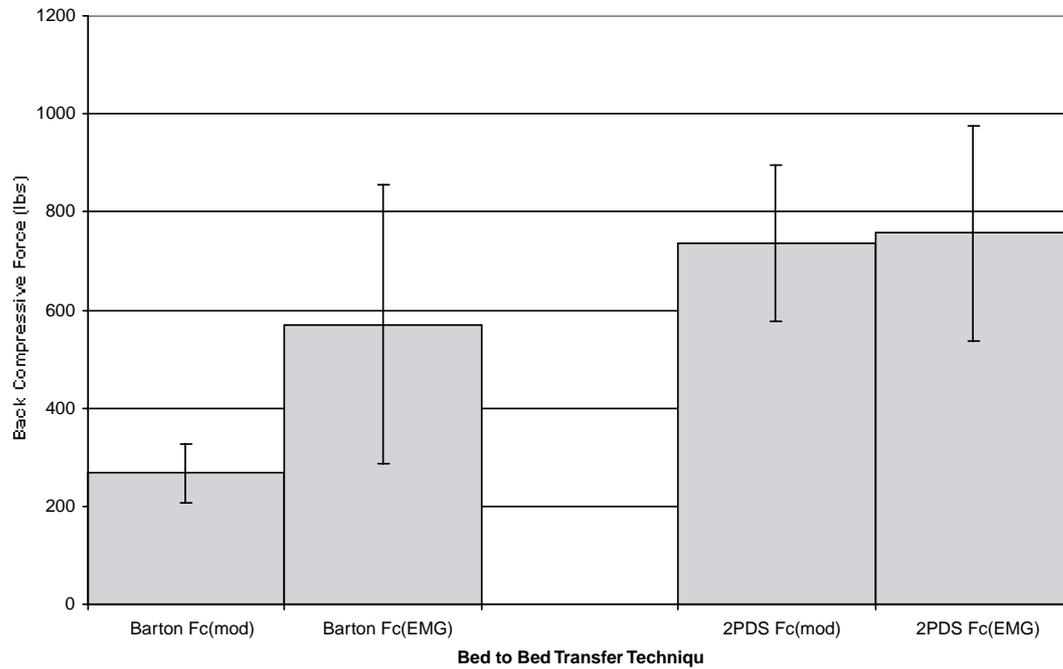


Fig. 7. Comparison of the average of the highest compressive forces for each subject for each bed to bed transfer technique (mean and standard deviation).

Table 1
Summary table of the results of the Bed to Bed Transfer Comparison Questionnaire

	Two-person draw sheet	Barton system
Was this technique easy to use? (1 = difficult . . . 5 = easy)	2.5	4.8
How much effort did this technique require? (1 = a great deal of effort . . . 5 = minimal effort)	2.7	5.0
Was this technique comfortable to use? (1 = uncomfortable . . . 5 = very comfortable)	2.2	5.0
Do you feel that this technique is safe for nursing personnel to perform? (1 = unsafe . . . 5 = safe)	2.2	4.7
Do you feel that this technique is safe for the patient? (1 = unsafe . . . 5 = safe)	2.7	4.3
Would you use this method in your work environment? (1 = no . . . 5 = yes)	3.0	4.5
Do you prefer to use this method? (1=no . . . 5 = yes)	1.0	5.0

based on the side of the patient on which the subject was standing. It was found that the lowers were more stressful than the lifts. This is because the subjects had to flex at the hips more when lowering the patient into the chair than when they lifted the patient off of the bed since the wheelchair was lower than the bed. When using the Michigan 3D Model, it was found that the greatest $F_{c_{mod}}$ (average = 519.2 lbs., range = 442.0 to 605.8 lbs.) was produced when the subject was lowering the patient into the wheelchair from the side

furthest from the chair or the “non-chair side”. The EMG data also reflected a greater amount of hip rotation when standing on the non-chair side than when standing close to the chair or the “chair side”. The average percent difference between the right and left erector spinae during the non-chair side transfers was 33.7% while the difference during the chair side transfer was 9.5%. It would appear that, due to this trunk rotation and asymmetrical back muscle activity, the back stress during the lowering segments of the non-chair side lift

is more hazardous than the average compressive force of 519.2 lbs. would indicate.

