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Loads on internal spinal fixators measured in different body positions

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Abstract Telemeterized internal spinal fixation devices were implanted in ten patients. The loads acting on the fixators were compared for different body positions, including standing, sitting, and lying in a supine, prone, and lateral position. Implant loads differed considerably from patient to patient depending, for example, on the indication for surgery and the surgical procedure. They were altered by anterior interbody fusion. Mostly, only small differences in implant loads were found

for the various lying positions. Flexion bending moments were significantly higher in upright than in lying body positions. Loads on the fixators were not higher for sitting than for standing. Patients who have undergone mono- or bisegmental spine stabilization should therefore be allowed to sit as soon as they can leave the bed.

Key words Internal spinal fixator · Load measurement · Body position · Telemetry · Spine

Introduction

Spines rendered unstable by traumatic, tumorous or degenerative disorders are often stabilized by an internal spinal fixation device. Different loads act on the spine and fixators in an upright and a lying body position. Direct measurement of the complete spinal load is not yet possible. Intradiscal pressure has been measured in different body positions [4, 12], and was found to be significantly lower in a lying than in an upright body position. Nachemson [4] reported a 40% higher intradiscal pressure for sitting than for standing. In a recent study, Wilke et al. [12] measured nearly the same pressure for standing as for sitting.

Little information exists about implant loads in different body positions. Rohlmann and co-workers instrumented an internal spinal fixator and measured the loads on the fixator for many activities, including physiotherapy, walking, and bending the upper body while standing [6–9]. Implant loads were altered by anterior interbody fusion (AIF) with an autologous bone graft from the iliac crest [11].

The aim of this study was to compare fixator loads for various body positions, including standing, sitting, and lying in a supine, prone, and lateral position.

Materials and methods

Instrumented internal fixator

The bisegmental internal spinal fixator described by Dick [2] was modified to measure three force and three moment components acting on it. A measuring cartridge was integrated into the longitudinal threaded rod containing six load sensors, a telemetric unit and a coil for the inductive power supply of the electronic system. The patients were videotaped during the measurements, and load-dependent signals of the paired implanted telemeterized fixators were stored together with the images. Implant loads were calculated from the telemetric signals and displayed online and offline on a computer monitor. The instrumented implant, the telemetric unit, the external equipment, and the accuracy of the device have previously been described in detail [3, 5].

Patients

Instrumented internal spinal fixators were implanted in ten patients (Table 1). Three patients evidenced degenerative instability, while

Table 1 Data on patients and surgical procedures

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8	Patient 9	Patient 10
Gender	Female	Male	Female	Male	Male	Male	Female	Female	Female	Female
Age (years)	59	34	54	72	36	42	46	62	47	54
Weight (kg)	75	90	66	80	75	81	53	85	48	68
Height (cm)	170	185	162	171	173	164	165	157	160	171
Indication	Degenerative instability	Compression fracture (old)	Compression fracture	Degenerative instability	Compression fracture	Degenerative instability	Compression fracture (old)	Compression fracture (old)	Compression fracture	Compression fracture
Bridged vertebra	L3	L4	L3	L4	T11	L4	T12	L1	L1	T12
Implant levels	L2-L4	L3-L5	L2-L4	L3-L5	T10-T12	L3-L5	T11-L1	T12-L2	T12-L2	T11-L1
Bone grafts	L2/3&L3/4	L3-L5	L2/L3	L3/4&L4/5	T10/T11	L3/4&L4/5	T11/T12	T12-L2	T12/L1	T11/T12
Implantation	4/94	6/94	8/95	8/96	7/97	8/97	9/97	5/98	6/98	6/98
Time between operations (days)	28	108	21	21	24	30	-25 ^a	28	16	18
Distraction	Yes	-	Yes	Yes	Yes	Yes	-	Yes ^b	-	-
Compression	-	Yes	-	-	-	-	Yes	-	-	-
Lordosis increased	-	-	Yes	-	Yes	-	Yes	-	Yes	Yes

^aFirst stage anterior interbody fusion, second stage implantation of fixators^bPlus anterior Zielke fixator

four had a fresh and three an old vertebral compression fracture. AIF using iliac crest bone grafts was performed in a second session except in patient 7, in whom it preceded fixator insertion. Thus, no fixator loads were available before AIF in that patient. Two bone grafts were inserted in the patients with degenerative instability, while one large bone graft was used in two patients with an old compression fracture (patients 2 and 8). Five patients (3, 5, 7, 9, and 10) had only the upper bridged disc removed and the lower one was left intact. A Zielke fixator was additionally implanted ventrally during AIF in patient 8.

