La Medicina del Lavoro

Med Lav 2016; *107*, 5: 356-363

Spinal load in nurses during emergency lifting of obese patients: preliminary results

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Key words
Spinal load; handling; ergonomics; health care personnel; biomechanics

Parole chiave
Carico vertebrale; sollevamento; ergonomia; personale sanitario; biomeccanica

Summary
Background: *Nurses are exposed to the risk of injury while handling patients. This is particularly true for obese patients.* **Objective:** *The goal of this paper is to estimate the spinal loads and the related risk of injury to nurses while lifting obese patients from the floor with a bariatric sheet during a hospital emergency.* **Methods:** *Six male nurses participated in this study. The biomechanical analysis focused on the lifting strategy. Thirty obese in-patients were enrolled to take part in the experimental study and divided into three groups according to their Body Mass Index (BMI). Three-dimensional motion analysis was conducted using an optoelectronic system. The trunk kinematics and the loading on the spines of the operating nurses were computed.* **Results:** *Our data showed that when the nurse was operating from the central handle, his trunk was more flexed at the end of the lift with a reduced range of motion. The values were higher when the nurse lifted patients with higher BMIs. All kinetic parameters and tension in the lumbar muscles at the end of the movement were characterised by lower values for the nurse placed beside the patient's head or feet if compared to the operator positioned beside the central handle in all patient groups.* **Conclusions:** *Our preliminary data suggest that only the reaction load on the spine of the nurse holding the central handle, closest to the patient's centre of mass, seems to exceed the recommended safety limits.*

Riassunto
***«Carico vertebrale in operatori durante il sollevamento in emergenza di pazienti obesi: risultati preliminari»*.** **Introduzione:** *Gli operatori sanitari sono esposti a rischio di infortunio durante il sollevamento di pazienti, specialmente nel caso di pazienti obesi.* **Obiettivi:** *L'obiettivo dello studio è valutare il carico a livello della colonna vertebrale e il rischio di infortunio ad esso connesso in operatori sanitari durante il sollevamento in emergenza di pazienti obesi utilizzando un telo bariatrico.* **Metodi:** *Hanno partecipato allo studio 6 operatori. L'analisi è stata condotta in termini di strategia biomeccanica durante il sollevamento. Sono stati reclutati 30 pazienti obesi suddivisi in tre*

Pervenuto il 27.1.2016 - Revisione pervenuta il 5.4.2016 - Accettato il 11.7.2016
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gruppi sulla base del loro Indice di Massa Corporea. Le acquisizioni sperimentali sono state condotte avvalendosi di un sistema optoelettronico. E' stata quantificata la cinematica del tronco e il carico a livello della colonna vertebrale dell'operatore. **Risultati:** *I dati hanno mostrato che in posizione centrale il tronco dell'operatore è più flesso al termine del sollevamento ed è caratterizzato da una ridotta escursione; i valori sono maggiori durante il sollevamento dei pazienti con un elevato indice di massa corporea. Tutti i parametri cinetici e la tensione dei muscoli lombari al termine del movimento sono caratterizzati da valori più bassi quando l'operatore si trova in prossimità della testa e dei piedi del paziente, indipendentemente dall'indice di massa corporea del paziente sollevato.* **Conclusioni:** *I risultati preliminari suggeriscono che il carico a livello della colonna vertebrale eccede i valori limite di sicurezza solo quando l'operatore si trova in posizione centrale, più vicino al centro di massa del paziente.*

Introduction

Obesity is a pandemic whose economics pose serious challenges to national health care systems worldwide, as they come under increasing pressure to gear up for the special needs of extremely large patients in terms of facility design, equipment planning and patient and caregiver injury prevention. With steadily rising national averages, nurses and health care staff are encountering obese patients in almost every practice area. Both in the community and the hospital, the safety needs of morbidly obese patients have been recognized as challenging available resources. The presence of high numbers of obese patients in the hospital setting has a direct impact on the safety of healthcare workers. Nurses in particular are exposed to the risk of injury even while handling normal-weight patients. The transfer of partially or completely dependent patients is a critical aspect of manual handling. In point of fact, the most frequent cause of work-related injuries among nurses is manually lifting patients and the risk of injury is associated with the frequency of such lifting and the patient's weight (1, 9). In the ISO 12296 (12), manual handling of dependent patients is classified as a high-risk task, whereas assisted handling is associated with mild-medium risk of injury.

