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ORIGINAL ARTICLE

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Effect of an internal fixator and a bone graft on intersegmental spinal motion and intradiscal pressure in the adjacent regions

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Abstract Stabilizing a lumbar spine with an implant alters the mechanical properties of the bridged region. In order to determine whether this procedure is associated with higher loads in the adjacent segments, seven lumbar cadaver spines were mounted in a spine tester and loaded with pure moments of flexion/extension, left and right lateral bending, and left and right axial rotation. The material studied comprised intact lumbar spines, intact spines with bisegmental internal spinal fixators, and post-corpectomy spines both with a graft and fixators and with fixators alone. Intradiscal pressures and intersegmental motion were measured at all levels. In the bridged region, these parameters were strongly affected by an internal fixator. In most cases, the effect was small in the regions above and below the fixators. Highly significant differences in these regions ($P<0.01$) were far below the inter-specimen range. We did not find any case where both intradiscal pressure changes and intersegmental motion showed highly significantly differences in the regions adjacent to the bridged one. Our results suggest that disc degeneration, which is sometimes found at the level directly above and below the fixators, is not caused by mechanical factors.

Keywords Intradiscal pressure · Internal spinal fixator · Biomechanics · Intervertebral disc · Spinal fusion

Introduction

The mechanical properties of a lumbar spine are altered by implantation of an internal spinal fixation device and insertion of a bone graft. Several clinical investigations [9, 11, 12, 23] describe degeneration of discs adjacent to instrumented or fused segments. Whereas some of these studies reported alteration of the adjacent segments in 40–50% of cases, others have found it only in very few patients [19, 25]. Thus it is still a matter of debate whether instrumentation has such a negative effect. Several biomechanical studies have therefore tried to find a mechanical explanation for this clinical problem.

Cunningham et al. [4] measured the intradiscal pressure at three levels in eleven cadaveric lumbar spines. In their study, the specimens were loaded in axial compression and were deformation controlled in anterior flexion and extension. After instrumentation, they found an increase of disc pressure of as much as 45% proximally, while in the bridged disc the pressure decreased by 41–55%. Several other experimental and finite-element studies found increased deformation in the segments adjacent to an instrumented region [3, 5, 28]. In these studies, deformation-controlled loads were usually applied. In contrast to these findings, instrumentation of the spine had no effect on the segment above and only a minor effect on that below the fixators in our own finite-element studies [22]. The reason may be that we applied load-controlled moments.

In vitro measurements of intradiscal pressure [1, 13, 16, 32] and intersegmental motion [2, 14, 24, 31] have been performed previously, mostly in monosegmental specimens or in only one segment of a multisegmental specimen. However, motion and intradiscal pressure measurements of multisegmental specimens are required to determine the complex behavior of the spine [6, 8, 33]. Intersegmental motion in the lumbar spine loaded with pure moments has been investigated by several groups [17, 18, 26, 31, 33].

The aims of this in vitro study were (a) to measure both intradiscal pressure and intersegmental motion in spines loaded with pure moments in the three orthogonal anatomic planes and (b) to determine the effect of an internal spinal fixator, a bone graft, and corpectomy on these parameters.

Materials and methods

Seven fresh-frozen lumbar cadaver spines (mean age, 28 years; range, 16–69 years) were used (Table 1). All soft tissue was removed, leaving the ligaments, capsules, and other supporting structures intact. The specimens were frozen in plastic bags at –20°C until testing. Before testing, the spines were thawed, and the outer vertebrae were potted with screws and bone cement (polymethylmetacrylate, PMMA) in stainless steel cups.

Biomechanical testing was performed in a spine tester [29] at room temperature. The lower part of the specimens was fixed rigidly to the frame of the loading apparatus with the upper part mounted in a gimbal to allow rotation around all three coordinate axes and vertical translation. A traveling gantry and a second slide enabled translation in the remaining two planes. Stepper motors integrated into the gimbal of the spine tester were used to continuously apply pure moments through each of three anatomic axes in alternating sequences. The constant loading rate was 1.7°/s.

