

Effect of individually chosen bed-height adjustments on the low-back stress of nurses

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OBJECTIVES — The effects of height-adjustable beds in hospitals on the subsequent prevalence of low-back problems among nurses depend on the capacity to reduce low-back stress by bed-height adjustment. This capacity was investigated in the present study.

METHODS — Professional nurses performed patient-handling tasks at a standard and an individually chosen bed height. Peak values and time integrals of spinal compression and shear forces were estimated with dynamic biomechanical modeling.

RESULTS — The bed-height adjustment led to lower values of time-integrated compression (average 8.8% lower), peak shear force (average 9.3% lower), and time-integrated shear force (average 18.1% lower). No significance was found for the effect on peak compression, nor for the results for each individual task. This finding can be explained by the minor adjustments made in comparison with the standard height or by the application of different criteria for bed-height adjustment.

CONCLUSIONS — The decreasing time-integrated forces and peak shear force, without a concomitant rise of peak compression, speak in favor of the use of height-adjustable beds in nursing.

KEY TERMS — bed height, ergonomics, mechanical loading, low-back problems, nursing.

Low-back problems are known as a major occupational health problem. Among the groups of workers most adversely affected by low-back problems is nursing personnel. Several epidemiologic studies have found relatively high prevalences and incidences of low-back problems and worker's compensation claims for nurses (1, 2). Although the exact nature of the mechanism causing low-back problems is not clear, it is generally believed that the mechanical stress on low-back structures in association with nursing activities is the main causative factor. The handling of patients in bed and the transfer of patients to and from their beds are considered activities that are the most susceptible to low-back injury (3-5).

To approach this problem, several strategies have been proposed (6). One strategy is the selection of workers to improve the capacity of nursing personnel to withstand low-back stress. Another is aimed at reducing low-back stress by teaching nurses to apply "safe" patient-handling techniques. The effects,

however, of both strategies on the subsequent prevalence of low-back problems can be questioned. Some investigators have not managed to demonstrate measurable effects, neither for selection programs aimed at the prevention of back injuries (7) nor for extensive education and training programs for nurses (1, 2).

A third strategy, seemingly more prosperous, concerns a reduction of physical stress by redesigning the work system. For instance, several mechanical devices which might be of help in patient-handling tasks have been suggested, for example, patient hoists, patient transfer chairs, patient sliding and roller boards, and gait and ambulation belts. All are aimed at reducing the pushing, pulling, or lifting forces exerted by nurses. Although the mechanical advantage for several devices has been clearly demonstrated (8, 9), the use of the equipment meets emotional barriers. Nurses feel negative about the equipment, since getting, installing, and using equipment usually takes much more time than handling the patient manually and patients can feel insecure when transferred by equipment (10). Another relatively simple method to optimize the work system, obviously less dramatic for the nurse and the patient, concerns the use of beds which are adjustable in height.

The effect of bed height on spinal forces during the task of turning a patient in bed was studied by Gagnon et al (11). Peak compressive forces on the lumbar spine were found to be 21% lower in a "high" bed position (at individual hip level) compared with

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a "low" bed position (0.10 m below hip level). This difference was attributed to the finding that the trunk was nearer vertical when a high bed was used, the result being smaller maximal muscle moments. On the other hand, Lindbeck & Engkvist (12) did not find a difference in L5-S1 moments between the use of a low bed (41% of body height) and a high bed (46% of body height).

As the optimal bed height probably depends on the task performed and certainly depends on the individual nurse, the use of beds of an adjustable height might be preferred above beds of a fixed height (which are still in use in many nursing environments). The effect of the implementation of adjustable beds in hospitals on the prevalence of low-back problems among nurses is however unknown. An important related question is whether the individual nurse is capable of decreasing the mechanical stress on his or her low back by adjusting the bed height.

In the present study the mechanical stress on the low back was investigated in different patient-handling and transferring tasks. These tasks were performed by professional nurses at two bed heights: a standard fixed bed height of 0.715 m above ground level [common height in the academic hospital (AZVUB) in Brussels] and a bed height chosen by each nurse for each task performed. The mechanical stress on the low back was expressed by peak and time-integrated values of compressive and shear forces on the lumbar spine, which were estimated on the basis of a dynamic biomechanical model. The aim of the study was to determine the effects of individually chosen bed-height adjustments on the various estimates of mechanical low-back stress.