Pronounced lumbar flexion and related reaction forces generate high compressive peak loads on the spine, approaching or exceeding the recommended safety limits (24, 25). Among health professionals, nurses have the highest incidence rate of work-related injuries, especially of the spine (20). In fact, nurses have an annual prevalence of back pain of 50% and a prevalence of work-related injuries more than 6 times higher than other workers (17), which may potentially lead to chronic pain, permanently reduced work capacity, job limitation or exclusion, and have obvious implications for organization and health costs. During hospital emergencies, such as assisting a patient who has collapsed on the floor with a sudden life-threatening condition or positioning him/her on a stretcher after a fall, postural and strength demands may increase dramatically, particularly when the patient has a high Body Mass Index (BMI). In such circumstances, handling obese patients is potentially risky even for the most skilled of operators (1).

Despite the use of devices, the rate of injury may be higher during emergencies because nurses often have to perform work in awkward, flexed and unsupported positions.

Best practice guidelines for the safe handling of morbidly obese patients have been previously published (14, 15, 23). Factors that were considered to impact safety were felt to include the patient's ability to assist, level of cooperation, comorbidities, ability to bear weight and to assist in making body parts accessible, level of respiratory compromise, upper extremity strength and, lastly, the availability of proper equipment. Other papers have focused on the safety for in-patients and health personnel during the daily health care routine (2, 11). However, beyond general recommendations (13, 22), there are no specific guidelines on preventing nurse injury in emergency situations (19) and little research has been done so far in this field.

Patient handling can be performed safely with the use of assistive equipment and devices that reduce the risks of injury. Assistive equipment generally ensures the simultaneous reduction of the risk of musculoskeletal injury and improvement of safety and quality of care for the patient.

The equipment for handling obese patients in the hospital setting has been defined (12). As for bariatric equipment, Nelson et al. (16) have developed some manoeuvre-specific algorithms designed to assist in selecting the appropriate equipment and number of operators needed. The devices described aim to maintain the dynamic and static load imposed by the manual task on nurses within acceptable limits. Nelson et al.'s algorithms do not however include the bariatric lifting sheet with handles for emergency manoeuvres. Several studies have focused on the measurement of the lumbar load of healthcare workers during care activity with patient transfers (6, 7, 10, 21). Jager et al. (10) and Theilmeier et al. (21) evaluated the lumbar load of manual handling activities involving patients in or beside a bed or seated on a chair via simulation calculations made using a comprehensive bio-mechanical model based on an optoelectronic system, a video-recording system and an established force-sensory on the bed and chair. During box lifts, Elsayed et al. (6) and Farrag et al. (7) assessed the main and interaction effects of mass knowledge and mass magnitude on trunk muscular activity and lumbosacral kinematics using electromyographic data, a lumbar motion monitor based on a triaxial exoskeleton of the spine and force plates.

In some situations, it may not be possible to use an assistive device such as an electric lifter; for reasons such as the unavailability of that specific aid on the spot, architectural barriers, the onset of a sudden event leaving no time to find or use a specific device. Morbidly obese inpatients with a range of comorbidities are at an increased risk of sudden life-threatening events. In such situations, healthcare staff may be driven to perform emergency manual manoeuvres such as attempting to lift collapsed patients from the floor or to reposition them on a stretcher where first aid can be provided, but by so doing, expose themselves to the risk of sudden jerky movements, overly strenuous tasks and stressed postures.

In the present study, we report some preliminary data with the aim of starting to fill in the gap in the literature on safety concerns for health care personnel when handling obese patients during emergencies.

Three-dimensional (3D) motion analysis was performed in nurses during a simulated hospital emergency while they lifted obese patients with different BMI from the floor, using a bariatric sheet. Kinematic strategies and low back loads were assessed.

