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Research Article

Methods for Avoiding or Reducing High Spinal Loads in Everyday Life

Abstract

Background: High loads on an anterior spinal implant can cause an implant to subside into the vertebral body. This alteration may endanger the clinical output of the treatment and can result in back pain. The aim of this paper is to show the possibilities for avoiding or reducing high spinal loads in daily life.

Methods: The loads on a telemeterized vertebral body replacement were measured in 5 patients for a variety of different activities. The effects of the ways an exercise was performed on implant loads were evaluated.

Results: Following a physiotherapist's instructions reduced implant loads by approximately 60% when changing from one body position to another or when performing physiotherapeutic exercises. Supporting the upper body with one hand can reduce loads by approximately 30% when washing the face in front of a washing basin. Leaning against a backrest in a sitting position reduced implant loads by an average of 38%. If possible, weight should be carried in a backpack or spilt bilaterally and evenly between both hands. Generally, any weight should be held close to the body.

Conclusions: Patients should follow their physiotherapists' instructions. Spinal loads are generally reduced by reducing the lever arm of the upper body's center of mass relative to the lumbar spine and by supporting the upper body, for example, with the hands.

Abbreviations

VBR: Vertebral Body Replacement; CoM: Center of Mass; %STG: Percent Relative to The Value for Standing

Introduction

Degenerative disc disease, spinal stenosis, compression fracture of a vertebral body and spinal tumors are indications for an anterior spinal implant [1]. Subsidence of a stiff anterior spinal implant into the weaker vertebral body is often observed in clinical practice [1-6]. This alteration may occur shortly after surgery or can develop typically within approximately one year [4]. A single or a small number of high spinal loads that cause stress that exceeds the strength of the bone are most likely the reason for early subsidence, whereas long-term subsidence is caused by repeated loads that cause stresses that are below the ultimate static bone strength. Osteoporotic vertebral bodies are more vulnerable to implant subsidence than are normal ones owing to the reduced bone strength [3,6]. The amount of subsidence may vary widely. Uchida et al. [6] reported an average subsidence of an expandable strut cage replacement of 2.5 ± 3 mm. At 12 months postoperatively, Marchi et al. [4] determined the subsidence of cages and found that up to 30% of patients had experienced implant subsidence of at least 50% of the cage height. Implant subsidence reduces the range of motion of artificial discs, it may lead to correction loss and can thus limit the maintenance of the initial decompression when using a cage [2,4]; furthermore, subsidence may change the local spinal curvature [1,2,4,6], and it may ultimately cause low back pain.

The fusion rate is generally not affected by implant subsidence [2,4]. However, the change in the local spinal curvature may promote the development of back problems in the long term. High body mass index increases the risk of implant subsidence [7]. Avoiding high loads on the vertebral body replacement (VBR) may prevent implant subsidence. Thus, patients should be told what activities they are allowed to perform and how they should perform the activities of daily living to reduce their implant loads and so as not to endanger their clinical outcomes.

The loads on internal spinal fixation devices were measured for many activities (e.g., physiotherapeutic exercises, sitting, walking, carrying weights) in 10 patients [8,9]. A VBR was also telemeterized [10], and the loads were measured for many activities of everyday life [11-15]. It was observed that the manner in which an exercise is performed may strongly affect spinal loads [11,13,15-17].

The aim of this paper is to provide advice on how to avoid or reduce the high loads that endanger the clinical outcomes of spine surgeries.

Material and Methods

Instrumented VBR

A clinically proven VBR (SYNEX, Synthes Inc., Bettlach, Switzerland) was modified [10]. Six load sensors, a telemetry unit

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and a coil for an inductive power supply were inserted into the hermetically sealed implant. Telemeterized VBRs allow for the measurement of three force and three moment components. Each implant was extensively calibrated prior to implantation. Accuracy tests revealed typical average errors below 2% for force and below 5% for moment components relative to the maximum applied force (3000 N) and moment (20 Nm). The resolution was better than 1 N and approximately 0.01 Nm. The implant has been described in detail elsewhere [10].