A flexible pressure transducer (Mammendorfer Institut für Physik und Medizin GmbH, Hattenhofen, Germany) with a diameter of 1.2 mm was placed in the pulpy nucleus of each of the four discs. These pressure transducers were implanted before mounting the specimen in the spine tester. X-rays were taken to check the correct position of the sensors. Intersegmental motion (angles in the three principle planes) was measured simultaneously using a three-dimensional motion analysis system (Zebris, cmstra v.1.0, Isny, Germany). This ultrasound-based system was fixed to the frame of the spine tester and to each mobile segment of the specimen.

The specimens were mounted in the spine tester [29] and loaded with pure moments of ±3.75 Nm for three successive cycles in the sagittal (flexion – extension), frontal (left and right lateral bending), and transverse plane (left and right axial rotation). These moments were chosen to allow multiple tests and avoid specimen damage or screw loosening. The specimens moved freely in the five uncontrolled degrees of freedom. Four situations were studied:

1. Intact spines.
2. Intact spines with fixators. The middle vertebra was bridged by an internal fixation device, leaving one intact segment above and below the implant. Schanz screws (diameter, 5 mm) were placed in the four pedicles adjacent to the bridged vertebrae. Instrumented internal fixators [20] were fastened to these screws in a standard fashion.
3. Postcorpectomy spines with a wooden graft and fixators. Corpectomy of the bridged vertebra was performed by removing the adjacent discs and the intervening vertebral body, leaving the posterior ligament and pedicles intact. A cylindrical piece of

Table 1 Data on the seven cadaver specimens

Specimen no.	Level	Age (years)	Sex	Bridged vertebra	Implant levels
1	L1–L5	69	Female	L3	L2–L4
2	L1–L5	28	Male	L3	L2–L4
3	L1–L5	16	Female	L3	L2–L4
4	L1–L5	28	Male	L3	L2–L4
5	T12–L4	19	Male	L2	L1–L3
6	T12–L4	42	Male	L2	L1–L3
7	T12–L4	22	Male	L2	L1–L3

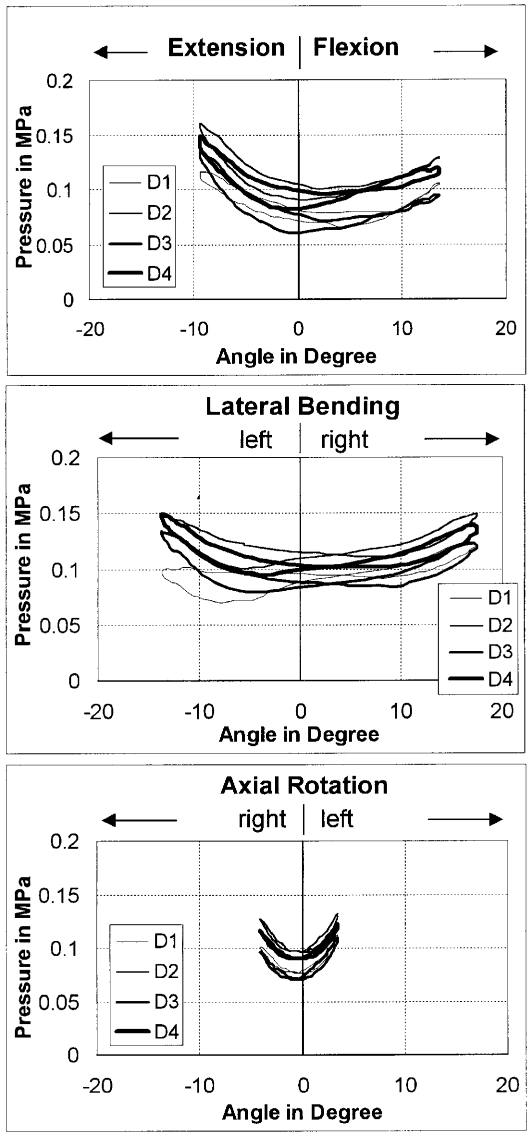

Fig. 1 Average intradiscal pressure in discs D1 (most cranial) to D4 (most caudal) as a function of total specimen motion. The intact specimens (L1–L5 or Th12–L4) were loaded with pure moments of ±3.75 Nm. For each disc, the curve of a loading cycle appears as a closed loop

wood simulating a bone graft was placed between the adjacent vertebrae.
4. Postcorpectomy spines with fixators but without a graft.

All measurements in each specimen were performed on the same day.

