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Loads on a vertebral body replacement during locomotion measured *in vivo*

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ABSTRACT

Walking is one of the most important activities in daily life, and walking exposes the spine to a high number of loading cycles. Little is known about the spinal loads during walking. Telemeterized spinal implants can provide data about their loading during different activities. The aim of this study was to measure the loads on a vertebral body replacement (VBR) during level and staircase walking and to determine the effects of walking speed and using walking aids.

Telemeterized VBRs were implanted in five patients suffering from compression fractures of the L1 or L3 lumbar vertebral body. The implant allows measurements of three force and three moment components. The resultant force on the VBR was measured during level and staircase walking, when walking on a treadmill at different speeds, and when using a wheeled invalid walker or crutches.

On average, the resultant force on the VBR for level walking was 171% of the value for standing. This force value increased to 265% of the standing force when ascending stairs and to 225% when descending stairs. Walking speed had a strong effect on the implant force. Using a walker during ambulation on level ground reduced the force on the implant to 62% of standing forces, whereas using two crutches had only a minor effect.

Walking causes much higher forces on the VBR than standing. A strong force reduction can be achieved by using a walker.

1. Introduction

Walking is one of the most important activities of daily living. During each step, the discs and vertebrae of the lumbar spine are loaded with a large force [1,2]. However, few *in vivo* data exist on the spinal loads experienced during level and staircase walking. Furthermore, almost no *in vivo* measured data exist on the impact of walking speed and walking aids on the loads. For preclinical implant tests, however, and for finite element studies, realistic loads are mandatory to obtain relevant results. In addition, knowledge about spinal loads may help to advice patients regarding using of walking aids. Several groups used electromyography, force plate and body kinematic data to calculate spine loading during walking [3–6]. For the validation of their models *in vivo* measured data are required.

The intradiscal pressure during level walking has been measured in a few subjects [2,7]. Wilke et al. measured a value in one subject that was 30% higher than the value measured for standing [2,8]. For slow walking, Nachemson and Elfström [7] measured an increase of intradiscal pressure of 15% in four patients compared with standing. These measurements were performed only during one measuring session per subject. The loads in internal spinal fixation devices during level walking were measured in 10 patients by Rohlmann et al. [1,8]. On average, they determined a maximum implant load during walking that was 28% higher than that for standing. For two patients [1], they reported only a small influence of walking speed on implant load. The normal use of crutches led to a small reduction of the implant loads, while a wheeled invalid walker reduced the loads on the internal spinal fixators by approximately 25%.

Staircase walking caused higher intradiscal pressure values than level walking did [2,8]. Ascending stairs led to a maximum pressure in the disc that was 40% higher than for walking, while the value for descending stairs was only 20% higher [2]. Similar load values were measured in spinal fixators [1], with the loads usually being higher for ascending than descending stairs. However, no *in vivo* measured data exists about the loads on an anterior spinal implant during level and staircase walking.

The telemeterized vertebral body replacement (VBR) allows the *in vivo* measurement of the loads acting in the anterior column of the lumbar spine. Such an implant has already been used to quantify the loads for several activities, including sitting, standing, lifting up and laying down a weight, and whole body vibration

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[9–12]. The force values varied strongly from patient to patient, while the measured moments were usually small.

The aims of the present study were (1) to measure *in vivo* the resultant force on a vertebral body replacement during level walking; (2) to determine the influence of walking speed on implant loads; (3) to measure the resultant implant force during ascending and descending stairs; and (4) to determine the effects of walking aids such as a wheeled invalid walker and crutches on implant loads.