However, the greatest F_{EMG} (average = 685.9 lbs., range 303.0 to 1221.0 lbs.) was produced during the chair side transfer. As the subject on the chair side lifts the patient, he or she must shuffle his or her feet backwards while in a torso-flexed posture in order to position the patient in the wheelchair. The EMG may reflect the added strain in the erector spinae during the movement whereas the static Michigan 3D model does not take this movement into account.

4.2.3. Sling Suspension lift

The Michigan 3D model was used to analyze four lift postures during this transfer technique. They include rolling the patient away from the subject's body to place the sling under the patient, rolling the patient towards the subject's body to place the sling under the patient, cranking the lever to raise the patient up off of the bed and pulling the Sling Suspension lift away from the bed with patient suspended in the sling. The two lift segments in which the patient was rolled onto her side while the sling was placed under her were the most stressful aspects of this transfer technique. In order for the subjects to complete these tasks, they had to flex at the hips and roll the patient with one arm while situating the sling under the patient with the other. The average F_{mod} while rolling the patient away and towards were found to be 596.0 lbs. (range = 495.3 to 725.2) and 501.7 lbs. (range = 436.4 to 649.8 lbs.) respectively. The F_{EMG} was found to be 675.5 lbs. (range = 281.8 to 1440.0 lbs.). It is expected that a great number of the patients in a standard hospital setting are much larger and heavier than the standard patient used to generate these compressive forces. Therefore, it is certainly conceivable that nursing personnel experience significantly higher back compressive forces on the job than did the subjects in this study.

4.2.4. One-person hug

The two lift postures analyzed for the One-Person Hug were the lift and the lower. The average F_{mod} was 792.8 lbs. (range = 712.7 lbs. to 992.6 lbs.) during the lift and 853.1 lbs. (range = 681.9 lbs. to 995.5 lbs.) during the lower. The F_{EMG} was 876.5 lbs. (range = 312.2 to 1660.4 lbs.).

4.2.5. The comparison and discussion

Figure 8 represents the average of the highest compressive force for each subject for bed to chair transfers. The comparison between the four different bed to chair transfers indicates that the One-Person Hug transfer technique is the most stressful. In addition, these back compressive forces can be expected to increase substantially when transferring a larger patient and when the transfer is being completed quickly in order to meet the demands of a non-controlled atmosphere.

When the subjects were asked to compare the four different techniques, all six subjects stated that they felt that the Barton System was the easiest to use, safest for both the nursing personnel and the patient, and required the least physical exertion to perform. Furthermore, the subjects interviewed all stated that they would prefer the Barton System over the other techniques and that they would use it in their work environment (see Table 2).

4.3. Chair to bed transfers

4.3.1. Barton System

Two lift postures were used to analyze this transfer technique: when the Barton was fully upright (top) and when the Barton was fully reclined (bottom). The posture when the Barton was fully upright resulted in a higher average F_{mod} (179.9 lbs., range = 131.8 to 222.9 lbs.) than did the posture when the Barton was fully reclined (109.2 lbs., range 43.2 to 248.4 lbs.). Although the subject's hip-flexed posture at the bottom of the transfer is more often associated with higher back compressive forces than the more neutral posture at the top of the transfer, the back compressive force is lower at the bottom of the transfer because of the difference in hand loads. At the top of the transfer, the subject must squeeze the brake release bar and initiate the transfer by pulling the head of the bed downward. At the bottom of the transfer, the subject must still squeeze the bar but the lowering of the head of the bed is accomplished mainly by allowing gravity to complete the technique. The F_{EMG} was 291.9 lbs. (range = 76.6 to 827.5 lbs.). As explained earlier, the EMG data may be confounded by movement artifacts not resulting from active contraction of the erector spinae muscles.