Subjects and methods

Subjects

Fourteen female and eight male nurses participated in the experiments. They were employed in different units of two hospitals in Belgium. Nine of them reported a history of low-back problems. At the time of the experiments all of the subjects were free of low-back problems or any other health problem. The subjects' characteristics are listed in table 1.

Tasks

The subjects performed five patient-handling tasks selected on the basis of a preliminary study on the attitude of nurses towards nursing tasks. The five

tasks were among the tasks that were experienced as the most stressful (13). The tasks largely comprised movements that were limited to the sagittal plane. The subjects were told to perform the tasks at a "normal" steady pace and to apply the patient-handling techniques prescribed by a professional nursing teacher. The man who acted as the patient weighed 78 kg, had a height of 1.86 m, and was 25 years of age. He was instructed to remain as relaxed as possible during the trials, hence, not to co-operate nor to work against the nurses' efforts. The following five tasks were performed: (i) turning the lying patient over from his back to his left side, (ii) positioning the lying patient on a bedpan by lifting and turning the patient from his left side to his back, (iii) pulling the lying patient towards the head of the bed, (iv) pulling and lifting the patient from sitting on the edge of the bed to standing on his feet, (v) lowering the patient from standing position to sitting on the edge of his bed.

Each task was performed at two different bed heights, at a fixed bed height of 0.715 m (from ground level to the upper side of the mattress), which is a standard bed height in the academic hospital (AZVUB) in Brussels, and at a variable height that was adjusted by the subjects. The procedure for adjusting the height was that, first, the bed was lowered to its lowest position (0.30 m above ground level) by the researcher and, next, the nurses were told (without any additional remarks or advice from the researcher) to adjust the bed height to their own comfort. This procedure was performed prior to tasks 1 and 2 (performed successively in one session), prior to task 3, and prior to tasks 4 and 5 (also performed in one session). The sequence of these sessions was varied systematically among the subjects.

Measurements

Kinematic data, ground reaction forces, and anthropometric data were required to apply the biomechanical model used in the investigation.

To analyze movements, we used light reflective markers placed on the subject's right side at relevant anatomical positions [the fifth metatarsophalangeal joint, the distal part of the lateral malleolus, the lateral femoral epicondyle, the uppermost margin of the greater trochanter, the intervertebral disk between the fifth lumbar and first sacral vertebra (L5-S1) from a lateral view (according to reference 14), the spinous process of the first thoracic (T1) vertebra, and the acromion]. The instantaneous positions of these markers during movement were recorded by use of a direct motion analysis system (VICON, Oxford Metrics) at a rate of 60 frames $\cdot$ s⁻¹. The marker's coordinates in the sagittal plane of motion were low-pass filtered (effective cut-off frequency of 5 Hz, zero phase lag, second order, Butterworth). From the filtered body-marker positions a dynamic linked segment model was constructed comprising the feet, the

Table 1. Subject characteristics.

	Age (years)		Total body mass (kg)		Body height (m)	
	Mean	SD	Mean	SD	Mean	SD
Women (N = 14)	31.0	7.6	62.0	5.3	1.66	0.06
Men (N = 8)	31.8	7.5	75.8	7.1	1.75	0.06

lower legs, the upper legs, the pelvis, and the trunk, which were interconnected at the ankle, the knee, the hip, and the L5-S1 joint (14).

Vertical and fore-aft components of the ground reaction forces were recorded by means of a force platform (Kistler). Analog force signals were low-pass filtered (30 Hz, 4th order at 24 DB/oct), sampled at 60 Hz. The sampling of the ground reaction force signals and marker coordinates was started and ended by the VICON computer (by one key stroke). From the force components the point of application of the ground reaction force was calculated.

Prior to the experiments, body height, total body mass, and body segment lengths were measured. On the basis of these measurements and tables (15), the segmental masses, the moments of inertia, and the relative positions of the centers of gravity were estimated for each subject.

