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Lifting up and laying down a weight causes high spinal loads

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ABSTRACT

Lifting up weights from a cupboard or table and putting them back are activities of daily living. Patients with spinal problems want to know whether they should avoid these activities. However, little is known about the spinal forces during these activities and about the effect of level height.

Loads on a telemeterized vertebral body replacement were measured in 5 patients. The effect of level height when lifting or setting down weights of 0.01, 1.5 and 3.0 kg in a standing posture were investigated. Furthermore, these weights were lifted and set down with a stretched arm while sitting at a table. No instructions were given on how to perform the task.

For these activities, forces as high as 5 times the value for standing alone were measured. In 2 patients, implant loads decreased with increasing level height. In the other patients the effect of level height was small. Lifting a weight from a table with a stretched arm while sitting led to a strong increase of the maximum implant force. Setting down the weight usually caused a slightly higher maximum implant force than lifting it.

Forces on a vertebral body replacement during lifting and setting down a weight varied strongly when no precise instructions were given on how to perform the activity. Thus, the measured forces are representative for such activities performed in daily life. This, however, led to wide variations in measured data. Compared to the value for standing, 5 times higher forces were measured for lifting and setting down of weights. This suggests that these activities should be avoided by patients who have spinal problems.

1. Introduction

Weights of up to a few kilograms often have to be lifted or set down during daily life, for example, when taking something out of a cupboard or when reaching for a coffee pot while sitting at a table. The level at which the weight has to be placed may vary and can be even above head height. After spinal surgery, patients often want to know whether they are allowed to perform these activities and which ones should be avoided. Little information exists about the spinal loads during such activities.

The pressure in a lumbar disc has been measured by several groups (Nachemson, 1981; Sato et al., 1999; Wilke et al., 2001). But to our knowledge, no such measurements were performed during lifting up and setting down weights at different heights.

In vivo measurements of skeletal loads during lifting and setting down of weights only exist for the shoulder joint. Westerhoff et al. (2009) measured the loads in this joint during lifting and setting down a coffee pot (1.5 kg) while sitting at a table as well as during lifting up and setting down a weight of 2 kg from or onto a shelf up to head height while standing. For the lifting tasks, they measured shoulder joint contact forces which were approximately that of the body weight. The shoulder joint forces were about 20–30% higher for setting down the weight than they were for lifting it. Higher forces were measured for picking up and setting down a weight at head height compared to belt height.

Measurement of the complete spinal loads is not yet possible. However, the loads on telemeterized vertebral body replacements (VBR) have been measured during physiotherapeutic exercises, sitting on different seats, during changing body positions, and during whole body vibration (Rohlmann et al., 2008, 2010, 2011).

The aim of this study was to measure the loads on a vertebral body replacement during the lifting up and setting down of different weights. The effects of the magnitude of the weight and the lifting height (hip, shoulder, head, and above head level) were to be determined. The loads should be measured under ordinary daily life conditions.

2. Material and Methods

2.1. Instrumented implant

To measure the forces and moments transferred by a VBR, the clinically proven implant Synex (Synthes Inc. Bettlach, Switzerland) was modified. Six semiconductor strain gauges, a 9-channel telemetry unit and a coil for the inductive power supply were arranged in a cylindrical tube with an original endplate on the lower side (Fig. 1). An adapter plate was welded onto the upper side of the tube. During surgery, an endplate of selectable height was screwed onto the adapter plate to achieve the

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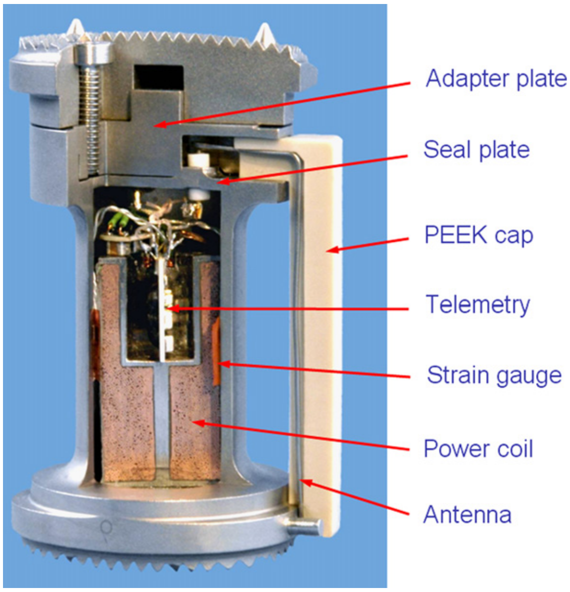

Fig. 1. Cut model of the instrumented vertebral body replacement.