2. Materials and methods

2.1. Telemeterized vertebral body replacement

A modified VBR (Synex, Synthes Inc., Bettlach, Switzerland) was used to measure the loading *in vivo*. Six semiconductor strain gauges (Type KSP 1-350-E4, Kyowa, Tokyo, Japan) were glued to the inner wall of the hollow implant, and they served as load sensors. A nine-channel telemetry unit and a coil for the inductive power supply of the electronic circuits were also integrated in the hermetically sealed implant. The instrumented implant allows the *in vivo* measurement of the three force and three moment components at a frequency of approximately 125 Hz. The resultant force is the geometric sum of the three force components. Prior to implantation, the VBRs were calibrated in the laboratory. The average measuring errors were within 2% for the force and 5% for the moment components as related to the maximum calibration values of 3000 N and 20 Nm, respectively. The sensitivity of the measuring implant is smaller than 1 N and 0.01 Nm. The telemeterized implant and the measuring system have been described in detail elsewhere [13,14].

2.2. Patients

Telemeterized VBRs were implanted into five patients who had suffered from an A3 type compression fracture [15] of a lumbar vertebral body. Four patients (WP1–WP4) had a fracture of the L1 vertebral body, and one patient (WP5) had a fracture of the L3 vertebral body. The fractures were first stabilized with pedicle-screw-based internal 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 VBR was inserted into the corpectomy defect. To enhance fusion of the adjacent segments, autologous bone material was added to the VBR. Table 1 provides data on patients and surgical procedures.

The Ethics Committee of our hospital approved implantation of the modified implant in patients (Registry number 213-01/225-20). The procedure was explained to the patients before surgery, and they gave their written consent for implantation of the telemeterized VBR, participation in measurements, and publication of their images.

2.3. Measurements

Measurements were taken with an inductive power coil placed around the patient's trunk at the level of the VBR and a small loop antenna fixed to the patient's back with a harness. The patients were videotaped during the measurements, and the load-dependent telemetric signals were recorded on the same videotape. This allowed a detailed analysis of implant loads and activity at a later state without the patient having to be present. Parallel to this, the implant forces and moments were calculated from these signals and displayed online on a monitor [13].

Measurements were taken during the following activities:

- Level walking at a self-chosen walking speed (approximately 3–4 km/h) in five patients during a total of 66 measuring sessions (9–17 per patient) up to 65 months postoperatively;
- Walking on a treadmill at different speeds in three sessions with patient WP1 and in one session each with patients WP2, WP4, and WP5. The speed of the treadmill was varied between 1 and 5 km/h in increments of 1 km/h. However, not all patients agreed to have measurements taken at all speeds. The patients did not use the handrail during the measurements;
- Walking with a wheeled invalid walker with arm support in four patients (WP1–WP4) during at least one session and walking with two crutches in all five patients in up to four sessions. The crutches were loaded alternatingly at the contralateral side of the supporting leg;
- Ascending and descending stairs in all five patients in up to six measuring sessions. The standard stairs had six treads. During some trials the patients used the handrail for safety;

A total of about 600 trials, each consisting of approximately 5 steps, were evaluated for these four basic activities. These trials were performed during 66 measuring sessions. The patients reported no pain during the measuring sessions.

2.4. Evaluation

During walking, the measured load components changed periodically. The peak values of a step were evaluated in this study. For each activity and session the median value of the peak resultant forces on the implant was determined. From these medians, the median value was determined for each activity and patient to obtain a representative value. The ranges of the peak resultant force values from several measuring sessions were also calculated for each patient.

In order to determine the load ranges during walking the differences between the maximum and minimum values of the resultant force (max–min difference of each measurement) were calculated as well.

The implant loads for standing relaxed were measured on the average nine times during each session. The median resultant force

Table 1
Data on patients and surgical procedures.

Parameter	Patient				
	WP1	WP2	WP3	WP4	WP5
Gender	Male	Male	Female	Male	Male
Age at the time of surgery (y)	62	71	69	63	66
Height (cm)	168	169	168	170	180
Body mass (kg)	66	74	64	60	63
Fractured vertebra	L1	L1	L1	L1	L3
Level of internal fixation device	T12-L2	T12-L2	T11-L3	T11-L3	L2–L4
Bone material added	Yes	Yes	Yes	Yes	Yes
Implantation date (mo/y)	09/2006	11/2006	03/2007	01/2008	07/2008