Biomechanical model

On the basis of the kinematic data, the measured forces and the anthropometric data, the instantaneous net joint moments and joint reaction forces at the ankle, the knee, the hip, and finally at the L5-S1 joint were estimated by means of an inverse dynamic analysis (16). Next, compressive and shear forces were estimated on the assumption that the L5-S1 moment was generated by a single extensor muscle acting 0.06 m posterior to the center of the disk. The possible effect of the abdominal pressure to support an extending lumbar moment, which has been seriously doubted (17), was ignored in the calculations.

Data analysis

In each trial the beginning and end points of the task were determined on the basis of the time history of the ground reaction force. Next, peak and time-integrated values for the L5-S1 moments and compressive and shear forces were calculated. For each subject the results from different trials of the same task were averaged. On the basis of an analysis of variance with repeated measures, the significance was

determined of the (combined) effects of the type of bed used (adjustable or fixed height) and the tasks performed. In addition, the significance of the differences in the results for each handling task between the fixed and adjusted bed height was tested by post-hoc comparisons (level of significance 0.05).

Results

The adjustments chosen for bed height (with respect to the standard height) are presented in table 2. For the tasks of turning (task 1), positioning (task 2), and pulling (task 3) the patient, most of the subjects chose a higher bed position in comparison with the standard position. For the tasks of lifting (task 4) and lowering (task 5) the patient, the percentages of subjects who preferred a lower and a higher bed position were equal. The mean adjustments were +65 mm for tasks 1 and 2, +40 mm for task 3, and +4 mm for tasks 4 and 5, which implied, respectively, bed heights that averaged 46.1 (SD 2.7)%, 44.7 (SD 2.9)%, and 42.5 (SD 3.1)% of the subject's body height. The observed intersubject variation in bed-height adjustment might have been expected beforehand, when the variation in body height among the subjects was taken into consideration (range 1.57–1.81 m). However, it was also found that the bed height chosen did not correlate with body parameters like body height (figure 1) or hip height.

The resulting values for the mechanical parameters for the standard and adjusted bed heights are presented in figures 2 and 3. The statistical results are listed in table 3.

With respect to spinal compression, the peak values ranged from 2626.3 (SD 715.0) N to 4575.7 (SD 857.2) N for the tasks performed with the standard bed height. A tendency towards slightly lower peak values were observed for the adjusted bed height for four of the five tasks (figure 2). However, the effect of bed-height adjustment on peak compression was not significant. On the other hand, a statistically significant effect of bed height adjustment was found for the time integrals of spinal compression.

Table 2. Bed-height adjustments chosen for the various tasks (means, standard deviations and ranges) with respect to the standard bed height of 0.715 m and the percentages of subjects that chose a higher, lower or equal bed height compared with the standard height.

Task ^a	Height adjustment (mm)			Adjustment choice ^b (% of subjects)		
	Mean	SD	Range	Higher	Lower	Equal
Turning from back to left side (1) and positioning on bedpan (2)	+ 64	44	– 25 – + 135	90.9	9.1	0.0
Pulling towards the head of the bed (3)	+ 40	43	– 35 – + 125	85.7	14.3	0.0
Pulling or lifting from the bed (4) and lowering onto the bed (5)	+ 4	46	– 75 – + 100	47.6	47.6	4.8

^a Number of task in parentheses.

^b In respect to standard bed height of 0.715 m.