4.3.2. Two-person hook

The analysis of this transfer technique incorporated two lift segments: lift and lower. Again, the lift and lower segments were differentiated into the chair and non-chair side categories. The non-chair side lift produced the highest average F_{mod} (521.2 lbs., range =

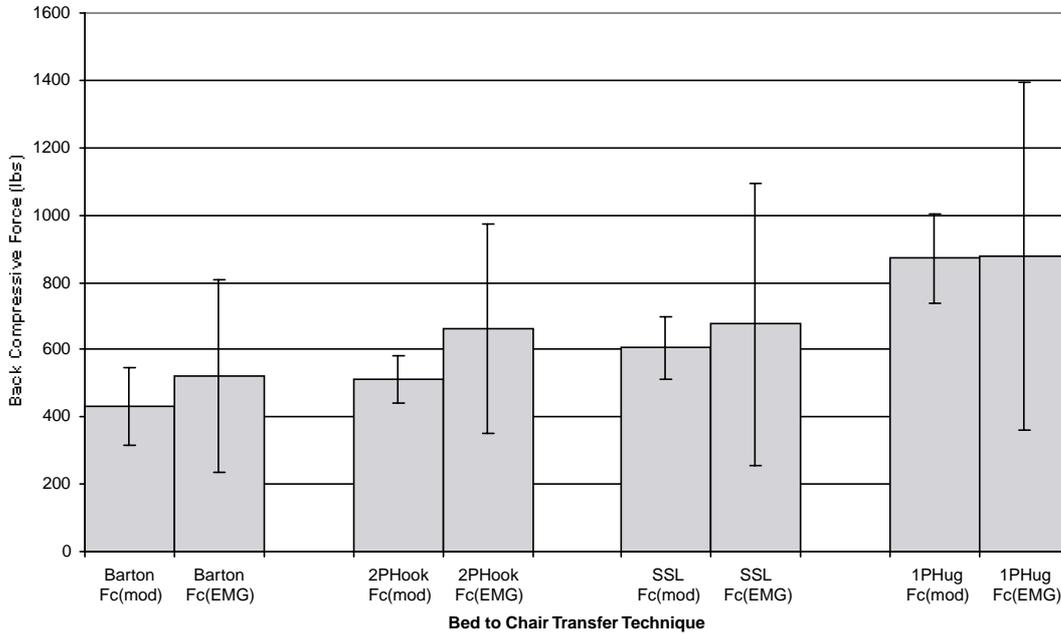


Fig. 8. Comparison of the average of the highest compressive forces for each subject for each bed to chair transfer technique (mean and standard deviation).

Table 2
Summary table of the results of the Bed to Chair and Chair to Bed Transfer Comparison Questionnaire

	Barton System	Two-person hook	Sling suspension lift	One-person hook
Was this technique easy to use? (1 = difficult ... 5 = easy)	5.0	3.5	2.3	2.8
How much effort did this technique require? (1 = a great deal of effort ... 5 = minimal effort)	5.0	3.2	3.8	2.3
Was this technique comfortable to use? (1 = uncomfortable ... 5 = very comfortable)	4.8	2.8	3.7	2.2
Do you feel that this technique is safe for nursing personnel to perform? (1 = unsafe ... 5 = safe)	4.5	2.8	3.5	1.7
Do you feel that this technique is safe for the patient? (1 = unsafe ... 5 = safe)	4.7	3.0	3.2	2.2
Would you use this method in your work environment? (1 = no ... 5 = yes)	4.8	4.0	3.7	3.3
Do you prefer to use this method? (1 = no ... 5 = yes)	4.8	2.2	1.3	1.3

430.1 to 598.4 lbs.). This is essentially the same posture as the non-chair side lower in the Two-Person Hook Bed to Chair transfer discussed above. The next most stressful posture for the chair to bed transfers using the two-person hook transfer technique was the chair side lower (average = 489.1 lbs., range = 377.9 to 608.3 lbs.), then the chair side lift (average = 472.4 lbs., range 346.1 to 570.7 lbs.) and finally the non-chair side lower

