Laboratory investigations were conducted regarding the (bio-)mechanical load on the lumbar spine of healthcare workers during patient-transfer activities which presumably result in high spinal loads for the nursing staff. The postural data of the healthcare worker were recorded opto-electronically and via video documentation, the nurse’s action-forces were captured via force sensors at a specifically modified bed, chair, floor, and bathtub. Based on these data, lumbar load was quantified via computer simulation (The Dortmunder). The results of the actual research project (Dortmund Lumbar Load Study 3) elucidate that lumbar load is often very high for the healthcare workers and exceeds recommended limits for work design (Dortmund Recommendations) in case of conventional task execution. A reduction of lumbar load can be achieved by an optimized mode of execution. The application of small aids is strongly recommended to achieve a vital load reduction for the lumbar spine, in particular, if high-loading activities are performed by older persons.

Introduction

Moving patients manually may lead to high load on the spine, to acute low-back pain, and may accelerate the development of degenerative disc-related diseases in the long run of occupational life of a healthcare worker. The aim of the study sketched in the following was to describe quantitatively subject's spinal load by several indicators, to evaluate the lumbar-spine overload risk, to support the assessment of work-related prerequisites in occupational-disease evaluations, to examine measures for work design and to derive potentialities for a biomechanically substantiated prevention with regard to workplace, working method, or work equipment.

The so-called Dortmund Lumbar Load Study 3 (DOLLY 3: Jäger et al., 2007) represents a comprehensive research project of several years on the determination of lumbar load in selected care-activities with patient transfers (cf. DOLLY: whole-shift lumbar-load monitoring
for deriving adequate cumulative load indices, Jäger et al., 2000; DOLLY 2: lumbar-load register for a large variety of materials handling tasks, Jäger et al., 2004). These activities are mainly classified by the Statutory Accident and Health Insurance Institution for Health Services and Welfare Care as “definitely being endangering” in the sense of the occupational disease “Intervertebral disc-related diseases of the lumbar spine caused by long-term lifting or carrying of heavy objects”. In cases of such severe disorders, specified criteria on disease as well as on work content have to be fulfilled according to German legislation so that knowledge on resultant biomechanical load on the lumbar spine is indispensable (Theilmeier et al., 2006a).

Experimental procedure

Laboratory investigations were conducted regarding the mechanical load on the lumbar spine of healthcare workers during patient-transfer activities. The examinations mainly refer to such actions, which presumably result in high spinal loads for the nursing staff. The examinations could not be performed in a hospital due to applying a measurement-assisted methodology for posture-and-force capturing. Figure 1 gives an impression of lab and equipment. Via combined video-analysis and opto-electronic measurements, information about the nurse’s postures was gathered (Jordan et al., 2006): Installed beside the nurse at the sidewall, a 1st camera documented preferably the trunk’s forward inclination and spinal curvature, a 2nd camera was mounted above the nurse at the ceiling and recorded lateral bending and turning. Patient’s posture was documented via a 3rd camera, and a 4th one gave a spatial view of the scene. Furthermore, small infrared markers attached to the subject were tracked with a 3-D opto-electronic motion capturing system. Markers at hands, shoulders, hips, heels and, for reference, the bed frame were tracked as 3-D coordinates’ time courses with two ”position sensors” consisting each of three infrared cameras, which were mounted at opposite sidewalls of the lab.

**Figure 1. Laboratory set-up:**

Recording of nurse’s postural data via opto-electronic position sensors (a), of action-forces via a ”measuring bed” (b), and of ground-reaction forces at nurse’s feet (c)
The action forces exerted by the healthcare worker during moving a patient in the bed were determined with regard to magnitude, direction and bilateral distribution by using a newly developed "measuring bed" (Theilmeier et al., 2006b). A common hospital bed was therefore equipped with an additional framework which was inserted between the bedstead and the bedspring frame via tri-axial force sensors at the four corners. Nurse's forces were measured "indirectly" in all three components (vertical, sagittal, lateral); the point of application of the resultant hand-force – i.e. the leverarm of the action force – was derived from the distribution of the "bed-forces". Via an additional sensor-equipped bar at the bed's side, nurse's leaning against the bed was considered. Two or three force platforms were used for ground-reaction force recording at the floor in cases when the patient was leaving the bed. A "measuring chair", a "measuring floor" and a "measuring bathtub", constructed analogously, enabled the analysis of transfers such as placing the patient in a chair, raising a lying patient from floor, or moving the patient into the bathtub.