The Ethics Committee of our university approved clinical implantation of the modified fixators in up to ten patients. Prior to surgery, the procedure was explained to the patients, and they gave their written consent to implantation of instrumented internal spinal fixators and subsequent implant load measurements.

Measurements

Implant loads were measured once or twice a week during hospitalization, and then about once a month until implant removal. In this study, loads for standing, sitting, and lying in a supine, prone, and lateral position are compared for two points in time. The first point was a few days before, the second about 100 days after AIF. Previous measurements had shown that the axial force and the bending moment Mb_{sag} in the sagittal plane are the most important load components. These two are thus compared here. However, bending moments are much more important than axial forces in protecting implants from breakage. A negative axial force component was evoked by implant compression and a negative (flexion) bending moment Mb_{sag} by a load approximating the ventral tips of the upper and lower Schanz screws.

Some patients had markedly different implant loads in consecutive sessions. Median implant load values for the body positions studied were therefore determined at the two time points during three measuring sessions. Average loads of single fixators were used to determine median and extreme values for the different groups of patients.

T-tests for matched pair differences were performed to detect statistical differences between implant loads in different body positions.

Results

Table 2 gives the median axial force and bending moment in the sagittal plane measured for different body positions in all patients prior to AIF. The fixators evidenced an axial compression force and a flexion bending moment in most cases. Considerable load differences were found between the left and right fixator. In some cases (e.g., patients 1 and 2), a flexion bending moment was measured on one side and an extension bending moment on the other.

Table 3 gives the median axial force and bending moment Mb_{sag} at about 100 days after AIF. Insertion of bone grafts altered implant loads considerably in some cases (patients 1, 4, 6 and 8). The bridged region was compressed by the fixators in patients 2 and 7, who thus had low and nearly constant fixator loads in different body positions.

Figure 1 compares the average fixator loads in different body positions for the times before and after AIF. Sig-

Table 2 Average implant loads in different body positions measured a few days before anterior interbody fusion

Surgical indication	Patient	Side	Axial forces (N)					Bending moment Mb,sag (Nm)				
			Standing	Sitting	Supine position	Prone position	Lateral position	Standing	Sitting	Supine position	Prone position	Lateral position
Degenerative instability	1	Left	-111	-68	-15	-33	-46	-1.934	-2.124	-0.810	-0.991	-1.173
		Right	-80	-21	-62	-29	-52	-0.821	0.034	0.364	1.209	0.230
	4	Left	-159	5	-54	-54	-19	-3.556	-2.018	0.378	-0.564	-0.827
		Right	-206	-99	-84	-72	-40	-2.601	-1.255	1.083	1.113	0.551
	6	Left	-119	-57	-60	-75	-32	-1.525	-1.140	0.145	-0.430	-0.226
		Right	-128	-46	-37	-41	-71	-2.260	-0.895	-0.382	-0.284	-1.832
Old vertebral fracture	2	Left	-95	-94	-82	-55	-60	0.322	0.447	0.699	0.930	0.921
		Right	-111	-86	-70	-57	-61	-2.576	-2.267	-0.924	-0.460	-1.002
	7 ^a	Left	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	8	Left	-63	-70	-55	-51	-131	-5.649	-4.910	-0.694	-0.866	-2.472
		Right	-147	-157	-93	-77	-51	-5.498	-4.843	-1.538	-1.452	-1.861
Fresh vertebral fracture	3	Left	-111	-101	-9	-40	-42	-3.976	-4.631	-0.118	-1.332	-1.492
		Right	-136	-144	-17	-63	-16	-4.863	-6.140	-0.365	-1.523	-1.163
	5	Left	-67	-28	-33	-2	-5	-5.652	-5.367	-2.153	-1.713	-2.153
		Right	-29	-42	-69	-3	-9	-5.437	-5.556	-1.674	-1.135	-1.782
	9 ^b	Left	25	-12	-5	N/A	-15	-4.393	-4.971	-1.248	N/A	-2.832
		Right	6	24	18	N/A	54	-1.446	-1.133	1.721	N/A	0.823
	10	Left	7	-17	-95	-79	-103	-4.131	-3.915	-0.810	-1.120	-1.870
		Right	-29	-43	-34	-27	-31	-3.335	-3.500	-1.539	-1.574	-1.790

