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Transfer of the horizontal patient: The effect of a friction reducing assistive device on low back mechanics

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Recognizing that the transfer of bedridden patients is associated with a high rate of low back injuries, various devices have been developed to assist with sparing the patient handlers. The purpose of this study was to quantify the friction-reducing ability of three different 'sliding' patient transfer devices together with the subsequent consequences on the low back loads of people performing the transfers. Coefficients of friction of the devices were determined by 'transferring' a standard object and a 'patient' over several surfaces common to a hospital setting. Then three participants performed controlled transfers with the various devices. Electromyography to measure muscle activation levels together with external forces and kinematic positional data were collected during push, pull and twist transfers. Spine loads were estimated with a three-dimensional biomechanical static link-segment model of the human body. Simply sliding a patient on a cotton sheet (control condition) produced a coefficient of friction of 0.45. The assistive devices substantially reduced friction by well over one-half (coefficients of 0.18 – 0.21). However, when using the devices the subjects adopted a variety of postures and techniques, such that there were no consistent influences on trunk inclination, low back compression or muscle activation profiles. Direct measurement of reduced friction between the bed and the patient with a friction-reducing device together with measurement of the back loads when actually transferring a patient formed a proof of principle. Specifically, while the device lowers friction, the transfer technique adopted by the lifter must be proper to reduce low back loading and any subsequent risks of back troubles associated with patient transfers. The direction of hand forces and torso position remains important.

Keywords: Back injury; Lift assists

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1. Introduction

Among the numerous responsibilities of health care workers, patient-handling tasks are associated with the highest level of low back injuries (Videman *et al.* 1984). Patient-handling ranges from turning and repositioning patients to transferring horizontal patients from one surface to another, such as from a gurney to a radiology table. To address the concern of low back injury associated with patient handling, more focus has been directed towards worker education and training proper biomechanically based movement techniques. In addition, certain friction-reducing devices have been developed to reduce the manual forces required to convert the task from lifting and carrying into a pushing and pulling task. Push/pulls have been found to be subjectively rated as less strenuous than lifts (Straker *et al.* 1997). Finally, these devices have been used to transfer burn patients, for example, who cannot tolerate being touched. This study qualified the changes in sliding friction with three patient transfer devices and then quantified low back loads in three knowledgeable workers to see if their low back loads were altered.

Various devices have been designed to reduce the friction between a bedridden patient and the bed. The interest in the present study was to assess some new technology where a Teflon coated sheet that rolls around a board is placed under a patient with the intention of reducing the manual forces required to move the patient horizontally.

Pushing, pulling and the development of horizontal force by a worker can be affected by many variables – one of which is the horizontal force vector needed to pull the patient. Given that low back loading is a concern with workers who perform patient transfers, muscle activity, hand force vectors and body posture were input to a biomechanical model to assess low back loading. For example, a device-assisted reduction in 50% of the required pulling force may, or may not, have a substantial affect on back loads since it is only one of many determinants. The purpose of this paper was to quantify the friction-reducing ability of three different patient transfer devices during push, pull and twist transfers, together with the effect on the low backs of workers performing the transfers.

2. Methods

Two experiments, with different methodologies, were conducted. First, three friction reducing devices were assessed for their ability to reduce sliding friction (Rollboard^{TM}, Bubbleboard^{TM} and Slider^{TM}). Then, three male subjects performed a series of patient transfers using the three different patient transfer devices together with a control condition (bed sheet). The Slider^{TM} is a semi-rigid sheet with cut-out handles along the edge for gripping. The Rollboard^{TM} is a ridge board with a sheet that has a Teflon-coated under surface that wraps around the long axis of the board. The sheet 'rolls' around the board during a transfer. The Bubbleboard^{TM} is similar to the Rollboard^{TM} except that the core of the board is made of a softer plastic covering and, rather than having a solid core, it contains air under pressure, providing a softer, more compliant consistency.

An anthropomorphic manikin (General Motors Hybrid III with a weight of 72.7 kg and articulating joints) was used to ensure a standardized mock patient. The influence of pushing, pulling and twisting transfers on low back loads was quantified using hand force, joint load and muscle activation data. Transverse plane twisting transfers were also assessed with the subject positioned at the head of the manikin pulling laterally to the right. This is typical of the patient repositioning that occurs in radiology suites. Calculation of joint loading necessitated the collection of electromyography (EMG), external forces and kinematic positional data. All procedures were approved by the University Office for Research Ethics.