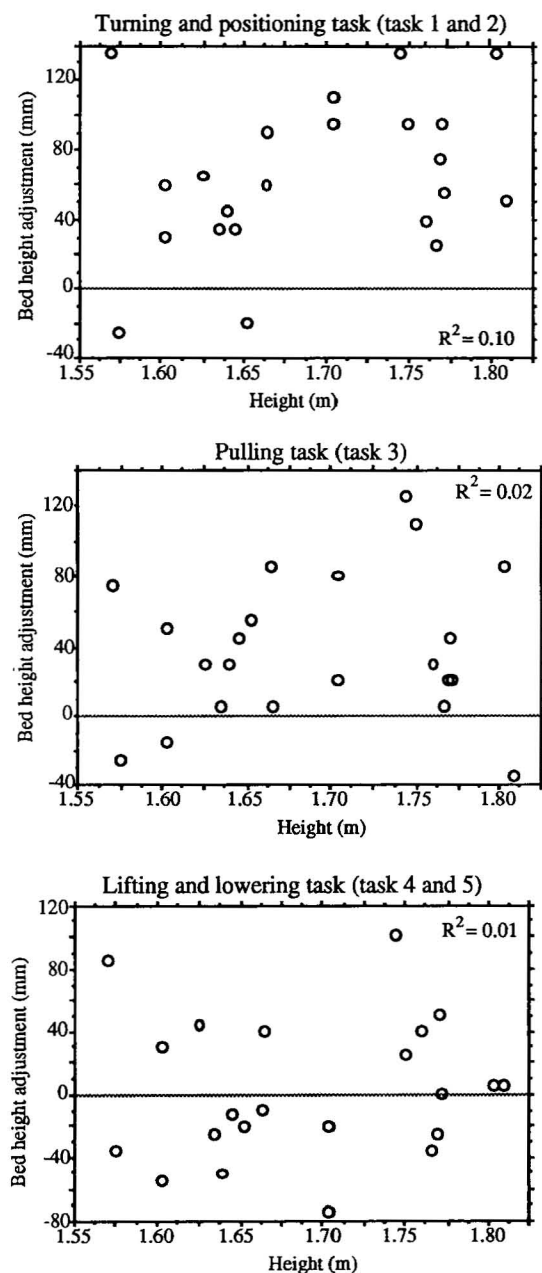


Figure 1. Chosen bed-height adjustments (with respect to standard bed height) in the turning and positioning, the pulling, and the lifting and lowering tasks, as plotted against the height of the subjects.

In general, the adjustment of bed height led to an average decrease of $562.6 \text{ N} \cdot \text{s}^{-1}$, or 8.8%, in the time-integrated compressive force. For individual tasks, the differences observed in the peak and time-integrated spinal compression between the fixed and adjusted bed position were not significant for any of the five tasks.

The peak and time-integrated shear forces are presented in figure 3. With the standard bed height the peak shear force ranged from $300.5 \text{ (SD } 86.7) \text{ to}$

$626.9 \text{ (SD } 101.5) \text{ N}$. In general, smaller values were found with the use of the adjusted bed height, an average of 35.4 N , or 9.3%, for the peak values and an average of $108.3 \text{ N} \cdot \text{s}^{-1}$, or 18.3%, for the integrated values. These general effects of bed height were statistically significant. For the individual tasks, significantly lower values were found for the adjusted bed height position only with respect to the peak shear force in task 1 ("turning") and the time-integrated shear force in task 3 ("pulling").

Additional statistical tests were performed to investigate several subject-related factors. Although the male nurses were subjected to higher spinal forces than the female nurses (which could be attributed to their higher total body mass), the effects of bed-height adjustment on the mechanical parameters were similar for both genders. In addition, no significant differences, with respect to the mechanical stress parameters or the effect of bed-height adjustment, were found between the nurses with and those without a history of low-back problems. In addition, a comparison was made between the nurses who had experience adjusting bed positions in their daily work and nurses who had no such experience. It was found that the bed-height adjustments made by the experienced nurses led to a significant decrease in time-integrated compression and peak and time-integrated shear force, while the effects were not significant for the inexperienced nurses. However, as the size of the inexperienced group was small ($N = 3$), the data for the effect of experience are too few to be considered carefully.

Finally, the effects on low-back stress were studied in relation to the adjustments made. It was found that tendencies towards lower values for the stress parameters with the bed adjustment were more pronounced for the subjects who raised the bed than with those who lowered it. When bed height was expressed as the percentage of body height, the stress parameters for adjusted height tended to be the most pronounced for the subjects who chose a bed height at a relatively high percentage of their individual body height (in comparison with the total group). Although most of the tendencies were not significant (mainly due to the necessity to split the total data set into smaller sets, both on a subject and a task level), these results suggest that the extent of favorable effects of bed height adjustment was limited by subjects who preferred a relatively low bed height in relation to their individual body height.