Materials and methods

Subjects

Six male nurses with similar anthropometric characteristics and age (mean age: 23 years; mean height: 1.82 m; mean weight: 75 kg) participated in the study. We enrolled the participants from among male nurses with no job task limitations (i.e. for back pain or conditions limiting physical exertion) who worked on the metabolic rehabilitation unit. We selected male nurses because during emergencies, when patient-handling tasks may not be facilitated by assistive equipment, they are more likely to be asked to perform manual lifting/transfers of the patient than their female colleagues. In particular, our biomechanical analysis focused on the lifting strategy of only one of the six nurses, who, in different trials, performed the tasks from three different handle positions of the bariatric sheet: by the side of the patient's head; the middle position and by the side of the patient's feet. Data were acquired in the laboratory by reproducing the real conditions of patient lifting from ground level by 6 nurses with a 6-handle bariatric sheet.

To evaluate the effect of BMI on low back loading, 30 obese in-patients were enrolled to take part in the experimental study: 10 patients with a BMI between 30-35 Kg/m^2 (Group 1), 10 patients with a BMI between 36-40 Kg/m^2 (Group 2) and 10 patients with a BMI between 41-46 Kg/m^2 (Group 3).

The nurse under study was assessed in all three of the lifting positions, while lifting each of the obese patients of the three groups in different sessions scheduled on different days. Each session consisted of 30 lifts with a comfortable recovery time in between.

The final lifting position was set at 70 cm off the ground. This height was high enough to reposition the patient on a stretcher.

A 150 cm x 43 cm nylon-made Maximove Ross (Romedic) bariatric lifting sheet with a capacity of 135 kg was used.

Experimental set-up

Three-dimensional motion analysis was conducted using an optoelectronic system with 6 cameras (460 VICON, Oxford Metrics Ltd., Oxford, UK) with a sample rate of 100 Hz.

The optoelectronic system performs a real time processing of images from two (or more) cameras to recognize in the field of view the presence of passive markers (with a diameter of 15 mm) that can be fixed onto proper anatomical landmarks of the subject; it then computes the subject's 3D coordinates. The system was calibrated to assure good accuracy: the calibrated volume for this application was 2 m in length (x-axis of the laboratory reference system), 2 m in height (y-axis of the laboratory reference system) and 2 m along the z-axis of the laboratory reference system. To evaluate the kinematics of each body segment, passive markers were positioned on the nurse under study's body according to the Helen Hayes Marker set by an experienced operator (5). However, for the present study, only markers on sacrum and C7 were considered; the other markers were acquired but not used for this analysis.

Data collection began in the initial position with the patient lying on the sheet on the ground, the 6 nurses each holding their handle (figure 1) and the nurse with the markers holding the handle while standing with his knees bent. After five seconds of holding the handles without effort, the 6 nurses were asked to simultaneously start lifting the patient to the final position and then to maintain this position for 5 seconds. Both feet of the nurse were in a comfortable position for the lifting task with heels close but not in contact.

In order to avoid overloading, the entire lifting operation was performed with only slight bending of the back. The lower position was achieved by fully flexing the knees, while the higher final position was reached through the extension of both legs until the upright position. The position of both hands on the handle was with palms facing down.

Data analysis
Movement Kinematics

We focused on the absolute angle of the trunk in the sagittal plane (positive values represent forward flexion of the spine, negative values the extension, values close to 0 degrees the upright position).