Two professionally experienced healthcare workers acted as subjects, i.e. alternately as a patient or a nurse, throughout the research project. They are both highly qualified in applying different performance conditions like conventional and optimized transfer modes.

**Biomechanical simulation**

Based on the posture and action-force data gathered via respective measurements in the laboratory, biomechanical simulation calculations were performed applying the previously developed 3-D multi-segmental dynamic validated model The Dortmunder (Jäger et al., 2001a). Therefore, postures and movements were digitally described in an iterative procedure to enable adequate model calculations for lumbar-load prediction. The human skeletal structure is represented in this computerized simulation tool by 30 body segments which are considered as rigid bodies from the mechanical point of view and supported in 27 punctiform joints in total. The body segments are characterized by the individual length, radius, distance between centre of gravity and adjacent joint, weight as well as moment of inertia. The intervertebral discs within the trunk up to shoulder height are considered as joints, i.e. the replicated five lumbar discs and the lower ten out of the twelve thoracic discs enable the simulation of sagittal and lateral bending, twisting, as well as the superposition of bending and twisting.

Within the biomechanical model The Dortmunder, the muscular structure in the lower trunk region, spreading over the lumbar discs, is replicated by the effect of 14 muscles or muscle cords at back and abdominal wall. The back musculature, summarized in the Erector Spinae muscle group, is represented by its two main cords: the Longissimus muscle with its lumbar part and the Iliocostalis muscle with its medial part which are implemented each on both sides of the body. Medial-part muscle cords of the anatomically fan-like shaped Abdominal Obliques are considered in the model: The internal and external parts of opposite sides are connected via a tendinous network which particularly enable twisting the trunk. In contrast, the lateral muscle cords of the Abdominal Obliques are mainly activated during side bending postures; these muscle cords are located near the skin and are discriminated into internal and external parts. The two cords of the Rectus Abdominal muscle are located beneath the tendinous texture mentioned above and running parallel near the mid-sagittal plane. In consequence, totally 9 equivalent force vectors for the analysis of lumbar load during manual materials handling and, in particular, during patient-transfer activities are considered in the simulation tool applied in DOLLY 3.

As main results of biomechanical simulation calculations, time courses for bending and torsional moments as well as compressive and shear forces at the lumbosacral disc were
determined considering inertial effects of the body and the handled subject "patient", the effects of asymmetry of posture and force exertion, as well as the effects of intra-abdominal pressure in supporting the trunk during forward-inclined positions.

**Lumbar-load results**

With respect to lumbar load of the healthcare worker, 162 representative transfers, i.e. actions being typical regarding posture and motion as well as regarding hand-force exertion, were analyzed in total. In Figure 2, selected results are demonstrated for the common lumbar-load indicator “compressive force on the lumbosacral disc”. The examined activities mainly referred to nurse's transferring the patient within the bed (nos. 1 to 11), to patient transfers from a bed to bed or to or from a chair (nos. 12-14), from the floor (no. 15) and to moving the patient into the bathtub (no. 16). If possible, those activities were carried out in a conventional way, in an optimized way and, in several cases, also using small aids such as a sliding board or mat.

![Graph showing mean values and ranges of compressive force on L5-S1 for 16 patient-transfer activities](image)

Figure 2. Mean values (columns) and ranges of the disc-related compressive-force values (maximum within the respective time course) for 16 groups of patient-transfer activities, partly performed in 3 modes (conventional, optimized, using small aids)
Lumbar-overload prevention

The research project demonstrates that spinal load may be very high for the healthcare workers (1½ to 9 kN for disc compression). Comparison of lumbar load with age-and-gender specific recommendations for maximum loading shows (Dortmund Recommendations, cf. Jäger et al., 2001b; age: 60° to 20 yrs.; for females, 1.8 to 4.4 kN; for males, 2.3 to 6.0 kN) exceeding the recommended limits for several tasks, if performed conventionally, design measures are therefore strongly advised. A substantial lumbar-load reduction – in particular, with respect to the high load partitions due to asymmetry of posture and action forces – can be achieved by an optimized task execution. However, this load decrease is evaluated being sufficient not in all cases, especially, when high-loading activities are performed by older persons. Usage of small aids is recommended to achieve a vital load reduction for the lumbar spine in such cases. In conclusion, as only a limited biomechanical overload risk enables the healthcare worker to guarantee patient’s safety during transfer activities, from the preventive point of view optimized handling modes should be trained and small aids should be provided to the employees.

References


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