(average = 424.2 lbs., range = 362.9 to 494.4 lbs.). The $F_{c(EMG)}$ was 733.7 lbs. (range = 286.1 to 1062.0 lbs.) for the chair side transfer and 664.52 lbs. (range 319.8 to 1034.0 lbs.) for the non-chair side transfer. The higher EMG results for the chair side transfer can be explained by the movements performed and postures assumed by the subjects while maneuvering around the chair as they lifted the patient out of the chair and low-

ered her onto the bed.

4.3.3. Sling Suspension lift

Two lift segments were used to analyze this technique: using the crank to raise the patient up out of the wheelchair and pushing the Sling Suspension lift, with the patient suspended, towards the bed. The back compressive forces calculated using the Michigan 3D model were quite low. The average $F_{c_{mod}}$ was 80.1 lbs. (range = 42.9 to 151.4 lbs.) during the cranking posture and 185.8 lbs. (range = 98.1 to 237.1) during the pushing of the Sling Suspension lift. The $F_{c_{EMG}}$ was 478.7 lbs. (range = 222.8 to 936.0 lbs.). It must be noted that this transfer technique was analyzed with the patient already in the mesh sling. At some point, however, the patient would have to have been placed in the sling. As stated above, the patient-rolling process was the most stressful lift segment for the bed to chair transfers using the Sling Suspension lift. Therefore, although this chair to bed transfer appears to be less than some of the other techniques in this transfer category, someone would have been placed in a posture prior to that point.

4.3.4. One-person hug

The Lift and the Lower were the two lift segments used to analyze this lift technique using the Michigan 3D model. As expected, the lift was the most stressful. That posture produced an average $F_{c_{mod}}$ of 861.8 lbs. (range = 690.7 to 1007.5 lbs.). The lowering posture produced an average $F_{c_{mod}}$ of 802.3 lbs. (range = 586.7 to 1033.7 lbs.). The $F_{c_{EMG}}$ was 884.7 lbs. (range = 418.3 to 1758.4 lbs.).

4.3.5. Comparison and discussion

Figure 9 represents the average of the highest compressive force for each subject for chair to bed transfers.

One-Person Hug transfer technique is the most hazardous technique in this category. It is assumed that it would be even worse with a larger patient. Despite the low measurements taken during the transfer using the Sling Suspension lift, care should be taken when using this technique due to the concerns mentioned above. It appears that the Barton System is the easiest technique for transferring a patient from a chair to a bed.

The results from the subject interviews concerning the chair to bed transfers were the same as the results of the bed to chair transfer (see Table 2). The subjects felt that the Barton System was the easiest and safest method and would use it over the other techniques in their work environment.

4.4. Repositioning techniques

4.4.1. Barton System

Two lift segments were analyzed during this task: the subject's posture when the crank was at the top of the crank cycle (top) and the subject's posture when the crank was at the bottom of the crank cycle (bottom). The posture at the "top" produced an average $F_{c_{mod}}$ of 179.3 lbs. (range = 106.8 to 290.7 lbs.) while the posture at the "bottom" produced a $F_{c_{mod}}$ of 271.4 lbs. (range = 188.4 to 387.3). The $F_{c_{EMG}}$ was 722.2 lbs. (range = 336.1 to 1394.5 lbs.). As noted earlier, this is possibly due to movement artifacts in the EMG electrodes as the body moves during the cranking, rather than the true electrical signals originating from contractions of the erector spinae muscle.