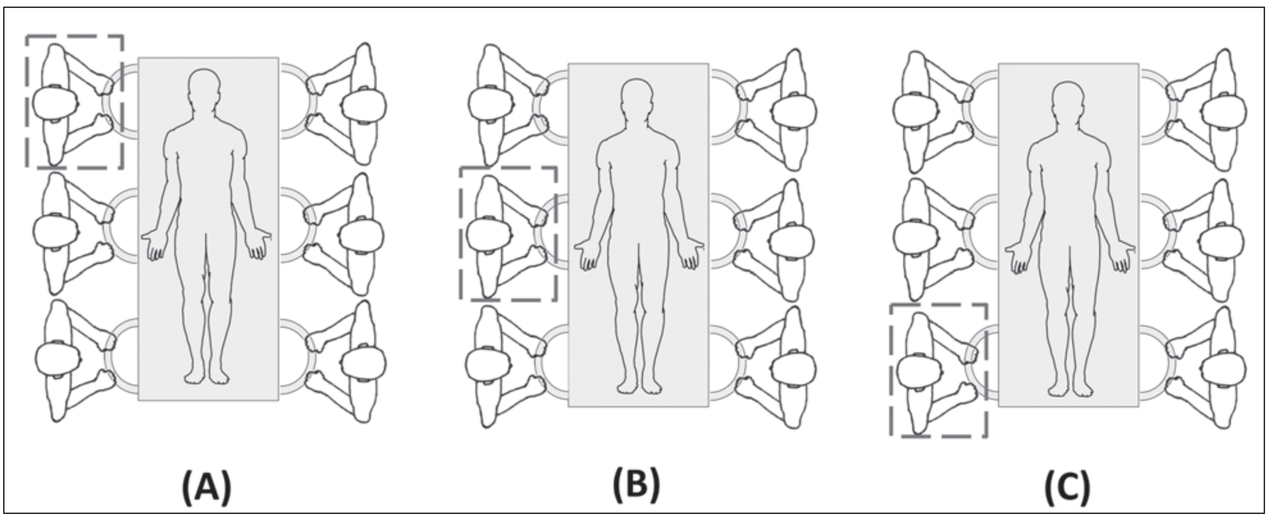

Figure 1 - Schematic representation of the lifting sessions according to the nurse position. (A) by the side of the patient's head; (B) the middle position; (C) by the side of the patient's feet

Kinetics

Forces exerted at L5/S1 level (R) and the tension of lumbar muscles (F_3) were computed according to the following model (4) (figure 2).

According to this model, the vertebral spine is like a flexible wand composed of a number of functional units, and spinal cavities are envisaged as two cylinders containing pressured liquids. The pelvis and the lower limbs act as a rigid block during the manoeuvre. The forces acting during lifting are in body weight, external forces supported by the body, the tension in lumbar muscles, the intra-abdominal pressure and the force exerted on the L5/S1 vertebral disc and through the spine.

Conventionally, the latter has a point of application at the centre of the pulpous nucleus of the inter-vertebral disc. As for body weight, the weight of the head, neck and upper limbs act as a single force on C7 (W_1), and the entire spinal weight as a single force on the midpoint between C7 and the sacrum (W_2). The reaction force (R) acting on L5/S1, the tension on the lumbar muscles and the intra-trunk pressure are present (F2). Since no direct contact exists between the thorax and low back, any effect would be acting through intra-abdominal pressure.

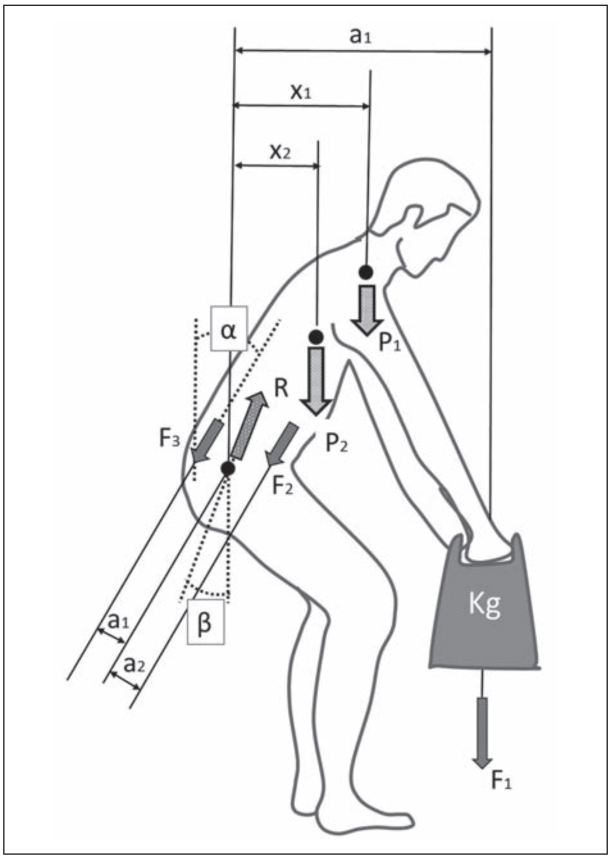

Figure 2 - Biomechanical model used to compute the forces exerted at L5/S1 level (R) and the tension of lumbar muscles (F_3) (4)

In order to find the moment arm, values were taken according to Perey (18).