Table 1
Data on patients and surgical procedures.

Parameter	Patient				
	WP1	WP2	WP3	WP4	WP5
Age at the time of surgery (years)	62	71	69	63	66
Height (cm)	168	169	168	170	180
Body mass (kg)	66	74	64	60	63
Gender (M/F)	M	M	F	M	M
Fractured vertebra	L1	L1	L1	L1	L3
Level of internal fixation device	T12-L2	T12-L2	T11-L3	T12-L2	L2-L4
Time between implantation and measuring session (months)	12	10	6	13	6

appropriate implant height. The instrumented implant allows the measurement of all 3 forces and 3 moment components.

Each implant was calibrated and an accuracy test was performed prior to implantation. Related to the maximum applied forces (3000 N) and moments (20 Nm), the average errors were below 2% for force and 5% for moment components. The sensitivity of the instrumented implant is smaller than 1 N and 0.01 Nm. More detailed information about the implant, the external equipment and the telemetry has already been presented elsewhere (Graichen et al., 2007; Rohlmann et al., 2007).

2.2. Patients

Five patients with an A3 type compression fracture (Magerl et al., 1994) participated in this study. Four (WP1 to WP4) had a fracture of the vertebral body L1 and one patient (WP5) a fracture of L3. They were aged 62–71 years. The fractures were first stabilized with internal spinal fixation devices, implanted from the posterior. In a second surgery, parts of the fractured vertebral body and the adjacent discs were removed, and the instrumented implant was inserted into the corpectomy defect. Autologous bone material was added to the VBR in order to enhance fusion of the adjacent segments. Table 1 provides data on patients and surgical procedures.

The Ethics Committee of our hospital approved clinical implantation of the modified implant in patients, and they gave their written consent to implantation of the instrumented VBR, subsequent load measurements, and publishing of their images.

2.3. Activities investigated

While standing, the five patients lifted and set down weights of 0.01 kg (sheet of paper), 1.5 and 3 kg on a shelf at hip, shoulder, head, and above head levels. The patients were also sitting at a table and lifted these weights which were placed close to the upper body; they then put the weight down back onto the table with a stretched arm. After that, all sequences were performed in reversed order. These measurements were performed in a measuring session at least half a year after surgery (Table 1). The patients repeated each activity once. Since we wanted to measure the loads as they occur during daily life, no additional instructions were given on how to perform the activities.

Table 2
Median values of the forces in (N) for standing and for sitting relaxed for the measuring day.

Patient	Standing	Sitting
WP1	95	112
WP2	251	432
WP3	56	54
WP4	188	313
WP5	78	166

2.4. Evaluation of data

The resultant forces (geometrical sums of the 3 components) on the VBR were determined. The peak values of the resultant force for the investigated activities were calculated relative to the value when standing relaxed with the arms hanging down (set to 100%) in one and the same patient, measured on the same day. The resultant implant forces for standing and sitting are given in Table 2. In the diagrams shown here, the mean values of the peak forces and the range of the forces are presented. Not all patients agreed to perform all activities. Therefore, only descriptive statistics were applied in this study.

3. Results

The maximum resultant force during the different exercises always acted when the weight in the hand had the largest lever arm relative to the lumbar spine. For the activities studied, this was the case immediately before setting down or shortly after lifting the weight.

3.1. Activities while standing

Setting down a weight of 3 kg at different levels of a shelf caused implants forces which were always much higher than those for standing (Fig. 2). In patient WP1, forces on the VBR of even 5 times the value for standing were measured. However, there was a large variation of the maximum force for the different patients. The measured forces decreased with increasing level height in 2 patients (WP1 and WP5). No clear trend could be observed in the other 3 patients. Similar dependencies of the force involving the shelf height were found for the other weights studied and when lifting up a weight at different levels instead of putting it down[1].

As expected, the maximum resultant implant forces increased with increasing weight in all patients when setting the weight down (Fig. 3). However, the amount of force increase was seen to be different in all of the 5 patients.

3.2. Activities while sitting

When lifting a weight from a table with a stretched arm while sitting, implant forces of 5 times the value for standing were measured. The maximum resultant implant force increased with the magnitude of the weight (Fig. 4). This force increase differed among patients and was most pronounced in patient WP1. Also

[1] Videos and data files containing all force and moment components for different activities and subjects can be downloaded from www.OrthoLoad.com.

