Biomechanical analysis of the effect of changing patient-handling technique

B. Schibye*, A. Faber Hansen, C.T. Hye-Knudsen, M. Essendrop, M. Böcher, J. Skotte
Department of Physiology, National Institute of Occupational Health, Lersø Parkallé 105, DK-2100 Copenhagen, Denmark
Received 12 February 2002; accepted 15 November 2002

Abstract

The objective of the study was to assess the changes in the mechanical load on the low-back when shifting from a self-chosen to a recommended patient-handling technique. Nine female health care workers without formal education in patient-handling carried out 8 different tasks involving moving, turning and lifting situations. By means of a dynamic 3D biomechanical model of the lower part of the body, peak torque, compression and shear forces at the L4/L5 joint were compared using the two different patient-handling techniques. In 5 of the 8 tasks, a significant reduction was observed in spinal loading. Application of the recommended technique decreased the compression value significantly for all tasks with a mean value above 3000N. For the two tasks with the highest compression values when using the self-chosen technique (4223, 4446N), the loading was reduced with 36% and 25%, respectively. If the principles behind the recommended technique are implemented and maintained, a decrease in the risk of low-back disorders during patient-handling should thus be expected.

Keywords: Patient-handling technique; Spinal loading; Biomechanical analysis

1. Introduction

A high prevalence of low-back disorders (LBD) is found among nursing personnel (Harber et al., 1985; Jensen et al., 1995; Jensen and Tüchsen 1995; Pheasant and Stubbs, 1992; Stubbs et al., 1983). Patient-handling and the associated task transfers have been considered the prime risk factor for LBD (Burdorf and Sorock, 1997; Harber et al., 1985; Hoogendoorn et al., 1999; Stubbs et al., 1983). In general, results from epidemiological studies show a strong association between heavy lifting, frequent bending and twisting, whole body vibration and LBD (Bernard, 1997; Hoogendoorn et al., 1999). Heavy lifting and/or asymmetric working postures are typical for patient-handling, e.g. during repositioning of the patient or transferring the patient from bed to wheelchair, and vice versa. Previous studies investigating low-back loading and patient-handling tasks have reported compression on the low-back exceeding the acceptable limit of 3400 N proposed by the American National Institute of Occupational Safety and Health (NIOSH) (Daynard et al., 2001; de Looze et al., 1994; Gagnon et al., 1986, 1987; Garg et al., 1991a, b; Garg and Owen, 1993; Ulin et al., 1997; Waters et al., 1993; Winkelmolen et al., 1994).

Different paradigms exist for patient-handling techniques with different focus on aides, ergonomic principles, or use of the patient’s physical functions. The fundamental principles behind the patient-handling technique used in this study combine the three paradigms (in Scandinavia often called the Halvor Lunde technique): plan everything in advance, handle the patient in more subtasks instead of in one uninterrupted process, use simple aides to reduce the friction between the moved part of the patient and the bed, use simple aides to increase the friction between the patient and the bed at the body parts that have to be fixed in the task, use remaining functions of the patient by giving descriptive commands focusing on the natural movement pattern behind the task. Furthermore, the general principles for manual materiel handling technique should be applied: use push/pull instead of lifting procedures, avoid non-neutral working postures, work with parallel feet and arms (arm and foot of the same body side in front) to avoid twisting
of the back, no flexion of the back, but flexion of the knee joints, transfer of the body weight from one leg to the other.

On this background the aim of this investigation was to compare changes in the mechanical load on the low back when shifting from a self-chosen technique to a recommended technique based on the above principles. The measurements were carried out in two test sessions: (I) self-chosen technique and (II) recommended technique.

2. Method

2.1. Subjects

The study included nine female health care workers (HCWs), 44±9 years old with a body height of 168±6 cm and a body weight of 72±13 kg. Their job experience with patient-handling was 20±6 years, and in the present job they carried out 7±6 patient-handling tasks per day. They had no formal education in patient-handling technique. Prior to test session II, the HCWs learned about the theory behind the recommended technique and trained practical use of the technique. The training period lasted about half a year until the HCW performed the patient-handling tasks satisfactorily. None of the HCWs experienced low back pain on the experimental day. All subjects gave their informed consent, and the study was approved by the Ethical Committee of Copenhagen.