3. Data collection

3.1. Baseline coefficient of friction

The coefficient of friction was determined for each of the patient transfer devices. Each device was placed on a horizontal surface and a pan weighing 409N (to standardize the load) was placed on top and pulled horizontally. The horizontal force was measured with an LVDT force transducer with the force signal sampled at 1024 Hz. The static and dynamic coefficients of friction were measured as the ratio of the horizontal force divided by the object weight, from the peak force and the sustained pulling force respectively.

Given that the compliance of the horizontal surface could affect the ‘rolling resistance’ of the devices, the friction protocol was performed on: 1) a patient examination table covered with a synthetic leather material; 2) a patient examination table covered with a cotton bed sheet; and 3) a standard bed mattress covered with a cotton bed sheet. Instead of the weighted pan used in the first two conditions, the third condition involved transferring a female subject with a weight of 66 kg and a stature of 1.68 m to see if a real human would influence the friction-reducing characteristics.

3.2. Patient transfer collection

Three males knowledgeable in patient handling with an average stature of 1.77 m (± 0.046 m) and weight of 76 kg (± 1.0 kg) volunteered to perform the patient transfers. None had a history of disabling low back pain.

For all of the transfers, the manikin was positioned on its back on a table that measured 0.76 m high and 0.8m wide. The subject was instructed to transfer the manikin from the centre of one table to the centre of another positioned immediately beside the first. Subjects were instructed to maintain a neutral spine posture (for ethical reasons) during the transfers and practice trials were performed for each condition.

For the push transfers subjects exerted a pushing force at the shoulder and hip of the manikin with their hands (see figure 1). The forces were exerted through two metal T-bars that contained force transducers, recording the magnitude of the push.

The pull transfers were also performed in front of the body using two hands (see figure 2).

For the twist trials, subjects were positioned at the head of the manikin (see figure 3) and, using only their right hand, pulled the manikin to the right. An assistant was used at the feet of the manikin to assist with the transfer. Subjects were instructed to only pull the manikin horizontally with no lifting.

All trials were presented in random order for each of the three transfer devices as well as for the control condition.

4. Instrumentation

4.1 Electromyography

Fourteen channels of EMG were collected from the following muscles bilaterally: rectus abdominis; oblique internus; oblique externus; latissimus dorsi; thoracic erector spinae

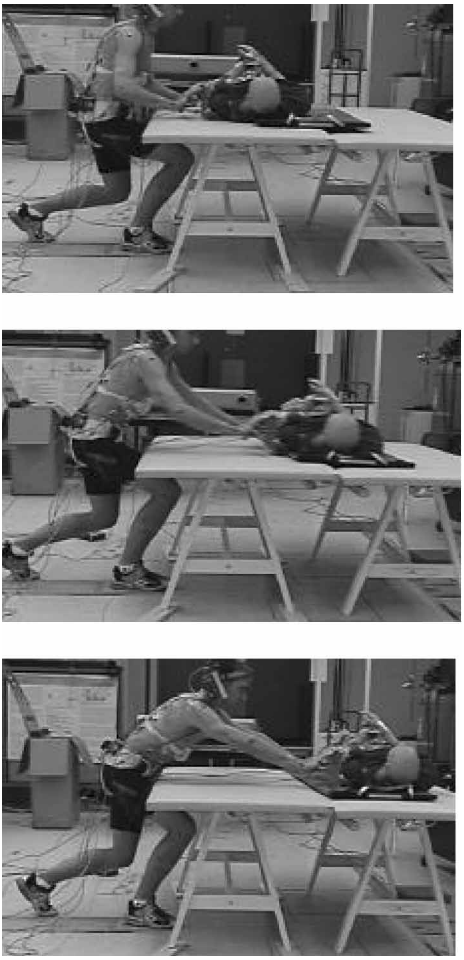

Figure 1. An example of a push transfer.

(longissimus thoracis and iliocostalis at T9); lumbar erector spinae at L3 (longissimus and iliocostalis lateral to L3); and lumbar erector spinae at L5 (1 cm lateral to L5). Ag-AgCl surface electrodes were adhered to the skin with an inter-electrode distance of about 3 cm. The EMG signals were amplified and then A/D converted with a 12-bit, 16-channel A/D converter at 1024 Hz.

Each subject was required to perform a maximal contraction for normalization of the signals. For the abdominal muscles each subject, while in a sit-up position and manually braced by a research assistant, produced a maximal isometric flexor moment followed sequentially by a right and left lateral bend moment and then a right and left twist moment; little motion took place. For the extensor muscles, a resisted maximum extension in the Biering Sorensen position was performed (see McGill 2002). The EMG signal was full wave rectified and low-pass filtered with a second order Butterworth filter. A filter cut-off frequency of 2.5 Hz was used to mimic the frequency response of the torso muscles (Cholewicki and McGill 1996). The subsequent EMG amplitudes recorded during the transfer were normalized to the maximal contractions described above.

