The external spinal fixator does not reduce anterior column motion under axial compressive loads

A mechanical in vitro study

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We performed an in vitro study to investigate the effect of external spinal fixation on anterior column motion under physiological axial compression loading. The AO external spinal fixator (ESF) was applied to 5 human cadaveric lumbar spine specimens (L3-S1) at levels L4 to S1. All specimens were tested in 4 configurations: i) intact, ii) ESF in a neutral position, iii) ESF in distraction (12 mm), and iv) ESF in compression (8–12 mm). Cyclic sinusoidal axial compressive loads from 60 to 600 N were applied for 10 cycles in each test condition. The axial displacement of the load application point was recorded as an indicator of anterior column axial translation.

The axial motion with the fixator in distraction was significantly greater than all other conditions, including intact. Compression of the fixator resulted in the least axial displacement. External fixation in the neutral position did not significantly affect the overall axial translation, when compared to the intact state.

In conclusion, the external spinal fixator did not significantly reduce anterior column axial translation and, in distraction, this motion exceeded that of the intact specimen. Since pain relief is frequently observed during distraction of the painful segment/s with the external fixator, the mechanical basis of the pain relief is not well understood.

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The AO external spinal fixator (ESF), developed by Magerl in the late 1970s, was initially introduced to stabilize thoracolumbar fractures and infections in the spine (Magerl 1982). As a diagnostic tool for degenerative conditions, external fixation was first utilized by Olerud et al. (1986) in the preoperative assessment of a lumbar spine fusion, to select patients to be operated on and to identify the levels to be stabilized. Several clinical studies have shown this to be a good predictor of patient outcome for postoperative pain relief, thus being an additional diagnostic aid for selecting patients who would benefit most from a spinal fusion (Esses et al. 1989, Soini et al. 1993, Jeanneret et al. 1994, Bednar and Raducan 1996). Pain relief has been achieved with the ESF after compression and distraction and after neutral stabilization. Despite promising clinical evidence of the usefulness of this diagnostic test, the mechanism of pain relief is still unknown. It has been attributed to stabilization of the painful "unstable" segment/s (Esses et al. 1989, Jeanneret et al. 1994) and to psychological or neurophysiological mechanisms (Ordeberg et al. 1993).

Few reports have been published to date investigating the mechanical performance of the external spinal fixator. Schläpfer et al. (1982) demonstrated in a vertebral fracture model that the fixator reduced spine flexibility in flexion loading. The stabilizing effect was better than that of an internal Harrington distraction rod system. In a more recent study by Stalder et al. (1996), the fixator provided rotational stability, particularly in axial rotation. However, the axial stiffness in compression was lower than in the intact spine. Axelsson et al. (1996) studied the in vivo effect of external fixation, using radiostereometric analysis (RSA), and concluded that the fixator provided good stability.

Several studies highlight the role of the intervertebral disc in chronic low-back pain, even in the presence of a solid posterior fusion (Wiberg 1950, Smyth and Wright 1958, Weatherley et al. 1986, Kuslich et al. 1991). Thus, the external fixator could be hypothesized to alleviate pain by reducing disc motion.

We investigated the mechanical effect of the external spinal fixator on anterior column motion and determined any differences between the three modes of fixation, i.e., compression, distraction and neutral stabilization. As a testing mode, a cyclic compressive axial load to simulate walking was chosen.

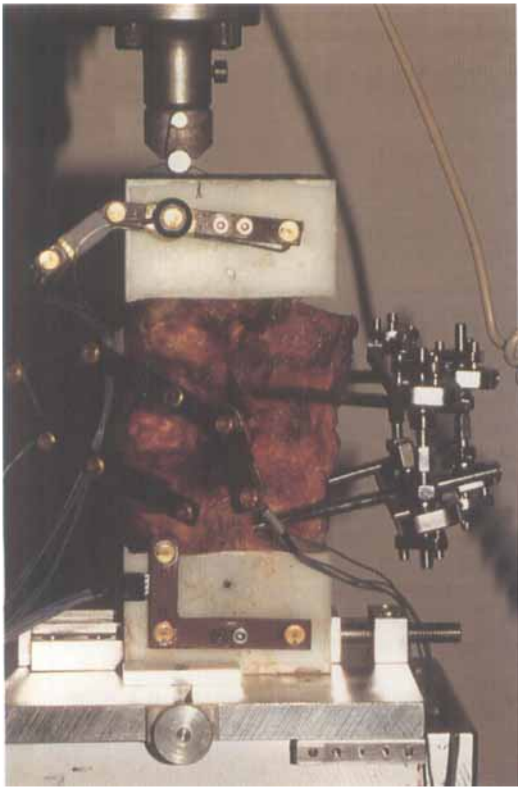

Figure 1. The set-up with the Instron testing machine. The vertebrae are instrumented with marker carriers, each with light-emitting diodes, the position of which could be detected with a precision optoelectronic camera. The loads were applied with a specific loading jig imposing compression approximately over the middle of the L4 vertebral body.