Discussion

The effect of installing height-adjustable beds in nursing environments on subsequent low-back problems depends on the nurse's capacity to reduce the low-back stress by bed-height adjustment. The present study demonstrated significant, favorable effects of individual bed-height adjustment on the fol-

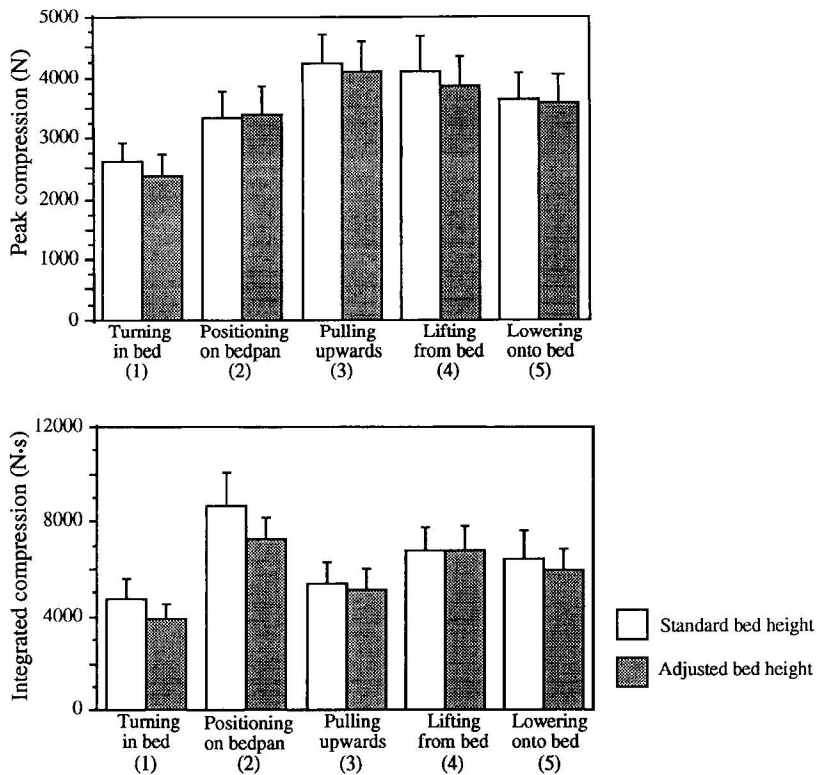


Figure 2. Peak and time-integrated values (averages and standard deviation for all subjects) of spinal compression for the tasks used with the standard and adjusted bed heights.

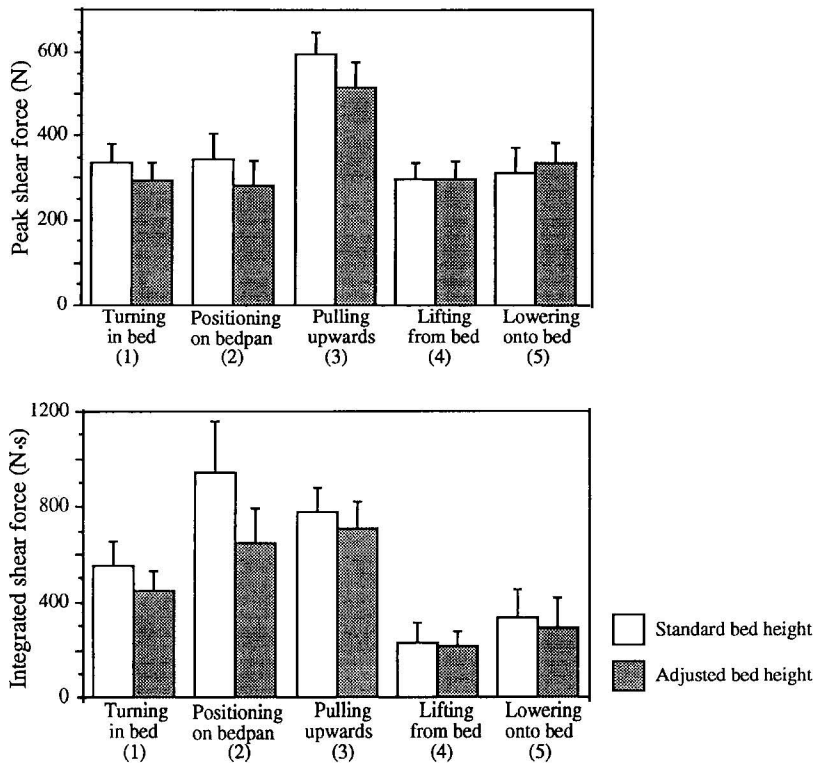


Figure 3. Peak and time-integrated values (averages and standard deviation for all subjects) of shear force for the tasks used with the standard and adjusted bed heights.