2.2. Procedure

The HCW performed eight different patient-handling tasks in partially randomised order in a laboratory set-up (Table 1). For each individual the tasks were carried out in the same order during the two sessions. In session I, the HCWs handled the patient using their own preferred technique and pace, and no instructions were given prior to performing the tasks. In session II, the HCWs used only the recommended technique. The patient was a male, who had suffered from stroke, was 53 years old, 175 cm high and had a body weight of 88 kg. He had spastic muscles paralysis bilaterally (primarily on the left side), but had normal function of the right arm. In session I, the patient was instructed to remain passive, but to co-operate if he was asked to. No assistive devices were used, and all tasks (except for a few HCWs in tasks 2 and 8) were performed without assistance from a second person. In session II, all tasks were performed without assistance from a second person, but simple devices to assist the HCW were used in some of the tasks; plastic bags were used to minimise the friction between the patient and the bed, and foam rubber wash cloths were used to increase the friction between the feet and the bed. Furthermore, the patient was instructed by the HCW to “help” as much as he was able to. The bed could be mechanically adjusted and was a typical hospital bed in Denmark. Besides the 8 tasks, a standardised symmetrical reference lift (SL) was performed in order to compare the load in the two sessions to a standardised lifting situation. This reference lift was expected to match a load on the low-back just below the acceptable limit recommended by the Danish Working Environment Authority. It consisted in lifting a 15 kg load from the middle of the bed to elbow height and back again. At the beginning of the lift, the horizontal distance from the tip of the toes to the handles of the load was 40 cm, and the height of the hands from the floor was 85 cm.

2.3. Measurements

A dynamic 3D biomechanical model of the lower part of the body including the feet, legs, thighs and pelvis was used for calculating the net torque at the L4/L5 joint. Ground reaction forces were measured by means of two force platforms (AMTI type OR6-5) with the subject standing with one leg on each platform or both legs on the same force platform. In addition, to measure the reaction force from the bed when the HCW pressed her leg against the bedside, two force transducers (AMTI type MC3) connected by a bar was fitted to the bed. The horizontal reaction force normal to the bedside and the centre of pressure were obtained from the output signals of the two force transducers at both ends of the bar. The experiments were videotaped with a 50 Hz video system using five cameras and digitised automatically with a Peak Motus 4.3 system that also collected the analogue data (sampling rate 1000 Hz). Compression and shear forces were estimated by a cross-sectional model of the low-back including 14 muscles and an optimisation procedure minimising the sum of cubed muscle stresses. Details on the biomechanical model used for calculating the torque, the muscle model and the method used for estimating the compression and the shear forces can be found in Skotte (2001) and Skotte et al. (2002). The biomechanical analysis was carried out for the central part of the tasks while the subject exerted herself by moving the trunk of the patient. Depending on the task, these periods ranged from 2 to 17 s in session I and from 1 to 8 s in session II. The maximum value of the torque, compression and shear force at L4/L5 during the central part of each task were chosen as the measure of the mechanical load on the HCW during the patient-handling.

The task was defined to start when the HCW moved forward to grip the patient, and end when she was standing upright after completion of the task.

The HCW was instructed to attempt to maintain a correct posture during each task without lifting the patient. He was instructed to leave the patient on the bed as short as possible, and to allow the patient to bear body weight as much as possible. In session I, the patient was instructed to help as much as he was able. In session II, the patient was asked to remain passive, but to co-operate if he was asked to. The task was performed in a hospital ward in the same way as in the hospital environment. The load measured in the present study was considered to be the most relevant load for both the HCW and the patient.
1. **Turn patient in bed towards the HCW from his back to his left side (causing his face to turn towards HCW).**
   Patient: Right knee flexed, right arm crossed over the trunk, head turned to the left. HCW: Stands in a walking position perpendicular to the bed with her left foot in front, her left hand on the knee and her right hand on the patient’s right shoulder. Patient instructed to make a set off with his right leg. At the same time, HCW shifts her weight from her front leg to her rear leg thereby pulling him over.