Material and methods

5 human cadaveric lumbar spines from L3 to S1 (age 31–55 years, with a degeneration grade ranging from mild to moderate) were dissected free of all nonligamentous soft tissue. The specimens were kept moist throughout the preparation and testing phases. The upper vertebra and the sacrum of each specimen were mounted in polymethylmethacrylate blocks, so that the L4–L5 disc was horizontal. Schanz screws with a 5 mm threaded part were inserted convergently at the L4 and S1 vertebral bodies transpedicularly. The screws were connected with the 2 horizontal and 3 longitudinal bars which comprise the external fixator. All specimens were tested in 4 testing configurations: i) intact (i.e., the specimen before insertion of the external fixator), ii) neutral ESF, iii) distracted ESF, and iv) compressed ESF. Configurations iii) and iv) were attained by turning the threaded longitudinal bars in the same direction for 15 half-turns according to our clinical practice. The amount of distraction, measured at the level of the horizontal bars, was on average 12 mm, and the amount of compression varied from 8 to 12 mm. The structure of the fixator sometimes prevented the use of 12 mm of compression.

Each vertebra was supplied with a marker carrier having at least 3 non-collinear light-emitting diodes as markers (Figure 1). An optoelectronic camera system (Optotrak 3020, Northern Digital, Waterloo, Ontario, Canada) measured the three-dimensional position of each marker, thereby facilitating the determination of relative intervertebral motion.

For each specimen, cyclic sinusoidal axial compressive loads in the physiological range of 60–600 N were applied for 10 cycles with a frequency of 0.5 Hz in each of the 4 test conditions (Instron 1270, High Wycombe, Bucks, U.K.). The peak load magnitude was selected to simulate a typical in vivo compression force, which may be expected to occur during walking (Nachemson 1966, Schultz and Andersson 1981). The loads were applied via a roller positioned 80 mm anterior to the frame of the fixator, i.e., approximately through the center of the L4 vertebral body (Figure 1). The axial displacement at the load application point was recorded as an indicator of anterior column motion. The average and range of the axial displacement for the 9th load cycle (i.e., the last complete cycle) in each specimen were calculated (Figure 2).

The axial displacements were compared using a Repeated Measures Analysis of Variance and post-hoc Scheffe's F-test. Specifically, the post-hoc comparisons made with the Scheffe's F-test were: 1) intact to neutral ESF, 2) neutral ESF to distracted ESF, and 3) neutral ESF to compressed ESF. Statistical significance level was taken to be $p < 0.05$. Parametric analysis was utilized, since the data distributions were not particularly skewed and Shapiro-Wilks' W-test was not significant in all groups.

Results

The axial displacement-time curves for one typical specimen in all test configurations are illustrated in Figure 3. All specimens showed essentially the same behavior, since the axial displacements were much larger when the fixator was distracted than any of the other test configurations. The analysis of variance showed that the ranges of motion between the four groups were different ($p = 0.001$) and that the average motions were also different ($p = 0.003$) (Table).

External fixation in the neutral position resulted in a 9% smaller average axial motion than intact and an 11% smaller range. However, these differences were

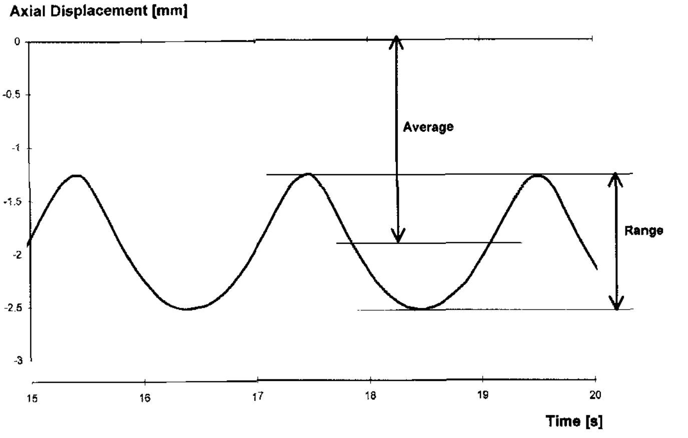

Figure 2. The 9th cycle was selected for analysis of the axial displacement data. The range of the axial displacement was defined, as well as the average displacement in the entire cycle.