Evaluation

Intradiscal pressure and intersegmental motion were continuously recorded and evaluated during the third loading cycle. Average pressure curves were calculated for the seven specimens (Fig. 1). Maximum changes in pressures and rotational angles during a loading cycle were also determined. Average values for the two loading directions were used for left and right lateral bending and for left and right axial rotation. Intersegmental rotation in the loading plane was evaluated for the different loading modes. Wilcoxon matched-pairs signed rank tests were performed to check for significant differences between the four situations studied. In four specimens, the L3 vertebra was bridged, and in the other three, the L2. Assuming similar behavior, the results for the adjacent segments were averaged for all seven specimens.

Results

Intradiscal pressure

Figure 1 shows intradiscal pressure in the four discs as a function of total specimen motion for loading with pure moments of ±3.75 Nm in the three orthogonal anatomic planes. We found that curves tended to vary individually for the different specimens when applying pure moments. Mean curves of the seven intact specimens are thus presented to show trends. These mean curves look fairly similar for the four lumbar segments. The total motion of a whole specimen for a moment of 3.75 Nm was about 9° for extension, 13° for flexion, 15° for lateral bending, and 4° for axial rotation. In the unloaded neutral position, the pressure in the nucleus was about 0.09 MPa (range, 0.075–0.11 MPa). In most cases, intradiscal pressure increased with an increasing external moment.

In extension, the mean pressure curves increased to about 0.15 MPa. This was a stronger increase than in flexion, where the mean pressure reached values of about 0.12 MPa. However, generalizations cannot be made here because we also had specimens which showed the opposite trend. In lateral bending, a definite pressure increase only started at an angle of about 8° in both directions and ranged up to 0.15 MPa. Very symmetrical behavior was found in axial rotation, where the pressure increased to about 0.12 MPa and the rotational angle was about 1° per lumbar level.

Intradiscal pressure changes and intersegmental rotation during extension

Mounting fixators to the intact spine strongly decreased intradiscal pressure changes in the bridged discs and reduced intersegmental motion in the bridged region (Fig. 2). Intradiscal pressure changes in the adjacent discs were

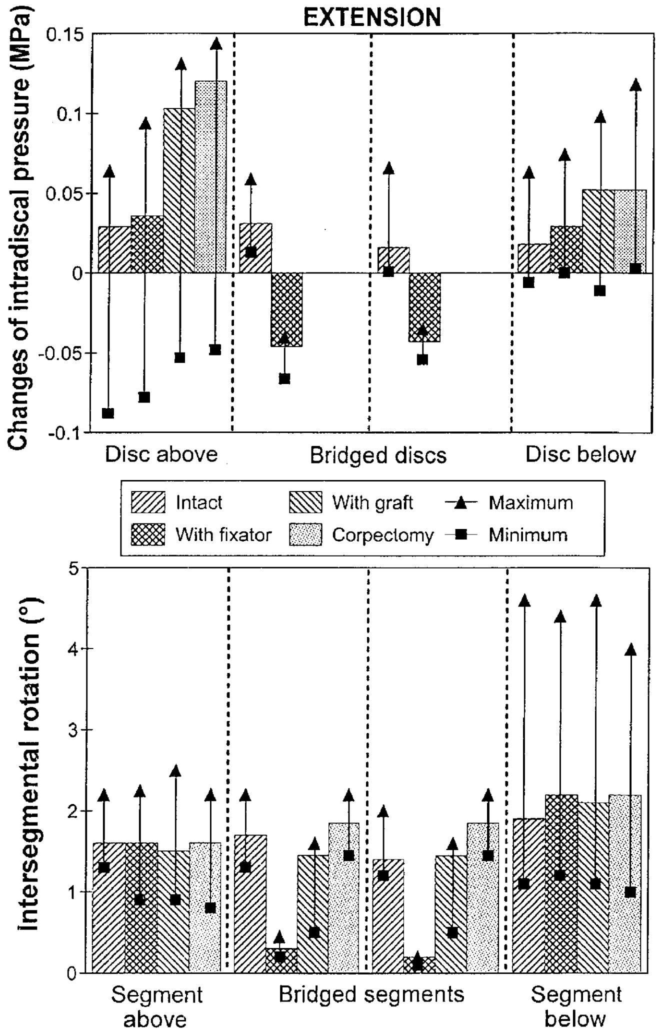

Fig. 2 Median and range of intradiscal pressure changes (*top*) and intersegmental rotation (*bottom*) for an extension bending moment of 3.75 Nm

nearly always slightly higher in the postcorpectomy spines than in the intact ones. Some cases showed strong differences between the median and maximum value and between the median and minimum value, indicating that one value differed strongly from the others.