2. **Reposition patient from lying on the back in the middle of the bed to the nearest bedside.** Patient: Both legs flexed and foam rubber washcloth under his feet. HCW: Stands in a walking position perpendicular to the bed with her right foot in front, her right hand under the patient’s pelvis and her left hand on his knees. Patient is told to lift his pelvis and at the same time HCW pulls it to the edge of the bed by making a weight transfer. To reposition the shoulders, the pillow is placed under the scapula and used for pulling this part to the bedside.

3. **Turn patient in bed away from HCW from his back to his right side.** Patient: Left leg flexed, left arm crossed over his trunk, head turned to the right. HCW: Stands in a walking position perpendicular to the bed with her right foot in front, left hand on the knee and her right hand on the patient’s left shoulder. Patient told to make a set off with his left leg. At the same time HCW shifts weight from her rear leg to her front leg thereby pushing him over on his side. To reposition him, the pelvis is further tilted by pulling with her right hand under the lower part of the pelvis and pushing with her left hand on upper part of the pelvis. The shoulders are repositioned by pulling with her right hand under the right shoulder and pushing with her left hand on his left shoulder. **3x:** The same procedure as in task 3 except the HCW uses a plastic bag around her right hand when repositioning the pelvis and shoulders.

4. **Elevate patient from supine position to sitting on edge of the bed.** Patient: Turned to his left side (As task 1) but with both legs flexed. Instructed to move his legs over the edge of the bed. HCW: Stands in a walking position beside the bed with her feet in an angle of 45° to the bedside with her left foot in front. Left hand on his upper hip/leg and her right arm under his neck and thorax. Patient instructed to set off with his right arm and left elbow. At the same time, HCW shifts weight from her rear leg to her front leg thereby pushing him into sitting position.

5. **Move patient from sitting on the edge of the bed to standing on the floor.** Patient: Feet placed just below knees. Instructed to lean forward and put the right hand around the shoulder of HCW. HCW: Stands in a walking position in front of patient with her right foot in front and her feet perpendicular to the bed. Patient is asked to rise and with her right hand at his left scapula and her left hand on his right upper arm, the HCW is at the same time pulling him forward by shifting her weight from her front to her rear foot, where after he rises slowly.

6. **Move patient from sitting on the bed to supine position.** Patient: The head part of the bed is elevated to 45° position. HCW: Stands in front of patient with the patient’s right hand in her right hand. Patient is now instructed to lie down on his left side and turn to his back. In this procedure HCW is guiding and decelerating the movements. Now HCW places herself in a walking position beside the bed with her feet in an angle of 45° to the bedside with her left foot in front and with her head facing the foot of the bed. Patient is instructed to lift his legs and HCW at the same time helps by lifting the legs while she is making a weight transfer forward from her right to her left leg (HCW has both hands below the patient’s lower legs).
Preparatory subtasks, for example adjustment of the bed height, positioning the extremities of the patient and placing assistive devices (plastic bag, foam rubber cloth), were not included in the tasks.

The HCW was asked to rate her perceived physical exertion (RPE) of the low-back by answering the question: “how did you perceive the exhaustion of your low-back”. The Borg CR 10 scale (Borg, 1990), where 0 implies “nothing at all” and 10 implies “extremely strong” perceptual intensity, was used for the rating. The HCW made the rating immediately after completion of each patient-handling task and not during the activity, which is the normal procedure when using the Borg scale.

2.4. Statistics

A two-way ANOVA for repeated measurements was used with tasks and technique as fixed factors and the subjects as random factor. The residuals were tested for normal distribution and variance homogeneity. Since interaction was found between tasks and technique, the effect of the technique during the different tasks was tested with a paired t-test. A paired Wilcoxon signed-rank test was used for testing the RPE ratings. The level of significance was $p \leq 0.05$.