^aNo loading data were available, since AIF preceded fixator implantation in this patient^bSince this patient could not lie in a prone position before AIF, the respective implant loads were not available**Table 3** Average implant loads in different body positions measured about 100 days after anterior interbody fusion

Surgical indication	Patient	Side	Axial forces (N)					Bending moment Mb,sag (Nm)				
			Standing	Sitting	Supine position	Prone position	Lateral position	Standing	Sitting	Supine position	Prone position	Lateral position
Degenerative instability	1	Left	-224	-161	-77	-102	-72	-6.348	-6.122	-2.464	-3.280	-3.178
		Right	-125	-133	-85	-89	-95	-4.143	-4.239	-0.586	-1.219	-1.668
	4	Left	-213	-117	-78	-141	-59	-7.959	-7.144	-0.848	-2.954	-2.123
		Right	-137	-45	-9	-41	34	-4.561	-2.304	1.057	-0.158	0.776
	6	Left	-144	-108	-78	-82	-91	-4.074	-3.808	-2.301	-2.318	-3.022
		Right	-158	-110	-77	-75	-72	-3.767	-3.000	-1.539	-1.500	-1.638
Old vertebral fracture	2	Left	-203	-187	-96	-100	-95	-0.502	-0.370	0.129	0.257	0.663
		Right	-109	-85	-108	-99	-91	-3.769	-3.271	-3.243	-3.082	-3.037
	7	Left	-68	-75	-94	-55	-90	-2.206	-2.203	-2.093	-1.705	-2.241
		Right	80	54	-16	12	38	0.656	0.280	-0.267	-0.078	-0.091
	8 ^a	Left	-39	-42	-29	-4	3	-2.001	-1.721	-0.092	-0.026	-0.253
		Right	-148	-119	-72	-54	-48	-4.175	-3.666	-1.293	-1.341	-1.457
Fresh vertebral fracture	3	Left	-141	-111	-12	-20	-54	-4.861	-4.294	-1.239	-1.538	-2.222
		Right	-135	-81	-21	-39	-28	-4.610	-3.927	-1.345	-1.974	-1.795
	5	Left	-41	-43	-47	-18	-52	-5.159	-4.965	-3.552	-3.192	-3.696
		Right	-59	-55	-90	-91	13	-4.236	-4.190	-2.589	-2.682	-2.156
	9	Left	-42	-105	-43	-23	-62	-5.274	-5.471	-2.444	-2.601	-3.311
		Right	-41	-50	-14	2	48	-2.314	-2.230	0.531	0.161	-0.261
	10	Left	22	39	-96	-46	-95	-5.573	-5.409	-1.632	-1.922	-2.585
		Right	-74	-77	-66	-48	-39	-4.672	-4.607	-2.480	-2.393	-2.630

^aAdditional Zielke fixator anteriorly

Fig. 1 Comparison of average axial force component (*top*) and bending moment Mb,sag in the sagittal plane (*bottom*) measured in different body positions before and after anterior interbody fusion (AIF)

Fig. 2 Average axial force component (*top*) and bending moment Mb,sag in the sagittal plane (*bottom*) measured in different body positions a few days before AIF in three groups of patients with different diagnoses

Table 4 Significance levels for implant loads in various body positions. The upper right shows the time before, the lower left the time after AIF. The first group of symbols stands for axial force and the second for bending moment in the fixator

	Standing	Sitting	Supine position	Prone position	Lateral position
Standing	—	*/NS	*/***	*/***	*/***
Sitting	*/*	—	NS/**	*/***	NS/**
Supine position	*/***	NS/**	—	NS/NS	NS/**
Prone position	*/***	*/***	NS/NS	—	NS/*
Lateral position	*/***	*/***	NS/**	NS/NS	—