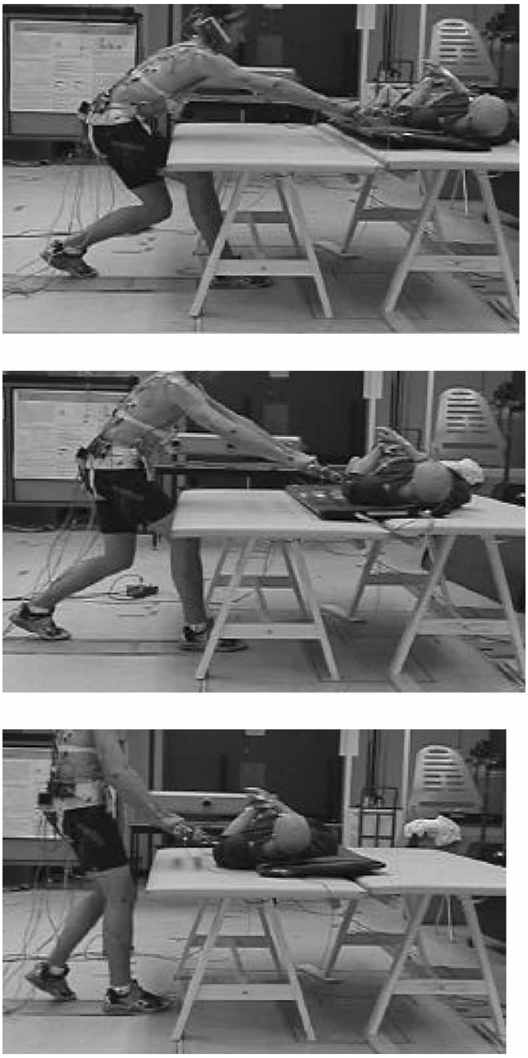

Figure 2. An example of a pull transfer.

4.2. Kinematic measures

Subjects were instrumented with 19 infrared emitting diodes placed at various body landmarks bilaterally. The landmark locations for the markers were as follows: proximal end of fifth metatarsal; lateral fibular maleole; lateral femoral epicondyle; greater femoral trochanter; L4-L5 intervertebral joint; spinous process of C7; ear opening; acromion; lateral humeral epicondyle; ulnar styloid process; and distal end of fifth metacarpal. Infrared diodes were also placed at each end of the two force transducers to represent the lines of action of the externally applied force. Kinematic data were collected at 64 Hz using two Optotrak camera banks (Northern Digital, Waterloo, Canada) positioned on the right and left side of the subject.

Figure 3. An example of a twist transfer where the subject applied horizontal forces, on the manikin's head moving it to their right.

4.3. *Biomechanical modelling*

Two phases within each trial were selected for analysis. The first phase was identified as the initiation of movement characterized by the instant in time at which the peak total hand force occurred. This horizontal force was used to calculate a static effective coefficient of friction. The second phase was defined as a range of either 20, 30 or 40 frames of data within the period of sustained sliding motion during the transfer. This was 'windowed' out of the data recorded on collection. The number of frames analysed was a function of the duration of the transfer, which varied across trials and subjects since velocity of the transfer was not controlled in the study. A slower trial would have more frames averaged. The average force was calculated through this range and was used to calculate the kinetic effective coefficient of friction for each condition. The static and dynamic effective coefficients of friction were calculated for each transfer device by dividing the mass of the manikin into the magnitude of the applied hand force. For the twist transfers, the mass of the manikin was divided in half since two subjects were involved in the transfer. The coefficient of friction is termed the ‘effective coefficient of friction’ because in the calculation the mass of the manikin was established.

Estimates of L4-L5 joint loads were performed for both phases of each transfer. For the initiation of movement phase, the maximum total hand force and total-body posture calculated from the corresponding frame of kinematic data was utilized for the analysis. For the sustained motion phase, the kinematic posture of the subject was that which occurred at the middle of the selected range (for example, if the range was 20 frames then the subject’s posture was taken at the10th frame). The associated total hand force was calculated as the average force occurring within the selected range. The analysis was performed with the 4D Watbak software program that is based on a three-dimensional static link segment model of the human body (see figure 4), using body posture kinematics and external hand force as input (Norman *et al*. 1994, 1998). Body anthropometrics were determined from body height and body mass. Output consisted of net external torque at the L4-L5 joint together with joint compression force and anterior/posterior shear force.