Intradiscal pressure changes showed highly significant differences (P<0.01) in the disc above the fixator between all cases and in the disc below the fixator between the intact spine and postcorpectomy spine without a graft (Table 2). The differences in intersegmental rotation were not significant in any of the cases (Table 3).

Intradiscal pressure changes and intersegmental rotation during flexion

Mounting fixators to the intact spines increased intradiscal pressure changes, especially in the bridged discs (Fig.

Table 2 Significance levels of intradiscal pressure changes for different loading modes (the upper right part of each of the four table segments shows the values for the disc above and the lower left part for the disc below the bridged region)

Loading mode		Intact	With fixator	With graft	Corpectomy
Extension	Intact	–	**	**	**
	With fixator	NS	–	**	**
	With graft	*	*	–	**
	Corpectomy	**	*	NS	–
Flexion	Intact	–	NS	NS	NS
	With fixator	*	–	NS	*
	With graft	NS	*	–	**
	Corpectomy	NS	**	*	–
Lateral bending	Intact	–	NS	NS	NS
	With fixator	*	–	NS	NS
	With graft	*	NS	–	NS
	Corpectomy	**	NS	*	–
Axial rotation	Intact	–	NS	NS	*
	With fixator	**	–	NS	NS
	With graft	NS	NS	–	NS
	Corpectomy	*	NS	NS	–

NS, not significant (P>0.06); *P<0.05; **P<0.01

Table 3 Significance levels of intersegmental rotation for different loading modes (the upper right part of each of the four table segments shows the values for the segment above and the lower left part for the segment below the bridged region)

Loading mode		Intact	With fixator	With graft	Corpectomy
Extension	Intact	–	NS	NS	NS
	With fixator	NS	–	NS	NS
	With graft	NS	NS	–	NS
	Corpectomy	NS	NS	NS	–
Flexion	Intact	–	*	*	**
	With fixator	*	–	NS	NS
	With graft	*	NS	–	NS
	Corpectomy	**	NS	NS	–
Lateral bending	Intact	–	*	*	*
	With fixator	**	–	NS	NS
	With graft	NS	NS	–	NS
	Corpectomy	*	NS	NS	–
Axial rotation	Intact	–	*	*	**
	With fixator	*	–-	NS	*
	With graft	NS	NS	–	NS
	Corpectomy	NS	NS	NS	–

NS, not significant (P>0.06); *P<0.05; **P<0.01

3, top), decreased intersegmental rotation in the bridged region, and increased intersegmental rotation in the lower adjacent segment (Fig. 3, bottom). Corpectomy had only a minor effect on intradiscal pressure changes and intersegmental rotation.

Highly significant differences in intradiscal pressure changes were found in the disc above the fixator between the postcorpectomy spine with and without a graft and in the disc below the fixator between the intact spine with a fixator and the postcorpectomy spine without a graft (Table 2). Highly significant differences in the flexion angle of a segment were found between the intact spine and the postcorpectomy spine without a graft in the segments above and below the fixator (Table 3).

Intradiscal pressure changes and intersegmental rotation during lateral bending

Mounting fixators decreased intradiscal pressure changes in the bridged discs and intersegmental rotation in the bridged region (Fig. 4). Corpectomy and a graft had only a negligible effect on intradiscal pressure changes and intersegmental rotation.

For intradiscal pressure changes, highly significant differences were only found in the disc below the fixator between the intact spine and the postcorpectomy spine without a graft (Table 2); for intersegmental rotation, they were seen in the segment below the fixator between the intact spine with and without fixators (Table 3).