3. Results

Figs. 1 and 2 illustrate a single trial of the sit to stand task (5) in the two sessions with respective compression values for the L4/L5 joint. Examples showing video clips and calculated low-back compression during other patient-handling tasks are shown on the internet address www.ami.dk/patient-handling/.

The task mean values of the peak torque, compression and shear forces for the two sessions are shown in Figs. 3–6 while the data for session II are reported in Table 2. The torque and compression values decreased significantly in tasks 2, 4, 5, 7, 8 and 8x. The anterior/posterior shear forces decreased significantly in tasks 1, 2, 4, 6, 8 and 8x, whereas in tasks 3 and 3x an increase was observed. The lateral shear forces decreased significantly in tasks 2, 5, 6, 8 and 8x. The range of differences between the two sessions for the torque, compression, anterior/posterior and lateral shear forces were $-6\%$ to $-71\%$, $-4\%$ to $-66\%$, 26% to $-55\%$ and 3% to $-73\%$, respectively. Fig. 7 shows individual differences in peak compression between test sessions. All HCWs experienced decreased peak compression values in tasks 4, 5, 7, 8, and 8x, and most HCWs experienced decreases during tasks 2, 3, and 3x.
The task duration increased significantly in all tasks except in task 7 where the duration was unchanged. The range of means was 11.0–21.4 s in session I and 15.7–46.1 s in session II. In session I four of the HCWs were assisted by a second HCW during task 8, but in session II all carried out tasks 8 and 8x without any aid from others. Mean RPE ratings were generally very low ranging from 0.6 to 2.9 in session I and 0.1 to 1.6 in session II. A significant decrease was observed in tasks 3x, 4, 8 and 8x.
The aim of the study was to assess the changes in the mechanical load on the low-back when shifting from a self-chosen to a recommended technique. In 5 of the 8 tasks, a significant reduction was observed in spinal loading. Substantial variations were found in low-back loading in the different patient-handling tasks when the

**Fig. 4.** Session I (black bars) and session II (white bars) task mean values of the low-back peak compression at the L4/L5 joint. *Indicates significant difference.

**Fig. 5.** Session I (black bars) and session II (white bars) task mean values of the low-back anterior/posterior shear force at the L4/L5 joint. *Indicates significant difference.

**Fig. 6.** Session I (black bars) and session II (white bars) task mean values of the low-back lateral force at the L4/L5 joint. *Indicates significant difference.

4. Discussion

The aim of the study was to assess the changes in the mechanical load on the low-back when shifting from a self-chosen to a recommended technique. In 5 of the 8 tasks, a significant reduction was observed in spinal loading. Substantial variations were found in low-back loading in the different patient-handling tasks when the
self-chosen technique was used. The highest peak compressions at the L4/L5 joint were found for tasks 5 and 7 where the HCW typically lifted almost the whole weight of the patient, who was passive. The lowest loadings were found in tasks 1 and 3 where the passive patient was turned. Medium loadings were found in tasks 2, 4, 6, and 8 during horizontal repositioning in bed or during repositioning from supine to sitting in bed and vice versa where the HCW typically pushed or pulled the passive patient. The most robust finding of the effect of changing the patient-handling technique was the decrease in the peak torque and the compression at the L4/L5 joint in tasks 2, 4, 5, 7, 8 and 8x. It is important to note that the recommended technique reduced peak loads in tasks that were associated with high loading on the lumbar spine and that all task mean peak compression values were below 3400N (the ‘safety limit’ of NIOSH (Waters et al., 1993)) when using the recommended technique. Compression was significantly reduced in all tasks where the session I task mean value was above 3000N. For example, in task 8x where peak compression decreased from 3110N in session I to 1063N in session II. The peak compression of task 8x in session II was found when the HCW was standing at the foot of the bed holding the patient’s feet while the patient was pushing/pulling himself towards the head of the bed. Peak

HCWs were assisted by a second HCW during this task, and in session II they all carried out tasks 8 and 8x without any aid from others. The explanation for this reduction was primarily that the patient was guided to assist by using his own resources. The compression during the standard lift was just below the NIOSH safety level, and no differences in spinal loading were observed between test sessions ensuring that conditions for the patient-handling tasks and measurements did not change during the study.