4.4. Statistical analysis

A one-way repeated measures ANOVA was used to identify any significant differences between the hand force values across the different transfer devices for each transfer type (i.e. push, pull, twist). A Tukey’s *post hoc* analysis assessed the significant differences ($p < 0.05$).

5. Results

5.1. Coefficients of friction

Calculation of the coefficient of friction on the patient examination table covered with synthetic leather (see figure 5) showed that across the three transfer devices, the

Figure 4. Kinematic posture obtained from video data and corresponding posture with 4D Watbak model. The Watbak analysis shows output of L4-L5 moment, compression and joint shear.

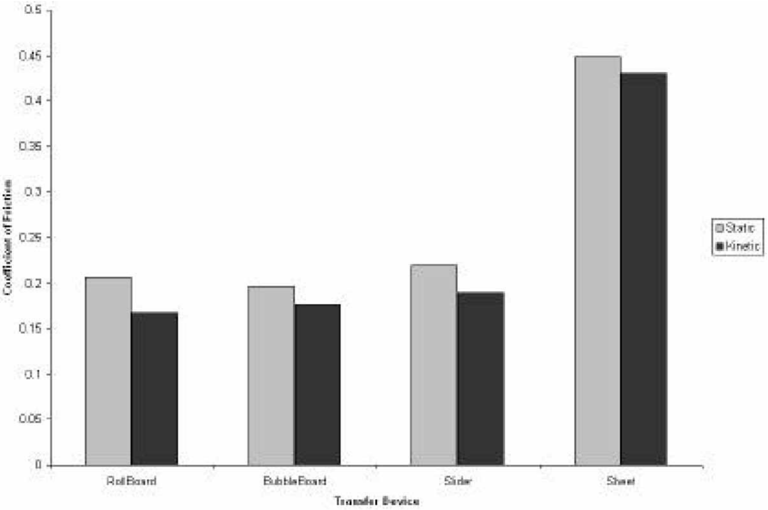

Figure 5. Static and kinetic coefficient of friction for the four different transfer conditions.

Bubbleboard^{TM} produced the lowest static coefficient of friction (static = 0.20, kinetic = 0.18) and the RollBoard^{TM} produced the lowest kinetic coefficient of friction (static = 0.21, kinetic = 0.17). The differences, however, were extremely small across the three devices. In comparison to the control sheet, each of the devices led to about a 50% reduction in friction between the moving device and the bed surface. No statistical analysis was performed since the friction moments were the same with each repeat – what matters here is the magnitude of the influence.

Sensitivity testing showed that replacing the weighted pan with a real person on the various transfer devices did not appear to change the coefficients of friction. This added content validity to the ability of the devices to influence friction.

5.2. Hand forces and effective coefficients of friction

Differences existed between the hand force profiles for each of the transfer devices. Figure 6 illustrates a typical example of the pull force-time curve for the four different patient transfer conditions. In both the control condition and with the Slider^{TM}, the magnitude of the sustained force was fairly consistent with that of the initial force. For the Rollboard^{TM} and the Bubbleboard^{TM} there was a significant drop in force magnitude once movement of the dummy was initiated.

Across the push, pull and twist transfers, both the Rollboard^{TM} and Bubbleboard^{TM} produced the lowest levels of initial and sustained forces; however, the values for the two transfer devices were not significantly different from each other. These two devices also produced the largest reductions between the required initial and sustained forces. This result was only statistically significant across tasks with the Bubbleboard^{TM} (shown in figures 7, 8, 9).

For the Slider^{TM}, there was a consistent significant reduction in the applied force between the initial and sustained phases of motion; however, the reduction was much less than that observed in both the Rollboard^{TM} and Bubbleboard^{TM}. All three transfer devices required lower levels of both initial and sustained forces compared to the control group. The last observation was that, in general, the magnitudes of force required for the