For the measurements, a power coil was placed around the patient's trunk at the level of the implant, and a wire antenna was placed on the patient's back [18]. The received signals from the 9-channel telemetry were fed into a notebook, where the load components and the resultant force were calculated and displayed on the monitor. During the measurements, the patients' activities were videotaped, and the load-dependent telemetry signals were stored simultaneously on the audio track of the same videotape. This process enabled a subsequent detailed analysis of the VBR loads without requiring the patient's presence.

Patients

Telemeterized VBRs were implanted in five patients (WP1–WP5, age range 62–71 years) with A3-type compression fractures of a lumbar vertebral body (classification after Magerl et al. [19]). In 4 patients, the L1 vertebral body had been fractured, and in 1 patient, the L3 had been fractured. In a first step, the spine was stabilized from the dorsal with internal fixators. In a second surgery, the VBR was implanted using a ventrolateral approach. A partial corpectomy of the fractured vertebral body was performed, and a length-adapted telemeterized VBR was inserted in the created niche. Autologous bone material from the iliac crest and the resected rib was used to cover the VBR.

The ethics committee of our hospital (Registry number 213-01/225-20) approved the implantation of the modified implants. Prior to the surgery, the procedure was explained to the patients, and they gave their written consent to the implantation of the telemeterized VBR, participating in measurements and agreeing to the publication of their images.

Evaluation

Measurements of VBR loads began a few days after surgery. During hospitalization (14 to 34 days), measurements were performed once to twice per week, and thereafter, approximately every one to six months. In 97 sessions, more than 1000 different combinations of activities and parameters were measured (e.g., physiotherapeutic exercises, walking at different speeds, sitting on various types of seats, carrying different weights, and whole-body vibration in different positions). The patients performed the physiotherapeutic exercises under the guidance of a physiotherapist while they were in the hospital. Afterward, the patients were generally not told how to perform an exercise because we wanted to measure the typical loads in their daily lives. Generally, each exercise was repeated 2 or 3 times. Each of these trials was evaluated, and the measured loads were stored in a database. Our internal VBR database consists of approximately 13,500 datasets. A selection is available at www.orthoload.com.

While it is important to avoid high spinal loads, in the first few days after surgery, it may also be necessary to avoid loads that would normally not be considered critical (e.g., loads that occur during physiotherapy). Therefore, possibilities for reducing spinal loads in different situations will be presented. Of course, those activities that cause the highest loads are the most critical.

Only the maximum resultant force on an implant is presented in this paper. The force was calculated from the three force components and was always positive. The force components perpendicular to the longitudinal spinal axis were generally much smaller than the axial component [20]. In those cases, the magnitude of the resultant force was always similar to that of the axial compressive force. The values presented here represent the median value of the maximum resultant forces for the 5 patients.

The resultant force is sometimes presented as a percent relative to the value for standing (%STG) measured in the same patient on the same day. Unfortunately, the loads for standing differed from patient to patient and mostly also varied within the postoperative time [12], which made comparing the loads difficult. Walking is the most important daily activity with relatively high spinal loads (approximately 170 % STG) [11]. Thus, the loads for some activities are compared with those for walking.

The loads for the various activities varied, often strongly and both inter- and intra-individually. Here, only general information is provided; more detailed information can be found in the referred corresponding articles.

Possibilities to Reduce Spinal Loads

Theoretical considerations regarding the effect of center of mass (CoM) location

In an upright body position, the upper body's CoM is typically in front of the spine. To achieve equilibrium, back muscle forces are required. Spinal load is affected by the weight of the upper body, including the head and the upper extremities, the trunk muscle forces as well as the external forces that act on the upper body and their related lever arms. Generally, a shift of the CoM in the anterior direction leads to higher back muscle forces and thus to higher spinal forces. Reducing the spinal load can be achieved by a posterior shift of the CoM. In a non-upright position, shifting the CoM in the direction of the lumbar spine generally reduces spinal loads.