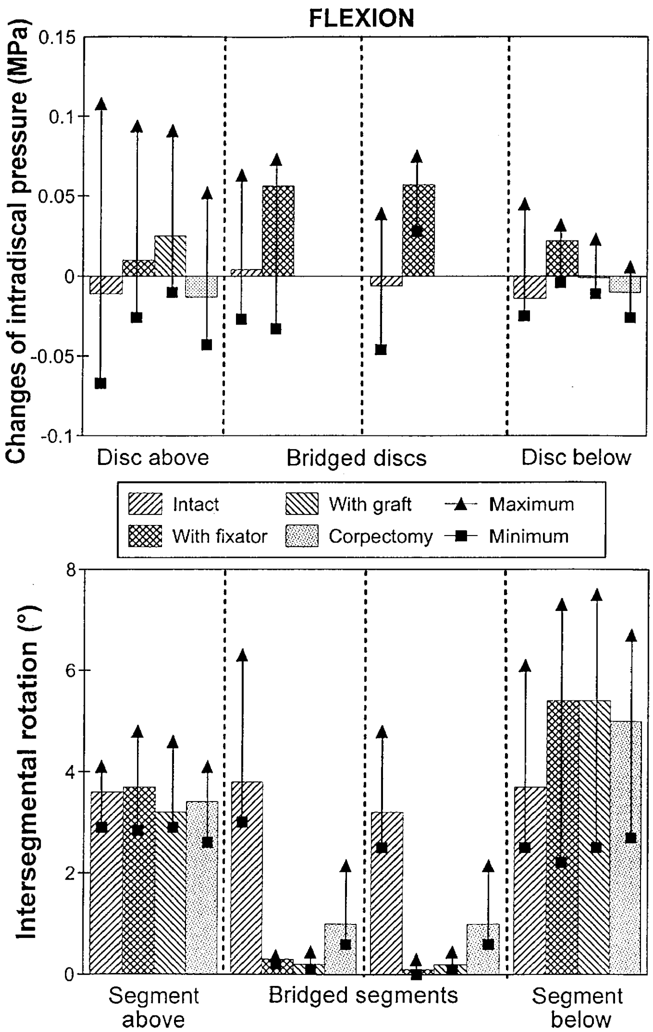

Fig. 3 Median and range of intradiscal pressure changes (*top*) and intersegmental rotation (*bottom*) for a flexion bending moment of 3.75 Nm

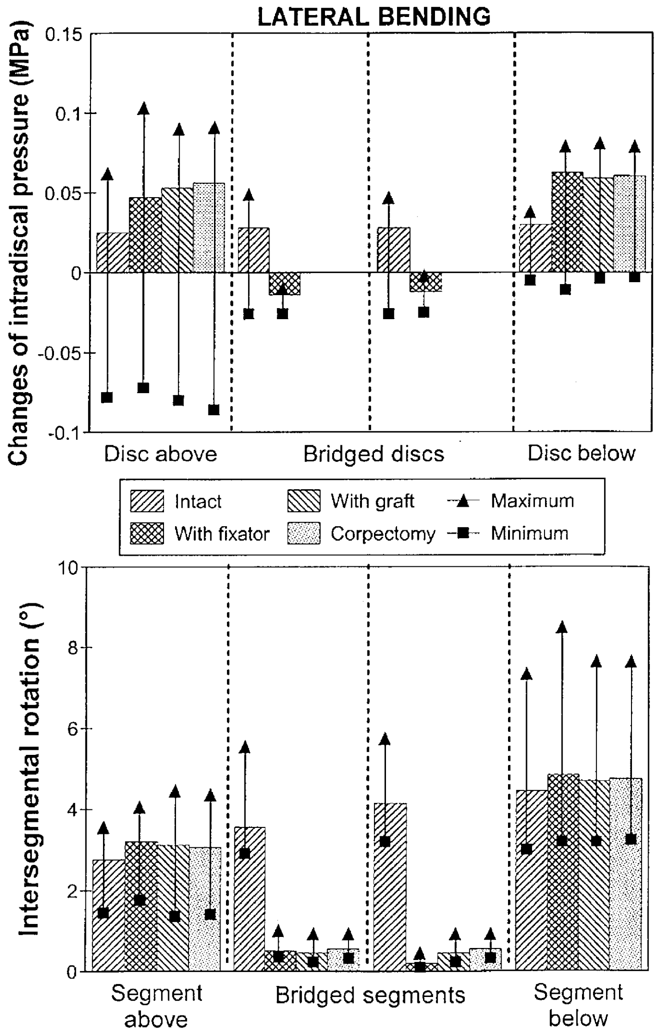

Fig. 4 Median and range of intradiscal pressure changes (*top*) and intersegmental rotation (*bottom*) for lateral bending with a pure moment of 3.75 Nm

Intradiscal pressure changes and intersegmental rotation during axial rotation

Mounting fixators again reduced intradiscal pressure changes in the bridged discs and intersegmental rotation in the bridged region (Fig. 5). As for the other loading cases, the two bridged discs and segments showed very similar behavior also during axial rotation. Corpectomy increased intersegmental rotation in the bridged region, but had only a minor effect on intradiscal pressure changes and intersegmental rotation in the adjacent regions.