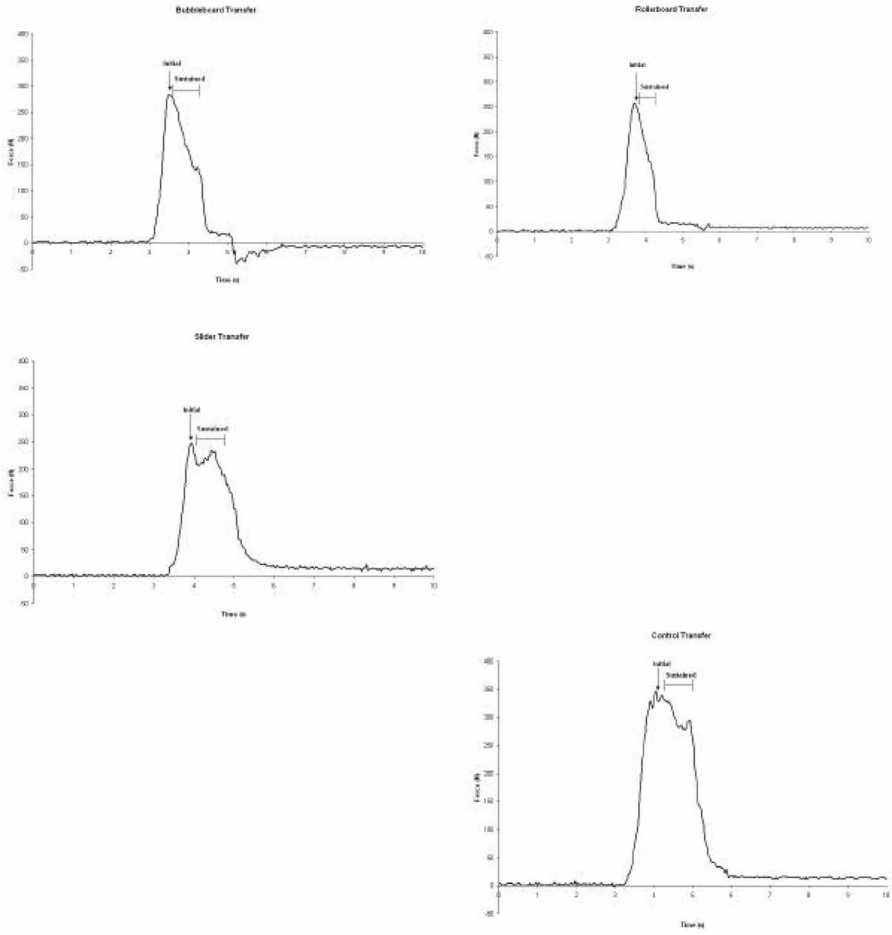

Figure 6. Representative force profiles from a single subject of a pull force performed with Bubbleboard^{TM} transfer (a), Rollboard^{TM} transfer (b), Slider^{TM} transfer (c) and control transfer (d).

pushing and pulling transfers (figures 7 and 8) were almost double that required for the twist transfers (figure 9). This is probably due to the fact that two people performed the twist transfers with each only moving approximately one-half of the manikin's weight. It is worth noting that Marras *et al*. (1999) found that two lifters actually must lift slightly more than half of the load each. In addition, the second person required for the twisting transfers was a research assistant positioned at the 'feet end' of the patient. One important note for the twist trials was that no subject was able to perform this movement in the control condition without lifting the manikin. Consequently, these results were left out of the analysis and the benefit of transfer devices is obvious.

5.3. Postures

The trunk inclination varied across the conditions. On average, the inclination was greatest during the pull trials at the initiation of motion and during the push trials during

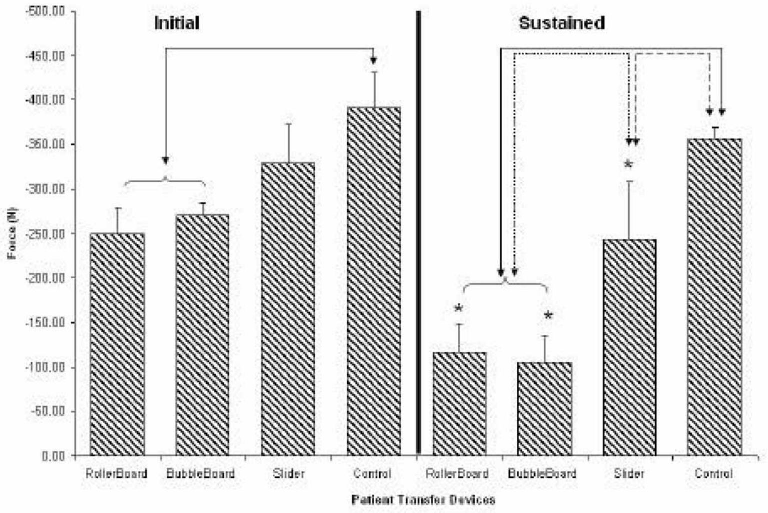

Figure 7. Average initial and sustained forces for each of the transfer devices during a 'push' transfer. Arrow lines represent the transfer devices that are significantly different from each other. * represents those transfer devices in which the sustained force is significantly different from the initial force.