The force referring to intra-abdominal pressure is calculated as follows

$F_2 = W*A$ (1)

where W is intra-abdominal pressure and A is the cross sectional area of the abdomen.

W_1 was the portion of loaded patient according to the nurse's position. In particular, the portion of the mass of the loaded segment in each position (by the side of the patient's head; the middle position and by the side of the patient's feet) was computed according to the method described in a previous study in obese adults, which defined segment mass of the head, trunk, upper arm, forearm, thigh and shank in females and males as a percentage of total body mass (3).

According to the static cardinal equation (2):

$$\sum_i F_i = 0 \qquad \sum_i M_i = 0 \qquad (2)$$

where F_i is each force exerting in this model and M_i each momentum, we obtained the following equations (3):

$$\begin{aligned} &W_1 + F_1 + W_2 - F_2 \cos\alpha - R\cos\beta + F_3\cos\alpha = 0 \\ &F_2 \sin\alpha + R\sin\beta - F_3 \sin\alpha = 0 \\ &F_1 a_1 - F_2 a_2 - F_3 * a_3, + W_1 * X_1 + W_2 * = 0 \end{aligned} \qquad (3)$$

where X_1 and X_2 are the moment arms respectively of W_1 and W_2, α is the trunk flexion angle and β is the angle between the line of action of R and absolute vertical axis; a_1, a_2 and a_3 are defined according to literature (18). According to these equations and from kinematics we can compute F_3, R and β.

All the parameters of interest were calculated after implementation of an algorithm using SMART analyser software (version 1.10.394.0; year 2006 by BTS, IT). In particular, the following parameters were identified and computed:

Kinematics:
- Maximum trunk angle: the maximum trunk angle on the sagittal plane reached when the nurse is performing the lifting task;
- Trunk angle at final position: values of the trunk angle on the sagittal plane at the end of lifting, when the nurse is in a stable position;
- Range Of Motion (ROM) of the trunk angle: calculated as the difference between the maximum trunk angle and the value of the trunk angle at the final position.

Kinetics:
- R_{end}: the value of forces exerted at L5/S1 level at the end of the lifting movement, when the nurse is in a stable position;
- $F3_{end}$: the tension value of the lumbar muscles at the end of lifting movement, when the nurse is in a stable position.

Statistical analysis

All parameters were calculated for each single trial of each session. The Kolmogorov-Smirnov test was used to verify normal distribution. The parameters were normally distributed and the mean and standard deviation for each parameter in each condition was computed; then we used the factorial ANOVA with the three groups of the patients who were lifted (Group**s** 1, 2 and 3) and the nurse's position (by the side of the patient's head; the middle position and by the side of the patient's feet) as factors. Statistical significance was set at $p<0.05$.

Results

Table 1 reports the values of the parameters related to the 3 positions of the nurse (by the side of the patient's head; the middle position and by the side of the patient's feet) and to the 3 groups of patients who were lifted.

Our data showed that when the nurse was operating from the central handle his trunk was more flexed at the end of the lift (Final Position index of Trunk angle) with a reduced range of motion (ROM of Trunk angle). The values were higher when the nurse lifted patients of Group 3. In terms of maximum flexion of the trunk (Maximum parameter of Trunk angle), no significant differences were found for nurse position and group of patients.

All kinetic parameters (forces at L5/S1 (R index)) and tension in the lumbar muscles (F_3 index) at the end of the movement were characterised by lower values when the nurse was by the side of patient's head and feet if compared to the nurse holding the central handle in all patient groups. No other statistical differences were found.