Table 3. Significance of effects of the bed height (fixed or adjustable) and the task performed on the peak and time-integrated values for spinal compression and shear force. (NS = not significant)

Dependent variable	Factor	Degrees of freedom	F-value	Level of significance
Peak compression	Bed height (B)	1	0.7	NS
	Task performed (T)	4	24.5	P<0.0001
	B · T	4	0.9	NS
Integrated compression	Bed height (B)	1	4.9	P<0.05
	Task performed (T)	4	14.3	P<0.0001
	B · T	4	1.0	NS
Peak shear force	Bed height (B)	1	4.173	P<0.05
	Task performed (T)	4	39.740	P<0.0001
	B · T	4	1.397	NS
Integrated shear force	Bed height (B)	1	7.772	P<0.01
	Task performed (T)	4	37.362	P<0.0001
	B · T	4	1.828	NS

lowing mechanical parameters: peak and time-integrated shear force and time-integrated spinal compression. On the other hand, there was no significance for the general effect of bed-height adjustment on peak compression, or for differences in the results for the individual tasks between the adjusted and fixed bed height (except for peak shear force in "turning" and integrated shear force in "pulling"). As is discussed later, several factors might have prevented the latter results from being significant.

Factors interfering with favorable effects

An obvious factor that could have limited the favorable effects to some extent is a restricted capacity of the nurses to select an optimal bed position with respect to physical stress on the low back. Although most of the subjects had experience in adjusting bed height for nursing tasks, some might have been unsuccessful in reducing low-back stress simply because they were not capable. However, there might have been other interfering factors as well.

In studying the practical advantage of height-adjustable beds, the use of the individually adjusted height was compared with the use of a bed with a standard height (as is generally available). It is likely that this standard height was already close to optimal for a substantial number of the subjects. This situation would have made it difficult to establish significance for any effect of the adjustment. Moreover, as a result of the supposedly near-optimal standard height, various nurses adjusted the bed to a minor extent in an upward or downward direction, while only a small portion of the nurses raised the bed significantly. With respect to maximal spinal compression, it is solely for these latter subjects that the mechanical advantage is clear. An increase in bed height yields a trunk position nearer the vertical and results in a lower muscle moment at the lumbar level (11).

Finally, the adjustments might have been chosen according to criteria other than minimizing low-back stress. Such a criterion might be the limitation of muscular effort in the upper body. It could be hy-

pothesized that a relatively low bed position might relieve the loading on the arm and shoulder muscles for two reasons. First, as a relatively high bed requires an erect standing position (extended legs and trunk), the power required to handle a patient can only be generated by the muscles of the upper extremities. With a relatively low bed, however, a substantial part of the muscle power can be generated by flexing and extending the lower extremities and trunk. Second, when the trunk can be flexed at this lower bed height, the patient can be handled closer to the horizontal position of the shoulders. This possibility implies a lower shoulder muscle moment than with the vertically erect trunk position imposed by a high bed. An attempt to relieve stress on upper-extremity muscles might have been the reason for some of the subjects choosing a relatively low bed position in relation to their body height. As noted before, these subjects might have limited the favorable effects of bed adjustment on low-back stress to some extent. Thus the application of different criteria by the nurses studied may have formed another obstacle to the achievement of significance for some of the results.

Individually chosen bed height in relation to body height

In the tasks in which the patient was handled in bed, the bed height was adjusted to a level that corresponded, on the average, with 46.1 (SD 2.7)% (tasks 1 and 2) and 44.7 (SD 2.9)% (task 3) of body height. For lifting and lowering the patient (tasks 4 and 5), this percentage was slightly lower: 42.5 (SD 3.1)%. The values are in close agreement with the findings of Lindbeck & Engkvist (12). In their study, nurses adjusted the bed height for the task of "moving the patient up the bed" by an average of 44.7 (SD 2.5)%.