Highly significant differences were found for intradiscal pressure changes in the disc below the fixator between the intact spine and the intact spine with a fixator (Table 2), and for intersegmental rotation in the segment above the fixator between the intact spine and the postcorpectomy spine without a graft (Table 3).

Discussion

This study examined the effect of stabilizing a lumbar spine with an implant on intradiscal pressure and intersegmental motion. Seven lumbar cadaver spines were mounted in a spine tester and loaded with pure moments in the three orthogonal anatomical planes. Four different situations (intact spine, intact spine plus fixators, and postcorpectomy spine both with a graft and fixators and with fixators alone) were studied, and intradiscal pressure and intersegmental motion were measured.

The average curves for intradiscal pressure during loading with a pure moment were similar for all disc levels (Fig. 1). The amount of intersegmental rotation depended strongly on the loading plane. Values were highest for lateral bending and lowest for axial rotation. Intersegmental rotation varied in the discs at different lumbar levels, although the load was constant throughout the entire

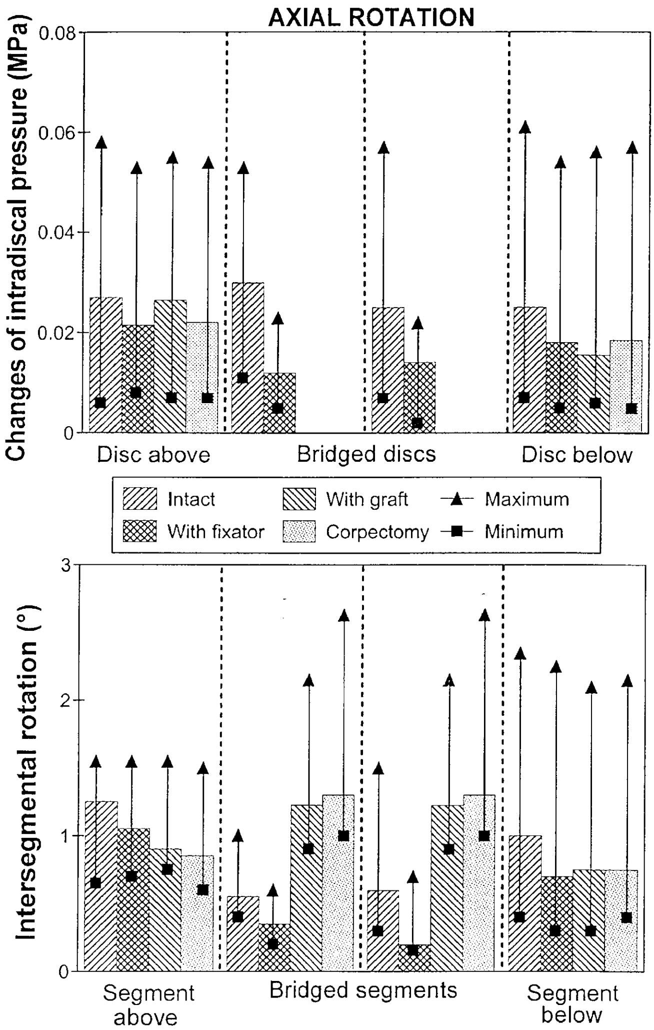

Fig. 5 Median and range of intradiscal pressure changes (*top*) and intersegmental rotation (*bottom*) for axial rotation with a pure moment of 3.75 Nm

specimen. We did not determine the degree of disc degeneration, but we assume low degeneration since the mean age of the specimens was 28 years (range, 16–69 years).