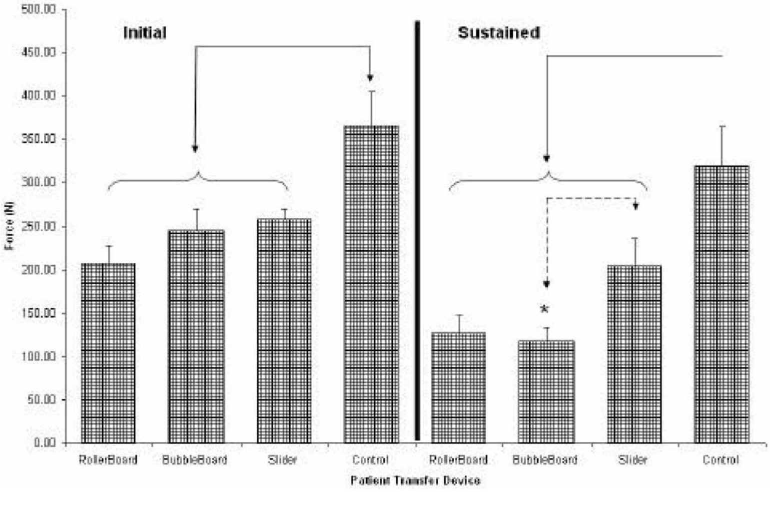

Figure 8. Average initial and sustained forces for each of the transfer devices during a 'pull' transfer. Arrow lines represent the transfer devices that are significantly different from each other. * represents those transfer devices in which the sustained force is significantly different from the initial force.

the sustained motion. However, in general, trunk inclination was highly variable both across subjects and across trials. Overall, there was no association between trunk angle and transfer device. Trunk angle ranged from 17 to 67°. This high level of variability can be explained by the fact that technique was not controlled in this study. Rather, using a

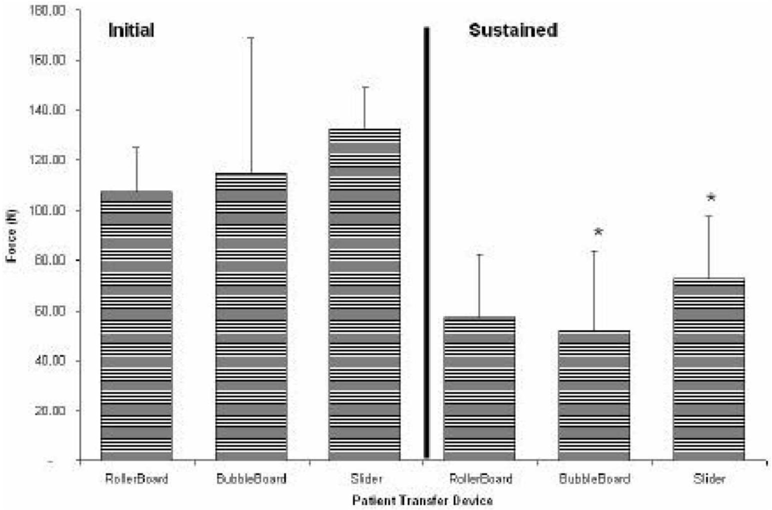

Figure 9. Average initial and sustained forces for each of the transfer devices during a ‘twist’ transfer. Arrow lines represent the transfer devices that are significantly different from each other. * represents those transfer devices in which the sustained force is significantly different from the initial force. In this condition the control trial was eliminated from this analysis. No subject was able to successfully move the manikin with a pure pulling force without lifting.

self-selected technique inherently increased content validity by allowing the experienced patient handlers to lift as they would in real life.

5.4. Electromyographic profile

The peak electromyographic profile of the 14 tested muscles was averaged across subjects and is shown in figures 10, 11 and 12 for the conditions of push, pull and twist respectively. Some general observations can be made. A high degree of variability existed between the peak EMG amplitudes for the different muscles. However, overall a general trend was observed in certain muscles. As expected, as the external force required to perform the transfer increased so did the peak EMG amplitude. This trend was particularly evident in the back extensors during the push and pull transfers and in the obliques during pull and twist transfers. Across the different transfer types, push transfers led to the highest levels of peak EMG across muscles, suggesting higher levels of muscle co-contraction. Pull and twist transfers produced much lower levels. One note is that in the push and pull transfers, only the Rollboard$^{\text{TM}}$ and Bubbleboard$^{\text{TM}}$ were successful in preventing subjects to produce levels of activation above 100% of their isometric maximum voluntary contraction. With the twist transfers, the highest levels of activation were observed in the right internal obliques, which is consistent with twisting to the right.

5.5. Load at L4-L5

There was no relationship between magnitude of push/pull force and L4-L5 torque or compression. This was due to the subjects changing their body posture in the sagittal plane to counter the change in hand force.