In the present study we did not find any relationship between bed-height adjustment and body height (or hip height). This rather surprising finding may be explained by the aforementioned factors of inter-subject variation in the application of criteria for bed-

height adjustment, the minor extent of bed-height adjustment by some nurses, and restrictions on the nurse's capability to adjust the bed correctly.

As the experiments were designed to determine the capacity of nurses to reduce back stress by adjusting the bed in comparison with a standard position, an optimal bed height cannot be determined from the results. This determination would have required a protocol of several imposed bed heights, from which the least stressful could be determined. From the preceding considerations, it can be stated that an optimal bed height is hard to define, since it not only depends on anthropometric dimensions but also on the nurse's physical work capacities and the task to be performed.

Peak versus time-integrated values

Despite the amount of bed height adjustment and the possible application of criteria other than the reduction of low-back stress, significant favorable effects of bed-height adjustment were observed for the time integrals of compression and shear force and for the peak shear force. Especially the reduction in time integrals is noteworthy. This reduction can be partly explained by a decrease in the time required to perform the tasks at the adjusted bed height.

One can only speculate about the relevance of the results with respect to the risks of low-back problems among nurses, for the etiology of low-back problems is still unclear (18). The main interest in ergonomics has always been to reduce the maximal forces operative on lumbar motion segments during peak loading activities. Most attention has been directed towards the peak compressive forces. The peak values of spinal compression may lead to fractures of the vertebral end plate and the underlying cancellous bone (19), which is a frequent type of damage observed in autopsy studies (20). Several guidelines for manual materials handling [eg, the guidelines of the National Institute for Occupational Safety and Health (NIOSH) in the United States] are (partly) based on the criterion of maximal motion segment compression (21). The present study showed that the NIOSH criterion for maximal compression of 3.4 kN was exceeded in four of the five tasks and that the chosen bed-height adjustments had no effect on this parameter.

Although shear forces have been estimated frequently in biomechanical research on low-back loading, shear force criteria are not available in the literature. Several authors have suggested that the point of damage directly on the vertebrae due to shear force is hardly reached in normal human activities (22, 23). On the other hand, it is generally believed that shear forces might lead to damage to the neural arch in human activity, as ventrally oriented shear force is counteracted by the facet joints. In addition, the facet joints have been found to be a direct source of pain (24). In the present study, we found that bed-

height adjustment leads to an average decrease of 9.3% in peak shear force. Whether this decrease is enough to decrease the risk of low-back problems can only be established on the basis of longitudinal epidemiologic research.

In contrast with the interest in the (peak) magnitude of forces, temporal aspects of the mechanical stress have received very little attention, although these aspects are likely to be highly relevant (25). Because of the visco-elastic nature of biological tissue, prolonged or repetitive loading may result in residual deformation and cumulative fatigue and therefore reduce the threshold stress at which tissues fail. In a recent epidemiologic study the temporal aspects of the load were incorporated successfully. The integral of the compressive force on the L5-S1 motion segment over a workday has been demonstrated to have a positive relation to the prevalence of low-back pain (26). In the present study the time integrals for the compression and shear force were found to decrease by 9.3 and 18.8% through the use of bed-height adjustment. In light of the aforementioned considerations a major conclusion of this study is that nurses are capable of adjusting beds in such a way that the total amount of mechanical stress on the L5-S1 motion segment over the total duration of patient-handling tasks (in terms of integrated forces) decreases without peak values of stress being increased.

Concluding remarks

In this study, significant favorable effects of bed-height adjustment were observed for the time integrals of compression and shear force and for peak shear force. The observed tendency for lower peak compression values with bed-height adjustment was not significant. This finding may be due to the minimal bed-height adjustments made (standard bed height might be close to the optimal height for various subjects) and the possible application of criteria other than the reduction of low-back stress. Nevertheless, the results of the present study, especially the reduction of exposure to a high level of force on the L5-S1 motion segment without a concomitant rise in peak forces, speak in favor of the use of height-adjustable beds in nursing.

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