Activities while lying in bed

The spinal force when lifting the pelvis in a supine position depends strongly on the lifting height [21]. Thus, when using a bedpan, the pelvis should not be lifted higher than necessary. Lifting the pelvis may lead to higher implant loads than those for walking to the restroom. Lifting the pelvis with the help of a trapeze bar mounted to the bed reduced the force by approximately 30% compared with performing the activity without the trapeze bar.

Moving the body to the head of the bed when lying supine using a trapeze bar resulted in nearly half the force compared to that of the same task without using the bar [16].

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Change of body position

In the first days after spine surgery, patients who were lying down had already changed their positions in bed. If they performed this movement in accordance with the physiotherapist's recommendations, the resultant force was nearly as high as it was when they were standing relaxed. Without instructions, the forces were nearly twice as high [16]. Thus, changing from one body position to another may cause high spinal loads.

Changing from a lying position to sitting and vice versa caused forces that were approximately 60% lower if the physiotherapist's instructions were followed [16]. Use of a trapeze bar led to approximately 20% less force compared to the force from performing the activity without a bar. However, reaching for the trapeze bar in a lying position before beginning the activity may cause higher forces than the activity itself. When the trapeze bar was beyond the shoulder position, reaching for it caused approximately 15% higher forces than those that occurred when the activity was performed without a trapeze bar. The way an activity is performed clearly has a strong effect on spinal loads.

Rising from a chair with the arms hanging laterally caused median peak forces that were 380 %STG. When the hands were placed on the thighs, the forces were only 225 % STG, and with hand support on armrests, the forces were only 180 %STG [16]. Supporting the upper body with the arms generally minimizes spinal loads.

Physiotherapeutic exercises

Most physiotherapeutic exercises in a lying position led to only small spinal loads. However, lifting the pelvis and lifting both outstretched legs in a supine position caused forces similar to those for walking [21]. Outstretching one arm cranially in the all-fours position, with or without simultaneously outstretching the contralateral leg, led to forces higher than those during walking, which was also the case when arching the back in the all-fours position. Thus, these exercises should be avoided in the early postoperative period [21]. Pulling a rubber band that was fixed to the wall towards the floor reduced the loads on the VBR, whereas pulling a rubber band that was fixed to the feet increased the spinal load.

Sitting

Leaning against a backrest while sitting on a chair or office chair reduced the implant loads by approximately 38% compared with sitting on a stool. Placing the hand on the thighs reduced loads on average by 19% in comparison with hanging the arms laterally [22]. Inclining the upper body when sitting on a stool increased spinal loads, but declining the upper body decreased the loads. Using a knee stool reduced loads on average by 19% compared with sitting on a normal stool [22].

Whole-body vibration, such as what may occur while driving a car or when using public transportation, increased spinal loads by approximately 90% compared with sitting relaxed. The force increased with the intensity level and the number of axes exposed to vibration. However, leaning against a backrest can reduce forces to values below those for sitting relaxed [13].

Standing

Flexion of the upper body increases the CoM's lever arm relative to the lumbar spine and increases the back muscle forces required for stabilizing the position; thus, flexion of the upper body increases spinal loads. This flexion was ranked 7th among the everyday-life exercises with the highest resultant forces [20]. Flexion of the upper body should be avoided shortly after surgery whenever possible.

Distending the abdomen also reduced spinal forces because the increased intra-abdominal pressure led to the direct support of a larger part of the upper body weight by the pelvis.

Washing one's face and brushing one's teeth

Shortly after spine surgery, patients want to wash themselves and brush their teeth in front of a sink. These activities are among the ten activities of everyday life that cause the highest resultant implant forces [20]. VBR forces of nearly 1000 N were measured. These activities may result in implant subsidence shortly after surgery. When these activities were performed with the patient sitting on a stool, the forces were slightly lower compared to when the activities were performed while standing. The forces were approximately 30% lower when the patients supported their upper bodies by placing a hand on the sink when standing or using the arms when sitting.