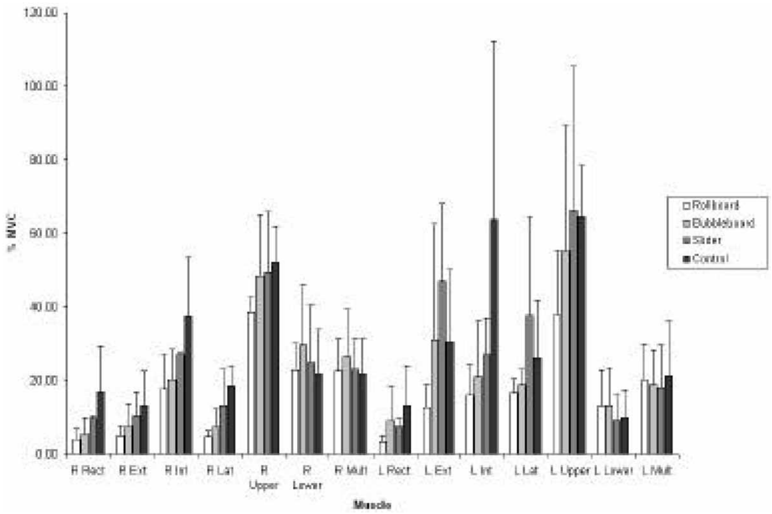

Figure 10. Means and standard deviations of the peak EMG amplitude for the torso musculature across the different transfer devices during push transfer. Muscles were right (R) and left (L) side rectus abdominis (rect), external oblique (ext), internal oblique (int), latissimus dersi (lat), upper erector spinae at T9 (upper), lower erector spinae at L3 (lower) and erector spinae at L5 (mult).

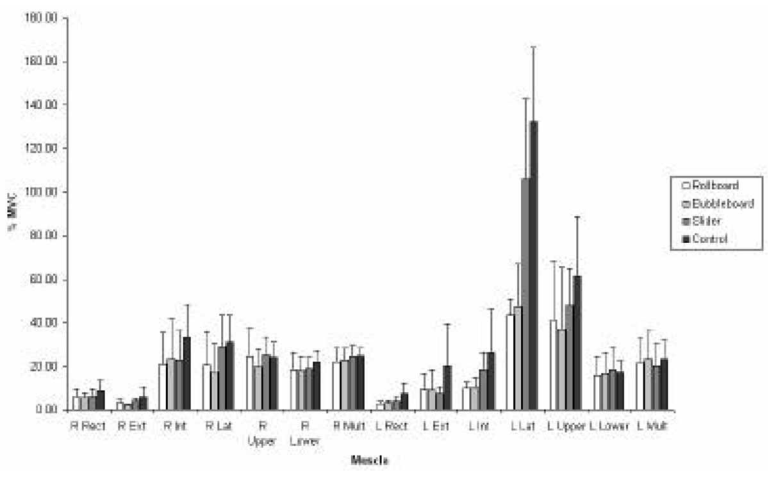

Figure 11. Means and standard deviations of the peak EMG amplitude for the torso musculature across the different transfer devices during a pull transfer. Muscles were right (R) and left (L) side rectus abdominis (rect), external oblique (ext), internal oblique (int), latissimus dersi (lat), upper erector spinae at T9 (upper), lower erector spinae at L3 (lower) and erector spinae at L5 (mult).

A high amount of variability in L4-L5 shear forces existed between subjects; however, a greater association between applied force and joint shear was observed compared to the association of applied force to joint compression. As with compression, the relationship

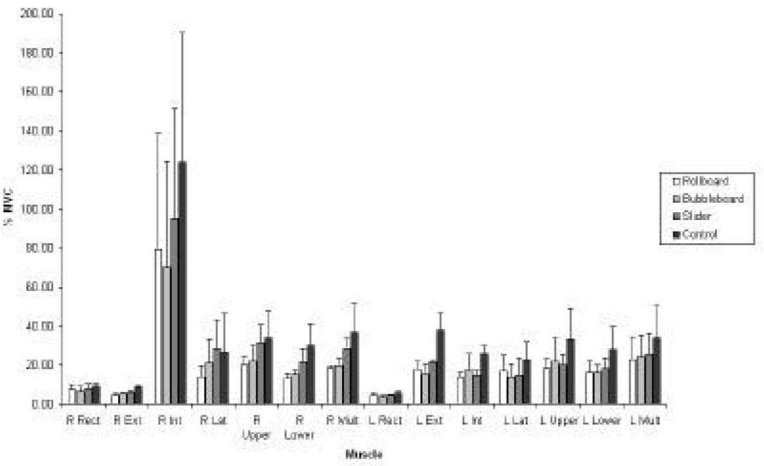

Figure 12. Means and standard deviations of the peak EMG amplitude for the torso musculature across the different transfer devices during a twist transfer. Muscles were right (R) and left (L) side rectus abdominis (rect), external oblique (ext), internal oblique (int), latissimus dersi (lat), upper erector spinae at T9 (upper), lower erector spinae at L3 (lower) and erector spinae at L5 (mult).