Table 1 - Mean (standard deviation) of evaluated parameters in the three positions of the nurse (by the side of the patient's head, the middle position and by the side of the patient's feet) and during the lifting of the 3 groups of patients (Group 1, Group 2, Group 3)

	By the side of the patient's head			Middle position			By the side of the patient's feet		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Trunk angle (°)									
ROM	39.9 (6.7)	36.2 (6.3)	35.9 (5.6)	29.7 (10.3)$^{§,\#}$	28.0 (8.4)$^{§,\#}$	27.4 (10.3)$^{§,\#}$	35.8 (7.5)	35.6 (5.7)	36.5 (8.5)
Maximum	46.4 (7.2)	40.9 (6.5)	42.9 (4.3)	41.6 (8.6)	39.5 (6.3)	43.3 (5.4)	40.8 (7.1)§	40.1 (5.9)	41.9 (7.2)
Final position	6.7 (3.4)	4.7 (2.9)	7.1 (3.0)	11.8 (7.6)$^{§,\#}$	11.5 (5.3)$^{§,\#,+}$	15.8 (6.7)$^{§,\#,*}$	5.0 (2.1)	4.5 (2.6)	5.4 (3.2)
Kinetics (Kg)									
R_{end}	282.1 (45.5)$^{\#}$	323.8 (78.8)$^{\#}$	352.7 (33.2)$^{\#}$	626.0 (35.5)	634.3 (55.4)	691.7 (33.2)	287.1 (50.1)$^{\#}$	300.5 (67.4)$^{\#}$	341.0 (96.3)$^{\#}$
$F3_{end}$	220.6 (62.5)$^{\#}$	240.3 (67.2)$^{\#}$	269.3 (49.9)$^{\#}$	558.9 (98.9)	597.3 (29.6)	685.2 (43.9)	277.7 (69.3)$^{\#}$	289.0 (34.4)$^{\#}$	336.5 (25.5)$^{\#}$

*= $p< 0.05$, Group 1 compared with Group 3

$^{\#}$= $p< 0.05$, middle position compared with by the side of the patient's head and/or feet

R_{end}: the value of forces exerted at L5/S1 level; $F3_{end}$: the tension value of the lumbar muscles (both at the end of lifting movement)

Discussion

Our data suggest that during 6-operator manual lifting of a patient with a 6-handle bariatric lifting sheet, the reaction load on the spine of the nurse generally falls within the recommended safety limits as defined by NIOSH (24, 25), except when the nurse is operating from the central handle, closer to the patient's centre of mass. In this position, in fact, the reaction forces generated at L5/S1 level and measured at the end of the lifts (R_{end}) exceed the Action Limit of 3500 N (350 kg).

The nurse operating from the central handle appears to be exposed to the highest strain on the lower back. He is the closest to the patient's pelvis, and therefore to his/her centre of mass and reaches the final position of the lift with the trunk more forwardly flexed if compared to the other operators. The spinal load increases in parallel with the patient's BMI. No statistical differences were observed when the nurse was operating in the other two positions.

Our study presents some limitations. Firstly, data were obtained from just one young and healthy operator; further research involving more participants is needed to confirm the biomechanical data obtained in this study. In addition, only trunk kinematics and longitudinal forces were considered; the biomechanical model used is a simplified one, where only longitudinal back compression forces (forces acting down the long axis of the spine) are computed. Although they represent the major component of the spinal load, the reaction shear forces (forces acting perpendicular to the compressive ones) and torsional forces (rotational forces acting around the long axis of the spine) may also be substantial during lifting, especially in forward bending (8). The interaction of those different forces and the spinal tolerance to loading is a complex and yet debated issue.

The study is further limited by the assumption that during the lift all six nurses exerted the same effort and used the same lifting strategy, gender bias and the consideration of a single event instead of the cumulative effect of repeated efforts. Future studies on this specific task may include kinematic data of other joints together with electromyographic data and ground reaction forces. In this way, more complex approaches could be used to determine lumbosacral loading of healthcare workers during manual patient lifting.

Based on our preliminary experimental data, considering only longitudinal forces and one young, healthy male nurse, lifting an obese patient from the ground using a 6-handle bariatric sheet can occasionally be a critical task (according to the existing recommended limits) for the nurse operating from the central handle. When the nurse was in other positions (by the side of the patient's head and by the side of the patient's feet), the values obtained seem to be within the recommended limits. However, further studies with a larger sample size and different operators are needed to confirm these promising but preliminary results.

No potential conflict of interest relevant to this article was reported

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