Walking

Walking is one of the most important activities of daily living, and walking exposes the spine to a high number of loading cycles [11]. Level walking caused an average force of approximately 170 %STG. Using a wheeled invalid walker decreased the implant force to approximately 60 %STG. In contrast, walking with two crutches and loading each crutch contralateral to the supporting leg had only a minor influence on implant force [11]. The resultant force on the VBR generally increased with the walking speed. On a treadmill, the force on the implant increased by approximately 22 N per 1 km/h speed. Thus, slower walking reduces spinal loads.

Ascending stairs increased implant loads on average to 265 %STG, and descending stairs to 225 %STG [11]. When ascending stairs, the upper body is generally more flexed than it is during the descent. Thus, less trunk muscle force is required for equilibrium when descending stairs, which explains the lower loads. Placing the hand on a stair-rail led to only slightly lower forces on the VBR. Staircase walking was ranked 5th among the everyday-life exercises with the highest resultant forces [20].

Carrying weights

Carrying a weight not only increases the weight the spine must carry but often also shifts the CoM anteriorly. The latter leads to higher back muscle forces and thus to higher spinal forces. The CoM shift depends on the position of the weight. When the weight is split bilaterally and evenly between both hands, there are theoretically no additional muscle forces required, and the spinal load increases by the magnitude of the carried weight.

Carrying a weight in front of the body strongly increased the implant loads (ranked 3rd among the exercises with the highest resultant forces [20]). Carrying a weight in a backpack led to implant

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force increases that were much lower on average than the gravitational force of the carried weight [15]. The position of the carried weight relative to the spine strongly affects the required trunk muscle forces and, thus, the spinal load. If possible, weights should be carried in a backpack or split bilaterally and evenly between both hands. When a weight is carried in front of the body, it should be held close to the body.

Lifting up and setting down weights

Lifting weights from a table or cupboard with a stretched arm and putting them back are activities of everyday life. However, these activities may cause forces on the VBR as high as 5 times the value for standing alone [17]. Setting down a weight generally caused a slightly higher maximum force on the VBR than did lifting it. The implant force can be reduced by shortening the lever arm between the carried weight and the spinal column. Patients should hold weights close to their upper bodies and should step close to the cupboard when lifting up or setting down the weights. In addition, supporting the upper body with a hand reduces implant force [22].

Lifting weights from the ground

Lifting a 10 kg crate of water from the ground caused the highest resultant force on the VBR (up to 1650 N) of all the activities of everyday life that we studied [20]. Thus, this activity should not be performed by patients shortly after surgery. In contrast to common assumptions, the manner in which the crate was lifted (knees bent or knees straight) often had only a minor influence on the implant load.

Discussion

Loads on a VBR were measured in 5 patients for different activities of daily living to identify exercises that cause high loads and to evaluate strategies for preventing or reducing high loads.

This study has some limitations: telemeterized VBRs were implanted in only 5 patients. Thus, no statistical tests could be performed. The measurements were performed at different postoperative times. However, loads generally changed with time because of various factors (e.g., the increasing stiffness of the fracture and the added bone material, and little implant subsidence) [12]. The surgical procedure, the treated spinal level and, thus, the VBR load sharing varied. Often, an exercise was measured only a small number of times, and not all exercises were performed by all patients. The supporting forces for various exercises most likely also differed and were not measured. Therefore, the determined load reductions often reflect only a trend.

In summary, there are generally two main possibilities for avoiding or reducing high spinal loads:

1. by reducing the lever arm of the upper body's CoM or by reducing the carried weights relative to the lumbar spine, e.g., by shifting the CoM posteriorly; and
2. by supporting the upper body with, for example, a hand.

In addition, patients should follow their physiotherapists' instructions to keep their spinal loads low.

To prevent implant subsidence, these rules should be obeyed, particularly during the initial postoperative period.

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