Intradiscal pressure changes and intersegmental rotation varied strongly from specimen to specimen. Inter-specimen differences in the regions adjacent to the bridged one were much higher than the changes due to fixators, a graft, or corpectomy. Even signs of intradiscal pressure changes often differed between specimens.

The curves for intradiscal pressure of the intact specimens were similar to those measured in a previous study [32]. The pressure changes in the present study, however, were slightly lower.

As expected, mounting internal fixators on intact spines strongly affected intradiscal pressure changes and intersegmental rotation in the bridged region. This was the case for all four loading modes studied. However, pressure changes and intersegmental rotation were only slightly affected in adjacent regions. Highly significant differences between intact spines with and without internal fixators were only found in the disc above the fixator for extension, in the disc below the fixator for axial rotation, and in the segment below the fixator for lateral bending. These differences, however, were very small in all cases. By applying deformation-controlled moments, Cunningham et al. [4] also found a decreased disc pressure in the bridged disc, but in contrast to us an increased disc pressure in the adjacent discs.

Compared to the intact spine with fixators, corpectomy with and without a graft had only a minor effect on intersegmental rotation in the adjacent segments. Its effect on intradiscal pressure changes was also negligible for lateral bending and axial rotation. However, we found a small but significant effect for flexion and extension (Table 2). Corpectomy cuts the connection between vertebral bodies. Extension causes separation in the anterior column, and the load is transferred by the fixators and facet joints. During lateral bending and axial rotation, a graft transfers even less load than discs and vertebral bodies of an intact spine. The absolute values for intradiscal pressure were relatively small. The differences between intersegmental pressure changes during loading were also small for the various situations, but in relative terms these differences were sometimes larger than 100%. If such differences are extrapolated to more physiologic loading levels, they may have a marked effect upon disc metabolism.

When the outer load is unchanged, a fixator or corpectomy should have only a negligible effect on motion and internal loads on the region above the fixator. Forces and moments in a plane above the bridged region can be calculated from the outer loads and are theoretically unrelated to the region below the plane. None of our cases showed highly significant differences in either intradiscal pressure changes or intersegmental rotation in the regions above and below the fixators. In 11 of 15 cases, differences were small but highly significant for one parameter and nonsignificant for the other one. The differences found in this study are probably mainly due to common experimental errors and the short specimens (only one disc above and below the bridged region) [10]. When the same overall *deformation* of the specimen was assumed, stronger deformations of the upper and lower discs and higher intradiscal pressure changes could be expected.

The most critical point of this study is the load case used. It has been a matter of debate between biomechanical engineers for many years now whether spine specimens should be tested under load or deformation control. Assuming that the patients would bend their spines to the same degree whether fused or not fused, a much higher load would be necessary if the spine were fused and the remaining nonbridged segments had to compensate for the motion of the bridged region. In this case, increased disc pressure and larger intersegmental motion are also expected in the adjacent segments. However, we believe that during most daily activities, patients tend to accept the limited motion. Load control is probably therefore the adequate loading condition.

In this study, the multisegmental specimens were loaded by applying pure moments in three orthogonal anatomic planes, which is a great advantage since all levels are subject to the same load. Pure moments are also suggested for standardized testing of spinal implants [30]. The loading situation in vivo, however, is much more complex and largely unknown. Muscles and/or external loads subject the spine to a combination of forces and moments and play an important role in spine loading [7, 15, 21, 31]. However, even under these complex loading conditions, disc pressure and stresses in the fibrous ring of the adjacent segments are not (in the disc above) or only slightly (in the disc below) affected, as shown in a finite-element study [22]. It is often assumed that disc degeneration is caused by increased intradiscal pressure and/or intersegmental motion. Our results suggest that the degeneration sometimes seen in discs above and below the fixators is probably not caused by mechanical factors, since the changes in intradiscal pressure and intersegmental motion due to mounting a fixator were small. Postoperative lumbar malalignment may be one reason for adjacent segment deterioration, since it may load the motion segment in a nonphysiologic fashion [27].

Conclusions

Mounting an internal fixation device on a spine specimen greatly affects intradiscal pressure changes and intersegmental rotation in the bridged region. However, in the region adjacent to the fixator, the changes in intradiscal pressure and intersegmental motion due to mounting a fixator are small as long as load-controlled moments are applied. Further studies are needed to clarify whether testing spine specimens under load or deformation control delivers more realistic results.

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