BIOMECHANICAL ANALYSIS OF PATIENT-TRANSFER ACTIVITIES FOR THE PREVENTION OF SPINE-RELATED HAZARDS OF HEALTHCARE WORKERS

Matthias Jäger
Andreas Theilmeier
Claus Jordan
Institut für Arbeitsphysiologie an der Universität Dortmund (*IfADo*)
Ardeystraße 67
44139 Dortmund
+49 (0) 231 1084-267
+49 (0) 231 1084-382
+49 (0) 231 1084-375
mjaeger@ifado.de
theilmeier@ifado.de
jordan@ifado.de

Norbert Wortmann
Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW), Hauptverwaltung
Pappelallee 35/37
22089 Hamburg
+49 (0) 40 20207-3232
norbert.wortmann@bgw-online.de

Stefan Kuhn
Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW), Präventionsdienst Mainz
Göttelmannstraße 3
55130 Mainz
+49 (0) 6131 808-204
stefan.kuhn@bgw-online.de

Alwin Luttmann
Institut für Arbeitsphysiologie an der Universität Dortmund (*IfADo*)
Ardeystraße 67
44139 Dortmund
+49 (0) 231 1084-376
luttmann@ifado.de

DOLLY Group
Members of the Dortmund Lumbar Load Study Group (besides *IfADo* authors):
Jörg Metzler, Hilary Mujih, Umut Öztürk, Rainer Göllner, Markus Konhoff,
Karin Lukaszewski, Jürgen Mattern, Martin Schmitz, Timo Scholz,
Richard Smolka, Jürgen Voß, Felix Ziolkewicz

TOPIC: PATIENT HANDLING ERGONOMICS AND MUSCULOSKELETAL DISORDERS

With regard to the mechanical load on the lumbar spine of healthcare workers during patient-transfer activities, laboratory investigations were conducted. The examinations mainly refer to such patient transfers, which presumably result in high spinal loads for the nursing staff. The aim of the present study – the so-called *Dortmund Lumbar Load Study 3* – was to describe quantitatively the (bio-)mechanical load on the lumbar spine for the subjects by several indicators, to identify overload situations and conditions and, finally, to derive potentialities for a biomechanically substantiated prevention. Hence, time courses for various indicators of lumbar load (bending and torsional moments, compressive and shear forces at the lumbosacral disc) were determined – via biomechanical model calculations with applying a complex simulation tool (*The Dortmunder*) – based on posture and action-force data measured in the laboratory. Due to the dynamic and spatial behaviour of patient-transfer activities, an appropriate indication of lumbar load demonstrates the necessity of a sophisticated posture-and-force capturing and biomechanical modelling. In total, more than 160 transfers were analyzed with respect to lumbar load of the healthcare worker. Comparison of lumbar load with corresponding work-design limits for maximum loading during occupational manual materials handling (*Dortmund Recommendations*) shows that lumbar load exceeds any recommended values for conventional task execution. A reduction of lumbar load can be achieved by using optimized transfer techniques. The application of small aids is recommended to achieve a vital load reduction for the lumbar spine and to limit the biomechanical overload risk for the healthcare worker.

KEYWORDS

healthcare worker, patient transfer, lumbar load, posture recording, hand-force measurement, biomechanical simulation, spine-related hazards, overload prevention, optimized technique, small aids

1. INTRODUCTION

The manual transfer of patients may result in high load on the lumbar spine of a healthcare worker, probably in acute low-back pain, and may accelerate the development of degenerative disc-related diseases in the long run of occupational life. 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 German occupational-disease evaluations, to examine measures for work design and – with regard to workplace, working method, or work equipment – to derive potentialities for a biomechanically substantiated prevention.

A comprehensive research project of several years was performed
regarding
activities v
Load Stud
load registe
al. 2004; *D*
adequate
activities
Health Insu
as ”definite
disease ”I
caused by
by long-te
specified c
fulfilled ac
knowledge
indispensal

2.

2.1

With rega
healthcare
investigatic
patient trai
the nursing
hospital du
recordings
the laborat
analysis an
nurse’s pos
the nurse a
the trunk’s
was moun
recorded m
documente
the scene.
subject we

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 laboratory. The calibrated measuring space amounts to approximately 5 times 1 ½ meters in the horizontal plane and about 2 meters in height.