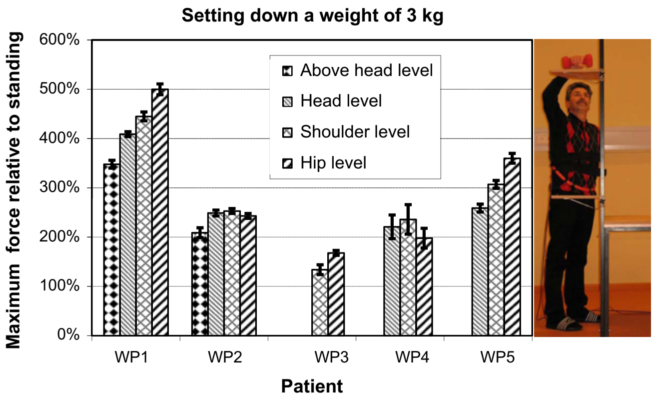

Fig. 2. Effect of the lifting height on the implant force for setting down a weight of 3 kg onto a shelf. The maximum resultant force on the vertebral body replacement is relative to its value for standing relaxed.

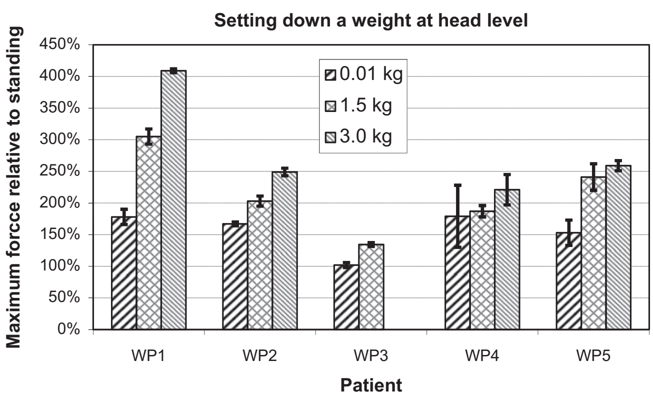

Fig. 3. Influence of the weight magnitude on the implant force when setting down a weight at head level onto a shelf. The maximum resultant force on the vertebral body replacement is relative to its value for standing relaxed.

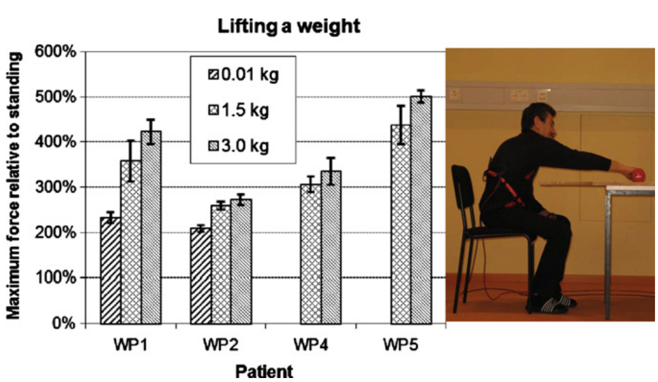

Fig. 4. Effect of the weight magnitude on the implant force for lifting a weight from a table with a stretched arm while sitting. The maximum resultant force on the vertebral body replacement is relative to its value for standing relaxed.

for this activity, the maximum forces for different patients varied strongly.

3.3. Comparison lifting and setting down

Slightly higher or similar implant forces were measured for setting down a weight of 3 kg instead of lifting it up (Fig. 5). Similar results were found for the other weights studied (0.01 and 1.5 kg) where these were lifted up and then put down again.

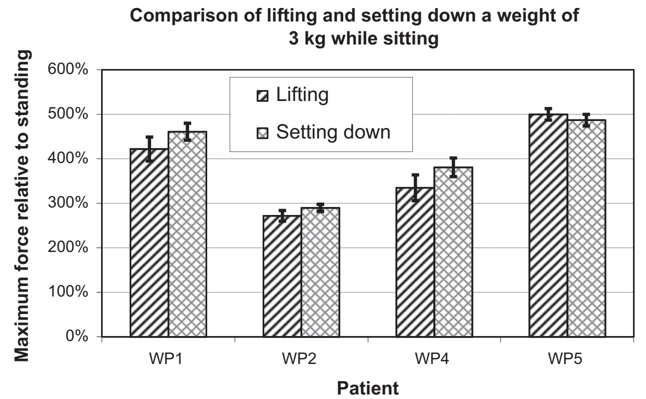

Fig. 5. Comparison of the implant forces for lifting a weight of 3 kg from a table and putting it down while sitting. The maximum resultant force on the vertebral body replacement is relative to its value for standing relaxed.