between joint shear and applied force was affected by trunk inclination. An example of this effect can be illustrated with the results from one of the subjects. For the push trials on the Rollboard^{TM}, the average trunk inclination was 30°, the average applied force was 246N and the average posterior shear force was 140N. For the push trials on the Bubbleboard^{TM}, the average trunk inclination was greater at 32°, the average applied force was greater at 271N yet the average posterior shear force was reduced to 129N. For the control trials, the average trunk inclination was 30°, the average applied force was 358N and the average posterior shear force was 208N. Despite the association to applied force, the magnitude of shear did not exceed 500N in any condition.

6. Discussion

The initial study to quantify the friction-reducing properties of the transfer devices was relatively easy to control and appropriate for statistical analysis. In contrast, by having real workers perform the tasks it was not easy to vary conditions due to ethical/safety concerns. Thus, while analysis of the devices may be considered a typical paradigm, the testing with three workers simply forms a proof of principle. All three transfer devices tested were successful at reducing the static and kinetic coefficients of friction during the patient transfer task. The three workers showed that their choice of technique was also important.

In terms of spine loads, no consistent results were obtained linking any transfer device to a change in loading characteristics. Rather the L4-L5 compression varied closely with L4-L5 moments and these moments were a function of trunk inclination, external force, moment arm and external force magnitude. In other words, the resultant spine loads were dominated by worker posture and force exertion angles chosen by the subject. The hand force was generally directed along a line of force that passed close to the low back and thus had little chance to have a major influence on back load. It should be recalled that it is the hand force magnitude that is modulated by any friction-reducing device. Thus, in terms of L4-L5 compression, personal technique and movement strategy proved to be a more important factor in reducing spine loads over reducing the required applied hand force.

A finding in the study was that as the trunk angle increased, an increase in the external force actually led to a reduction in compression because the external force applied above the L4-L5 joint acted to balance the moment generated by the weight of the upper body segment. This was also reported during push and pull tasks by Laursen and Schibye (2002). Once again an element of technique to consider when performing patient transfers similar to the one performed in this study is to reduce the L4-L5 moment produced. Observations here confirmed that this was done by reducing both the trunk inclination and the moment arm of the externally applied load. When these techniques were followed, further reducing the magnitude of the externally applied load successfully resulted in a reduction in L4-L5 compression. Hence, obtaining the full beneficial effects of the transfer devices to spare the back requires a ‘proper’ technique.

After examining the L4-L5 shear loads, it was clear that hand force magnitude played more of a role; however, the impact was still modulated by trunk inclination. One important note is that although the values for shear obtained during the transfers were well below the recommended limit for a single instance, cumulative loading may be an issue in some patient care facilities (Daynard *et al.* 2001).

The limited results obtained from EMG data also showed a slight association with the patient transfer device; however, a large amount of variability in peak EMG amplitude existed. Skotte *et al.* (2001) also reported that during manual tasks performed by health care workers, EMG was found to be more dependent on the health care worker than on a specific transfer device. In the present limited study of just three workers, the ‘proof of principle’ conclusions substantiate the Skotte findings. It is very possible that a more robust pool of workers would have demonstrated a wider variety of transfer techniques. However, this would not change the conclusions reached here. In addition, the conclusions may not be generalized to much heavier patients. Even though different applied loads did not appear to affect the coefficient of friction of the devices, moving heavier patients may need different postures for the patient handlers. Finally, the observations were under ‘ideal conditions’ since all other factors were controlled, such as time pressures, uncooperative patients, etc.

In summary, both the Rollboard^{TM} and the Bubbleboard^{TM} successfully reduced the coefficient of friction and hand forces. But what is clear is that worker transfer technique remains a critical determinant of back load. The proof of principle obtained in this work demonstrates that directing the hand force vector through the low back diminished the magnitude of this force to influence back load. This would be considered good form. This relegates the variables of trunk inclination and forward reach to dominate the magnitude of the back load. The full potential effectiveness of these devices requires some education on these manual patient transfer techniques, recognizing these variables.

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