By using a newly developed ”measuring bed” (Theilmeier et al. 2006b), 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. 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,

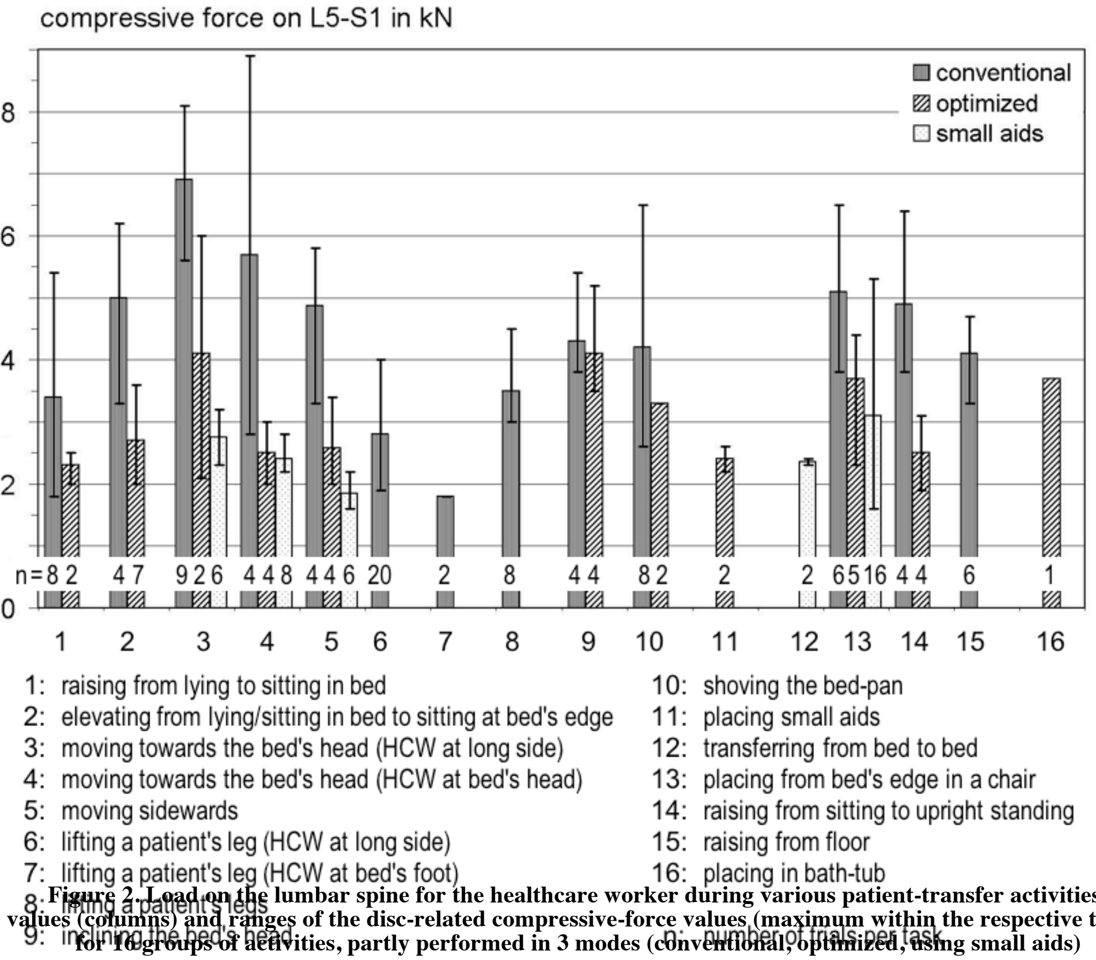

Figure 2. Load on the lumbar spine for the healthcare worker during various patient-transfer activities:
Mean values (columns) and ranges of the disc-related compressive-force values (maximum within the respective time course)
for 16 groups of activities, partly performed in 3 modes (conventional, optimized, using small aids)

performance conditions like conventional and optimized transfer modes and usage of small aids.

2.2 Biomechanical simulation

Applying the previously developed 3-D multi-segmental dynamic validated model *The Dortmunder* (Jäger et al. 2001a), biomechanical simulation calculations were performed which are based on the posture and action-force data gathered via respective measurements in the laboratory. Therefore, postures and movements were digitally described in an iterative procedure to enable adequate model calculations for lumbar-load prediction.

In this computerized simulation tool, the human skeletal structure is represented 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 commonly occurring in reality.

The muscular structure in the lower trunk region – in particular, spreading over the lumbar discs – is replicated by the effect of 14 muscles or muscle cords at the back and the abdominal wall. The back musculature, summarized in the Erector Spinae muscle group, is represented by its two main muscle 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. Besides back muscles, 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 total, 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 *The Dortmunder*.

In consequence, as main results of the 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 postures with considerable forward inclination of the upper body.

3. RESULTS

Within *DOLLY 3*, in total 162 representative transfers – being typical regarding posture and motion as well as regarding action-force exertion – were analyzed with respect to lumbar load of the healthcare worker. 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). Those activities were carried out in a conventional way, in an optimized way and, if possible, also using small aids (e.g. sliding board or mat) in several cases.