The recommended technique also reduced peak anterior/posterior shear forces in tasks that were associated with high shear loading on the lumbar spine. However, an increase was observed for tasks 3 and 3x (borderline significance for task 3) with a low anterior/posterior shear force value (252 N) in session I. Increases were observed during a final pull of the patient’s pelvis putting him in a more stable position on his side. Shear forces of the low-back reported in the literature generally show considerable variation which most likely is caused by different low-back models for estimating internal forces. Small differences in the assumed line of action of the erector spinae muscle may result in significant changes in calculated anterior/posterior shear forces (Nussbaum et al., 1995). However, when estimating differences in shear forces between two test sessions using the same model, it is not considered that the results would depend on the exact characteristics of the model.

It was not feasible to perform biomechanical analysis for the entire duration of the tasks. Therefore, analysis was carried out for the central part of the tasks when peak exertion of the HCW was expected, i.e. during the movement of the patient’s trunk. It is possible that peak compression could occur outside the central part of the task in a few of the trials with low compression, especially in session II where very low peak compression (1000–2000N) was found in some of the tasks. For example, in task 8x where peak compression decreased from 3110N in session I to 1063N in session II. The peak compression of task 8x in session II was found when the HCW was standing at the foot of the bed holding the patient’s feet while the patient was pushing/pulling himself towards the head of the bed. Peak

Table 2
Task means and standard deviations (inside brackets) of peak torque, compression and shear forces at L4/L5 in session II

<table>
<thead>
<tr>
<th>Task</th>
<th>SL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3x</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>8x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque (Nm)</td>
<td>150.6</td>
<td>70.5</td>
<td>104.6</td>
<td>87.4</td>
<td>81.3</td>
<td>82.8</td>
<td>122.9</td>
<td>112.6</td>
<td>153.6</td>
<td>91.0</td>
<td>41.8</td>
</tr>
<tr>
<td>(22.5)</td>
<td>(18.1)</td>
<td>(31.8)</td>
<td>(25.3)</td>
<td>(24.1)</td>
<td>(17.0)</td>
<td>(26.3)</td>
<td>(27.6)</td>
<td>(30.1)</td>
<td>(21.6)</td>
<td>(14.0)</td>
<td></td>
</tr>
<tr>
<td>Compression (N)</td>
<td>3722</td>
<td>1603</td>
<td>2442</td>
<td>1909</td>
<td>1816</td>
<td>1909</td>
<td>2708</td>
<td>2717</td>
<td>3326</td>
<td>1991</td>
<td>1063</td>
</tr>
<tr>
<td>(349)</td>
<td>(326)</td>
<td>(717)</td>
<td>(562)</td>
<td>(453)</td>
<td>(355)</td>
<td>(520)</td>
<td>(575)</td>
<td>(722)</td>
<td>(369)</td>
<td>(266)</td>
<td></td>
</tr>
<tr>
<td>Ant/pos shear (N)</td>
<td>226.7</td>
<td>221.2</td>
<td>308.4</td>
<td>308.6</td>
<td>317.0</td>
<td>286.4</td>
<td>231.3</td>
<td>275.5</td>
<td>285.5</td>
<td>253.8</td>
<td>159.7</td>
</tr>
<tr>
<td>(53.0)</td>
<td>(43.0)</td>
<td>(69.8)</td>
<td>(46.7)</td>
<td>(56.0)</td>
<td>(70.8)</td>
<td>(46.4)</td>
<td>(81.9)</td>
<td>(63.5)</td>
<td>(70.5)</td>
<td>(40.4)</td>
<td></td>
</tr>
<tr>
<td>Lateral shear (N)</td>
<td>60.6</td>
<td>62.7</td>
<td>73.0</td>
<td>68.2</td>
<td>65.4</td>
<td>143.2</td>
<td>91.1</td>
<td>138.7</td>
<td>119.9</td>
<td>46.9</td>
<td>34.2</td>
</tr>
<tr>
<td>(27.9)</td>
<td>(31.3)</td>
<td>(30.9)</td>
<td>(28.4)</td>
<td>(40.0)</td>
<td>(77.6)</td>
<td>(26.6)</td>
<td>(53.1)</td>
<td>(62.7)</td>
<td>(26.2)</td>
<td>(18.6)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7. Individual differences (session II–session I) in the peak compression for all tasks.