4.4.2. Two-person hook

Two lift segments in two lift categories were analyzed during this task. A lift segment and a lower segment using the right and left arm were analyzed for each subject. The data from the Michigan 3D model indicated that there was little difference in using the right or the left side. The $F_{c_{mod}}$ for the lift segments were 394.3 lbs. (range = 301.5 to 491.7 lbs.) and 386.8 lbs. (range = 301.5 to 494.5 lbs.) when using the right and left arm respectively. The $F_{c_{mod}}$ for the lower segments were 440.5 lbs. (range = 344.3 to 532.2 lbs.) and 418.5 lbs. (range = 345.2 to 491.7 lbs.) when using the right and left arm respectively. Lowering produced higher back compressive forces than did the lifting because the subjects, in general, did not move their feet during the task. Instead, during the lower, they would lift the patient and then lean forward to lower her onto the bed. The combination of the hip flexion and the extended distance of the hand load from the subject's torso caused the increased back compressive force. The EMG data shows that, on average, $F_{c_{EMG}}$ was higher on the right, 711.7 lbs. (range 534.5 to 1062.0 lbs.), than on the left, 560.7 lbs. (312.8 to 901.0 lbs.). The back compressive forces produced when using the right arm to perform the repositioning task may be higher because the predominately right-handed group of subjects may have relied upon their stronger right arm and back muscles when using their right side whereas they may have been forced to use their legs and better body mechanics to compensate for their weaker left side.

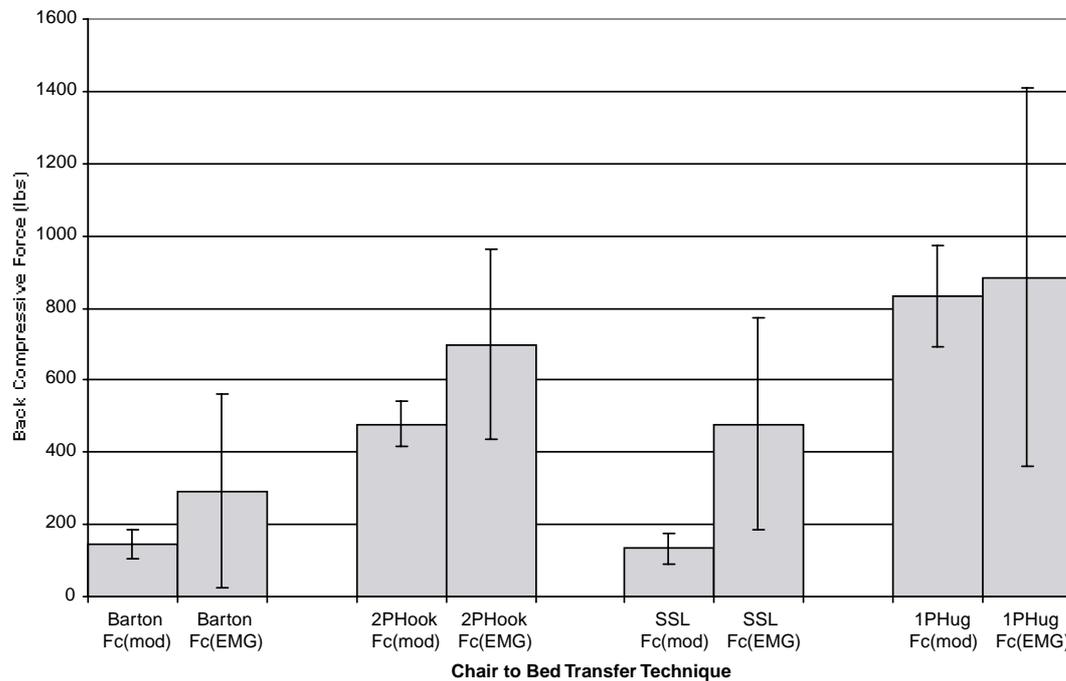


Fig. 9. Comparison of the average of the highest compressive forces for each subject for each chair to bed transfer technique (mean and standard deviation).