NS = not significant ($P > 0.10$); * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

nificance levels for implant loads in different body positions are given in Table 4. The highest axial forces were measured for standing. However, axial forces acting on the fixators were mostly low. Flexion bending moments were significantly lower ($P < 0.001$) in a lying than in an upright body position. Implant loads differed only slightly for the various lying positions. No significant differences were found between lying in a supine and a prone position. However, flexion bending moments for lying were significantly higher in a lateral than in a supine position. Except in the case of flexion bending moments before AIF, implant loads were significantly higher for standing than for sitting ($P < 0.05$). Slightly higher flexion bending moments were measured after than before AIF.

Figure 2 shows the median and extreme pre-AIF implant loads measured in different body positions for various surgical indications. There are considerable differences between median values of single fixators within a group, as reflected by the broad ranges of loads measured. Flexion bending mo-

Fig. 3 Fixator loads in different body positions for three groups of patients with different diagnoses measured about 100 days after AIF

ments were lower on average in cases with degenerative instability than in those with a vertebral compression fracture. The average fixator load was lower for sitting than for standing in patients with degenerative instability.

Implant loads after AIF are shown in Fig. 3 for different surgical indications and various body positions. Due to AIF, flexion bending moments in the fixators increased in the cases with degenerative instability and decreased in those with an old vertebral compression fracture, but stayed nearly constant in those with a fresh compression fracture (cf. loads in Fig. 2). The lower of the bridged intervertebral discs was left intact in the latter group.

Discussion

The indication for surgery, the bridged vertebral level, and the surgical procedure differed in the ten cases studied.

However, there were some common findings relating to implant loads:

1. Axial forces were usually compression forces, bending moments mostly flexion bending moments.
2. They were altered by AIF.
3. They were not higher for sitting than for standing.
4. They were generally higher for an upright than for a lying position.
5. Mostly minor differences were found for the various lying positions.

Fixator loads varied from one measuring session to another. They are influenced by factors such as wound pain and muscle condition. Wound pain was normally mild in the sessions shortly before AIF. For comparison of implant loads after AIF, we chose measuring sessions around 100 days after AIF, when wound pain was gone and solid fusion had not yet occurred. In most cases implant loads changed only slightly in the postoperative temporal course.

Implant loads differed from patient to patient. The partial body weight above the implant level influences the loads, but an even greater influence was exerted by other factors such as the indication for surgery and the surgical procedure (increasing lordosis, compression or distraction of the bridged region) [11]. In patients with degenerative instability, distracting the bridged region led to relatively low bending moments in the fixators before AIF (Fig. 1), but much higher ones thereafter. In patients with a fractured vertebral body, distraction involved relatively high bending moments before AIF. Their loads were much less influenced by AIF than those in the patients with degenerative instability. When the bridged region was compressed by the fixators (patients 2 and 7), implant loads differed only slightly for the various body positions. Loads were low in these cases.

Three patients were wearing a Boston overlap brace during some measuring sessions. However, a brace has only a negligible influence on implant loads [10].

Marked implant load differences were often found between the left and right fixator. Possible reasons for this include unilateral distraction during implantation of the fixators to compensate for slight scoliosis, the position of the bone graft, and unilateral alteration of the muscle strength due to the surgical approach.

The difference between bending moments in the sagittal plane for an upright and a lying position indicates the stiffness of the bridged region. Compression of that region (patients 2 and 7) was associated with a small difference and thus a high stiffness. Distraction led to marked load difference and a low stiffness.

Leaving the lower bridged intervertebral disc intact caused relatively high flexion bending moments in the fixators when the bridged region was not compressed by the implants. Preloading may cause nutritional problems for the disc involved. Little is known about the fate of bridged intervertebral discs when the fixators have been removed.