The results of the research project elucidate that the low-back load is often very high for the healthcare workers considering the examined activities (up to 9 kN for disc compression). Comparison of the gathered lumbar-load values with corresponding age-and-gender specific recommendations for maximum loading (*Dortmund Recommendations*: 1.8 kN [60$^+$ years of age] up to 4.4 kN [20 y.] for females, 2.3 kN [60$^+$ y.] up to 6.0 kN [20 y.] for males; cf. Jäger et al. 2001b) shows that lumbar load may exceed the recommended limits for several tasks, if performed conventionally, and that design measures are therefore strongly advised. A substantial reduction of lumbar load – in particular, with respect to the considerable high load partitions due to asymmetry of posture and action forces – can be achieved by an optimized execution of the activities. However, this load decrease is evaluated being sufficient not in all cases, especially, when high-loading activities are performed by older persons. In particular in these cases, the application of small aids is recommended to achieve a vital load reduction for the lumbar spine.

4. CONCLUSIONS

A limited biomechanical overload risk should be guaranteed for the healthcare worker which may furthermore improve patient's safety during transfer activities. In consequence, optimized handling modes should be trained and small aids should be provided to the employees from the preventive point of view.

5. ACKNOWLEDGMENTS

Statutory Accident and Health Insurance Institution for Health Services and Welfare Care (Hamburg, Germany) for financial funding as well as Barbara-Beate Beck and Beate Wiedmann (Forum fBB, Hamburg, Germany) for competent and helpful support.

6. REFERENCES

Jäger, M., Jordan, C., Luttmann, A., Laurig, W., DOLLY Group, Evaluation and assessment of lumbar load during total shifts for occupational manual materials handling jobs within the Dortmund Lumbar Load Study – DOLLY. *International Journal of Industrial Ergonomics* 2000; 25: 553-571.

Jäger, M., Luttmann, A., Göllner, R., Laurig, W., *The Dortmunder* - Biomechanical model for quantification and assessment of the load on the lumbar spine. In: Society of Automotive Engineers (ed.) *Digital Human Modeling Conference Proceedings,* SAE, Arlington VA, paper 2001-01-2085, CD-ROM, 2001a.

Jäger, M., Luttmann, A., Göllner, R., Analysis of lumbar ultimate compressive strength for deriving recommended lumbar-load limits. In: R. Müller, H. Gerber, A. Stacoff (eds.) *Int. Soc. Biomechanics, Book of Abstracts*, ETH Zürich, Laboratory for Biomechanics, 263-264, 2001b.

Jäger, M., Jordan, C., Theilmeier, A., Göllner, R., Luttmann, A., Belastung der Lendenwirbelsäule bei branchenübergreifend auftretenden Arbeitssituationen mit Lastenhandhabung. In: J. Konietzko, H. Dupuis, St. Letzel (eds.) *Handbuch der Arbeitsmedizin*, ecomed, Landsberg a.L., Kap. IV-3.1, 2004.

Jäger, M., Jordan, C., Theilmeier, A., Luttmann, A., DOLLY Group, Spinal-load analysis of patient-transfer activities. In: T.M. Buzug, D. Holz, S. Weber, J. Bongartz, M. Kohl-Bareis, U. Hartmann (eds.) *Advances in Medical Engineering*, Springer, Berlin, 273-278, 2007.

Jordan, C., Theilmeier, A., Luttmann, A., Jäger, M., DOLLY Group, Lumbar-load analysis for health-care workers during patient transfer activities. In: R.N. Pikaar, E.A.P. Koningsveld, P.J.M. Settles (eds.) *Meeting Diversity in Ergonomics, Int. Ergonomics Ass., World Congr. Proc.,* Elsevier, Amsterdam, CD-ROM, 2006.

Theilmeier, A., Jordan, C., Wortmann, N., Kuhn, S., Nienhaus, A., Luttmann, A., Jäger, M., Belastung der Lendenwirbelsäule von Pflegepersonen bei Patiententransfers – Kennwerte zur Nutzung in Berufskrankheiten-Feststellungsverfahren. *Zentralblatt für Arbeitsmedizin* 2006a; 56: 228-251.

Theilmeier, A., Jordan, C., Luttmann, A., Jäger, M., DOLLY Group, Measurement of exerted forces for determining nurses' lumbar load. In: R.N. Pikaar, E.A.P. Koningsveld, P.J.M. Settles (eds.) *Meeting Diversity in Ergonomics, Int. Ergonomics Ass., World Congr. Proc.*, Elsevier, Amsterdam, CD-ROM, 2006b.