4.4.3. Two-person draw sheet

Two lift segments in two categories were also evaluated during this task. Lift and lower segments were measured for each subject twice. One measurement was taken while the subject stood on the patient's right side and one measurement was taken while the subject stood on the patient's left side. The highest $F_{c(mod)}$ was measured during the left-side lower (598.5 lbs., range = 485.3 to 795.2 lbs.). However, the EMG data shows that $F_{c(EMG)}$ (555.9 lbs., range = 316.5 to 725.7 lbs.) was slightly higher when the subjects were on the right side of the patient as opposed to the left side (526.4 lbs., range = 294.9 to 651.4 lbs.). This can be explained by analyzing the postures of the subjects. As the subject on the right side of the patient lifts the patient and then lowers her, the subject's left arm moves from being directly in front of his or her body to being far off to the side. Since all but one of the subjects were right-handed, they may have had to struggle more and assume a more awkward torso posture during the task on the right side of the patient because their weaker left arm was at more of a mechanical disadvantage.

4.4.4. One-person hug

Lift and lower tasks segments were used during the analysis of this repositioning task. It was found that

the average $F_{c(mod)}$ caused by the postures during the lift segments and lower segments were 858.5 (range = 767.5 to 952.0 lbs.) and 866.4 lbs. (range = 767.5 to 965.6 lbs.) respectively. Furthermore, the EMG data found that $F_{c(EMG)}$ was 910.9 lbs. (range = 271.1 to 1930.0 lbs.). The high back compressive forces are attributed to both the posture and the hand load. The posture was one of extreme hip flexion and the hand load was not only great but also not evenly distributed. Although both hands were used during the technique, the hand position made it so that one hand was performing the majority of the load bearing.

4.4.5. Comparison and discussion

Figure 10 represents the average of the highest compressive force for each subject during the repositioning activity.

The Barton System appears to be comparable to the Two-Person Hook and Two-Person Draw Sheet. The EMG data for the Barton System Repositioning task may be somewhat misleading, because the physical activity required to perform this task is primarily generated by the muscles of the shoulder complex. The EMG data may have been artificially inflated by movement originating in the shoulder and not a true indicator of active contraction of the back muscles. The back com-

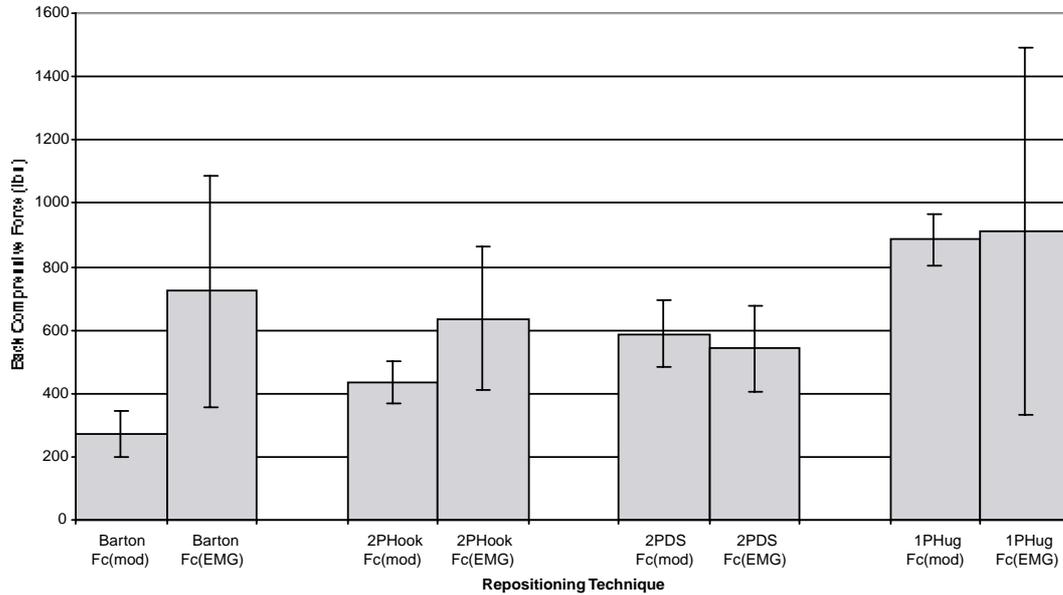


Fig. 10. Comparison of the average of the highest compressive forces for each subject for each repositioning technique (mean and standard deviation).