B. Schibye et al. / Applied Ergonomics 34 (2003) 115–123

121
compressions somewhat above 1000 N are likely to occur preparatory to the handling of the patient, e.g. when the HCW puts a foam rubber washcloth under the feet of the patient. By detailed analysis of the standard lift, it was found that an inclination of the back of 35–45° with the hands put forward caused compression at the L4/L5 joint in the range 1000–2000 N (1412 ± 310 N) without any external loading on the upper part of the body (i.e. just before the HCW grabbed the handle of the box).

Recently, Daynard et al. (2001) reported spinal peak loadings similar to the results found in this study for a group of untrained HCWs and groups of trained HCWs who used assistive equipment. Interestingly, though there were several differences in the way the tasks were carried out in the two studies, it resulted in the same peak compression for the bed boost task (task 8). In the study of Daynard the task was carried out by two trained persons handling a person simulating a passive patient, whereas in this study one trained person handled a cooperative patient. The peak compression was a little higher in this study for the chair boost task (task 7); however, the trials in Daynard’s study were carried out as a two-person handling task with transfer belt or lift, which is likely to explain the difference.

The finding that the mechanical load was reduced by using a recommended technique is in line with the overall tendency towards lower RPE. This is also consistent with findings from other studies (Garg et al., 1991a; Garg and Owen, 1994). Earlier studies, which examined RPE during different patient-handling techniques reported a trend towards lower ratings when using assistive devices (Garg and Owen, 1992; Ulin et al., 1997).

This study has a number of limitations: The measurement of the task duration is limited by not including preparatory subtasks in the task duration. Practically, these subtasks only occurred in session II resulting in an underestimation of the actual task duration. However, the increase in this “limited” measure of task durations in session II is due to the fact that the patient is handled in several subtasks and the use of descriptive commands instead of handling the patient in one unified task, which was often the case in session I. Quantifying mechanical load during patient-handling tasks induces several problems. Video recordings require a free line of sight calling for a careful control of the position/movement of patient, bed, wheelchair and other assistive devices. This can normally be achieved in the laboratory environment; however, it cannot be excluded that sometimes these considerations may have an effect on the patient-handling situation. To ensure realistic working conditions and loading conditions to the HCW, this study employed a disabled person. However, the optimal method for handling one patient may differ from another depending on how disabled the patient is. Accordingly, loads experienced by the HCW depend on the physical functions of the patient and their utilisation. In this study the mechanical load was estimated by means of modelling the lower body and by recording ground reaction forces and forces interacting between the thighs of the HCW and the bed (Skotte, 2001).

The force platforms were positioned in order to measure ground reaction forces during the peak loading of the low-back, but force platforms impose some limitation in the freedom of movements to the HCW because of their limited size. Thus, it cannot be ruled out that the presence of platforms could influence the movements of the HCW in some of the tasks. Furthermore, the HCW was not allowed to use her legs in order to support and fix the knees of the patient during the trials, as this would introduce an error in the measurement of the reaction forces on the HCW.

5. Conclusion

Our results indicate that the mechanical load was reduced below 3400 N for all tasks when using a recommended patient-handling technique. Although the time spent by performing each task increased, trends towards lower ratings of perceived exertion were observed. Therefore, by following the recommended technique one may expect a reduced risk of low-back disorders during patient-handling tasks; however, this calls for studies focusing on the practical implementation of the technique.

References