Wilke et al. [12] measured the intradiscal pressure and found values between 0.08 and 0.12 MPa for lying positions. They varied between 0.45 and 0.50 MPa for sitting and standing. The intradiscal pressure was about five times higher in an upright than in a lying position. Our patients also tended towards higher implant loads in an upright than in a lying position, but the differences were generally smaller. Flexion bending moments differed only slightly for sitting and standing, except before AIF in patients with degenerative instability (Fig. 2), where loads were significantly lower for sitting than for standing. Nachemson [4] found a 40% higher intradiscal pressure for sitting than for standing. Measuring intradiscal pressure with a more advanced transducer, Wilke et al. [12] measured slightly lower values for sitting than for standing. Althoff et al. [1] precisely investigated body height in several test persons and found that prolonged standing decreased body height by reducing disc height. When the test person sat after standing, the body height increased again. This suggests that the spinal load is higher in a standing than in a sitting position. We think that patients submitted to spine stabilization with mono- or bisegmental fixators should be mobilized for sitting and standing at the same time.

Implant loads for various lying positions usually differed only slightly, and no statistical differences were found between lying in a supine and a prone position. The highest bending moment in a fixator was measured 23 times for a right lateral position, 10 times for a prone position, and 6 times for a supine position. Nachemson [4] found a three-fold pressure increase from lying supine to lying on one's side, while Wilke et al. [12], using the new device, measured nearly a constant intradiscal pressure for lying in a supine (0.10 MPa), a prone (0.11 MPa), and a lateral

position (0.12 MPa). Lateral flexion of the upper body while standing increased implant loads on the concave side and decreased them on the convex side [8, 9]. Gravitational forces and different supporting points should change the spinal shape in various lying positions. Since implant loads differ only slightly for these body positions, there should only be minor deformations of the bridged region. Spinal shape changes when moving from one lying position to another probably occurred mainly in the adjacent motion segments. Since these deformations are much lower than the possible motion ranges of these segments, they should cause no harm to the adjacent intervertebral discs.

Patient 8 had an additional Zielke fixator mounted onto the left side of the vertebral bodies, since the spinal curvature could not be re-established during implantation of the dorsal fixators. The anterior implant decreased fixator loads, especially on the left.

For at least one fixator of patients 5, 7, and 10, the axial compression force was higher in a lying than in an upright body position (Tables 2, 3). In these patients the T11 or T12 vertebra was bridged. The fixators are mounted on the concave side in the lumbar spine and on the convex side in the thoracic spine. In an upright position the axial load on the spine is higher, which increases the spinal curvature. Since the axis of rotation is on the ventral side of the fixators, an increasing spinal curvature raises the concave-sided and lowers the convex-sided compression force.

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References

1. Althoff I, Brinckmann P, Frobin W, Sandover J, Burton K (1992) An improved method of stature measurement for quantitative determination of spinal loading. *Spine* 17:682–693
2. Dick W (1989) Internal fixation of thoracic and lumbar spine fractures. Huber, Berne
3. Graichen F, Bergmann G, Rohlmann A (1996) Patient monitoring system for load measurement with spinal fixation devices. *Med Eng Phys* 18:167–174
4. Nachemson A (1966) The load on lumbar discs in different positions of the body. *Clin Orthop* 45:107–122
5. Rohlmann A, Bergmann G, Graichen F (1994) A spinal fixation device for in vivo load measurement. *J Biomech* 27:961–967
6. Rohlmann A, Bergmann G, Graichen F (1997) Loads on an internal spinal fixation device during walking. *J Biomech* 30:41–47
7. Rohlmann A, Bergmann G, Graichen F, Mayer H-M (1998) Influence of muscle forces on loads in internal spinal fixation devices. *Spine* 23:537–542
8. Rohlmann A, Bergmann G, Graichen F, Mayer H-M (1995) Telemeterized load measurement using instrumented spinal internal fixators in a patient with degenerative instability. *Spine* 20:2683–2689
9. Rohlmann A, Bergmann G, Graichen F, Weber U (1997) Comparison of loads on internal spinal fixation devices measured in vitro and in vivo. *Med Eng Phys* 19:539–546
10. Rohlmann A, Bergmann G, Graichen F, Weber U (1999) Braces do not reduce loads on internal spinal fixation devices. *Clin Biomech* 14:97–102
11. Rohlmann A, Bergmann G, Graichen F, Weber U (in press) Changes in loads on an internal spinal fixator due to an iliac crest bone graft. *J Bone Joint Surg [Br]*
12. Wilke H-J, Neef P, Caimi M, Hoogland T, Claes LE (1999) New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine* 24:755–762