pressive forces calculated by the Michigan 3D Model (which are not subject to the same potential for EMG artifacts) are significantly less than any of the other three methods. The Two-Person Hook and the Two-Person Draw Sheet were very comparable in the back compressive forces that they produced. It appears that the One-Person Hug was the most dangerous lift, not only in this category but also in the entire study. The combination of the extreme hip flexed posture and the high hand load cause this lift to be far more stressful to perform than the other techniques.

All subjects felt that the Barton System was very easy to use in patient repositioning, required the least amount of physical exertion to perform, was comfortable to use, and was safe for both the patient and nursing personnel. Furthermore, five of the six subjects stated that they would prefer to use the Barton System over the other methods. The one subject who did not prefer the Barton System stated that time restraints made it less desirable. All subjects stated that they preferred to use the Barton System as much, if not more, than the other techniques (see Table 3).

5. Conclusion

From the data and discussion above, it is concluded and recommended that mechanical assist devices be used. They appear to be both less hazardous and more

desirable to use than the manual techniques. This conforms to the recommendations presented by Marras [9]. Overall, the Barton System was found to be less stressful and more preferable than the Sling Suspension lift.

During the Bed to Bed Transfer the Barton System resulted in less compressive force than the Two-Person Draw Sheet. During the Chair to Bed Transfer the Barton System and the Sling Suspension Lift resulted in less compressive force than either the Sling Suspension Lift or patient movement without mechanical assist. (The Barton System resulted in slightly less compressive force than the Sling Suspension Lift.) During the Bed to Chair Transfer the Barton System, the Sling Suspension Lift, and the Two-Person Hug resulted in less compressive force than the One-Person Hug. (Again, the Barton System resulted in slightly less compressive force than either the Sling Suspension Lift or the Two-Person Hug.) During the Repositioning activity the Barton System, the Two-Person Hug and the Two-Person Draw Sheet methods resulted in less compressive force than the One-Person Hug. All six subjects felt that the Barton System was the easiest and safest patient transfer method for Bed to Bed, Bed to Chair, Chair to Bed, and Repositioning activities. All six subjects also felt that they would prefer to use the Barton System for Bed to Chair and Chair to Bed transfers. Four of the six subjects felt that they would use the Barton System for Bed to Bed transfers and five of the six felt that they would use the Barton System for Repositioning activities.

Table 3
Summary table of the results of the Repositioning Task Comparison Questionnaire

	Barton System	Two-person hook	Sling suspension lift	One-person hook
Was this technique easy to use? (1 = difficult . . . 5 = easy)	4.7	3.3	3.2	1.7
How much effort did this technique require? (1 = a great deal of effort . . . 5 = minimal effort)	4.8	3.3	3.0	1.5
Was this technique comfortable to use? (1 = uncomfortable . . . 5 = very comfortable)	4.8	3.0	2.8	1.5
Do you feel that this technique is safe for nursing personnel to perform? (1 = unsafe . . . 5 = safe)	5.0	3.5	3.5	1.2
Do you feel that this technique is safe for the patient? (1 = unsafe . . . 5 = safe)	4.8	3.2	3.7	2.0
Would you use this method in your work environment? (1 = no . . . 5 = yes)	4.3	3.8	4.0	2.3
Do you prefer to use this method? (1 = no . . . 5 = yes)	4.3	1.7	1.7	1.7

In summary it was found that test subjects (all personnel involved in patient transfer and repositioning) experienced less back compressive force when using mechanical patient transfer assist devices than when transferring patients manually. In general, the Barton Assist System resulted in lower back compressive force than the Sling Suspension Type Lift and was overwhelmingly preferred by personnel experienced in patient transfer activities.

It is recommended that patient transfers be accomplished with mechanical assist devices. When mechanical assist devices are not available, two people should perform patient transfers.

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