4. Discussion

Forces on a VBR were measured in 5 patients for lifting and setting down a weight at different levels while standing in a neutral position as well as for lifting and setting down a weight with a stretched arm while sitting at a table.

When lifting up or setting down a weight on a shelf in a standing position, the carried weight in combination with the lever arm relative to the spine causes an additional bending moment which has to be compensated for by back muscle forces. Higher muscle forces increase the forces on the VBR. The bending moment increases with increasing magnitude of the weight and increasing length of the lever arm. The lever arm of the carried weight was not measured accurately in the current study; but the video clips proved it was the largest immediately after lifting or shortly before setting down the weight. Since we wanted to measure the implant forces which occur during daily living, no precise instruction were given on how to perform a task. Thus, the patients could, for example, choose the distance from the shelf to the best of their own convenience. This distance, however, affects the lever arm between weight and the spinal column and thus the implant loads. Additionally, the effective lever arm is smaller when the direction of the arm is above shoulder level. In 2 patients, arm elevation was associated with stretching the trunk and moving the head slightly backwards, especially for the height levels ‘head’ and ‘above head’, which reduces the lever arm between center of gravity of the upper body and the spinal column. In the other patients, the elevation of the arm was not associated with a visible shift of the center of gravity of the upper body and thus the shelf height had only a minor effect on implant forces.

Lifting a weight from a table, while sitting, also causes a bending moment relative to the spine. This activity can be performed with different degrees of upper body flexion. Some patients tried to place the weight as far away as possible and bend their upper body forward during this activity. Flexion of the upper body increases the implant force (Rohlmann et al., 2011). However, the flexion angle varied slightly for the different trials. In other patients no bending of the trunk was observed. The difference in the upper body flexion angle is probably the main reason why the force increase on the VBR differed so much for different patients.

Lifting a weight requires acceleration and thus causes an additional force and higher back muscle forces to ensure equilibrium. However, the implant force increase due to acceleration of arm and weight is usually small. Nevertheless, lifting a weight leads mostly to less than 10 N higher implant forces than just holding it. Setting down a weight is usually done gently to avoid a hard impact of the weight. This requires, however, antagonistic muscle forces to stabilize the arm and spine positions at each instant, which leads to higher implant forces. Similar results were found when the loads in the shoulder joint were measured (Westerhoff et al., 2009).

This study has some limitations. It was only five elderly patients who qualified to receive an instrumented VBR and thus only these subjects could be included in this study. The trials could only be repeated once in order not to overstress the subjects since these were also involved in several other load measuring studies. No motion analysis was possible, due to the same reason. However, the patients were videotaped during the measurements. Not all patients agreed to perform all activities investigated in this study. Thus, exploratory data analyses were not allowed, but intra-individual comparison of load magnitudes for different activities could still be performed. The activities were performed without exact instructions since we wanted to measure the activities in a way which they are usually performed in daily life. Due to this reason, the exact position of the patients could vary between different trails of a subject as well as in between subjects. This increased the range of the measured loads. The measured forces were related to those for standing, as measured on the same day. But even the implant forces during standing depend on many parameters such as the position of the center of gravity of the upper body and the degree of relaxation of the muscles and are therefore not absolutely constant. Nevertheless, standing belongs to the best reproducible postures. The instrumented VBR did not measure the complete spinal load since parts of the spinal load were transferred by the posteriorly inserted internal fixation device, the preserved part of the fractured vertebra and the attached bone graft. However, the load sharing between the different components should be constant for the activities compared in this study since they were measured on the same day.

In conclusion, the *in vivo* measured forces presented here are unique and may help us to better understand spinal loads when lifting and setting down weights. *In vivo* measured data is also essential for improvements of analytical models since, e.g. the exact effect of antagonistic muscle activities is very difficult to simulate in such models. The results of the present study demonstrate that even such a simple task as lifting a weight from a shelf at a certain level can be performed differently, leading to a great range of possible maximum resultant implant forces. However, when the activity is repeated in the same way, the force variation in one single patient remains small. The finding of very high forces (up to 5 times higher than the value for standing relaxed) measured for lifting up and setting down a weight suggests that patients with spinal problems should avoid these activities. Implant forces can be reduced by reducing the lever arm between carried weight and spinal column. Thus, such patients should hold the weight close to their upper body and step close to the shelf when laying down or lifting up a weight. Another possibility to reduce implant forces is supporting the upper body by a hand (Rohlmann et al., 2011).

Conflict of interest statement

The authors do not have any conflict of interest.

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