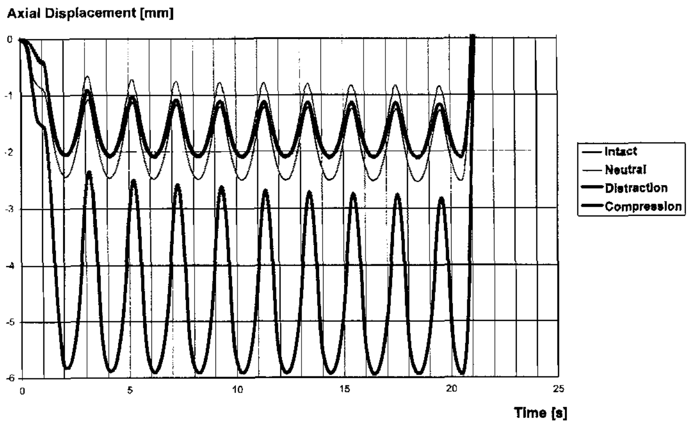

Figure 3. Typical axial displacement-time curves of the 4 test configurations in the entire test.

not significant (average p = 1.0; range p = 1.0, Scheffe's F-test). The axial motion with the fixator in distraction had a 50% larger average and 77% larger range than in the intact condition. Both the average and the range in distraction were greater than in all other conditions, including the neutral fixation (average p = 0.01; range p = 0.007). The least axial displacement was recorded when the external fixator was compressed, where the average was 11% less than intact and the range 22% less than intact. The effect of fixator compression did not change the axial displacement from the neutral condition (average p = 1.0; range p = 0.9) or from that of the intact specimen (average p = 0.9; range p = 0.7).

Sagittal plane rotations calculated from the Optotrak data were generally small (i.e., less than 2 degrees) under this compressive loading regime.

Discussion

In clinical practice, the preoperative external spinal fixation test is a valuable diagnostic tool in the assessment of a selected group of low-back pain patients, both in

Axial displacement of the load application point for all specimens during the 9th load cycle in each testing condition. The range is the amplitude for the 9th cycle while the average is the mean offset from an unloaded state, see Figure 2. For both the range and the average, the motion in the distracted state, as marked by [a], was significantly greater than the other 3 states. No other significant differences were observed

Spec	Range, mm				Average, mm			
	Intact	Neutral	Distracted	Compressed	Intact	Neutral	Distracted	Compressed
1	1.3	1.1	1.7	0.9	1.3	1.1	1.7	1.3
2	1.6	1.4	3.6	1.4	2.3	1.5	2.9	1.8
3	1.4	1.4	2.1	1.3	1.5	1.7	2.4	1.6
4	1.6	1.3	1.7	1.1	1.7	2.2	2.9	1.4
5	1.3	1.2	3.1	1.0	1.9	1.5	4.4	1.6
Mean	1.4	1.3	2.5 [a]	1.1	1.7	1.6	2.9 [a]	1.5
SD	0.2	0.1	0.9	0.2	0.4	0.4	1.0	0.2

predicting the result of a possible fusion, as well as in selecting the proper fusion level/s. Undoubtedly, since its result is dependent on the subjective information given by the patient, it may be affected, at least partly, by psychological factors. Neurophysiological and biochemical mechanisms have been proposed as explanations of the pain relief. However, the immediate relief of symptoms sometimes observed after the application of an external fixator also suggests other underlying mechanisms, such as the increased stability of the painful segment.

It is important to note that our investigation concerns only axial compressive loading of the spinal construct. The application of non-axial forces and bending moments might produce different results.

Although our findings do not reveal the mechanical basis underlying pain relief achieved during a preoperative external fixation test, some possible explanations can be discussed. The discs of the specimens tested here were assessed radiographically and macroscopically, as being from mildly to moderately degenerated. The behavior of more degenerated specimens might therefore be somewhat different. Furthermore, several anatomical factors, e.g., reduction of a degenerative slip or a protruding disc and nerve root decompression by distraction of the foramen, may have an effect in a clinical situation.

We found that the external fixator does not reduce anterior column motion under axial compressive loads, which is probably due to the large posterior moment arm of the construct. In fact, the external fixator in distraction results in greater anterior column motion when compared to the intact segments. We believe this is caused by distraction of the facet joints which, in this configuration, become unable to resist the compression loads applied. Accordingly, the external spinal fixator in compression results in the least axial displacement, probably with the same mechanism, i.e., by compressing the facet joints. Beyond the facets, it is also possible that the fixator distraction increases the disc height, which may result in a more flexible anterior column.

The various testing configurations were achieved by adjusting all three longitudinal threaded bars to distraction and compression, respectively. This differs from the original concept of Magerl (1982) in the treatment of thoracolumbar fractures where he suggested prestressing the fixator with the middle rod. It would be worthwhile to investigate whether this technique produces different results. However, we would expect findings very similar to those we observed.

We chose to span two intervertebral levels with the fixator, instead of one due to the commonest clinical situation at our institution. This would not alter the findings, since the axial compressive force we applied produces a constant bending moment on the fixator. The only difference would be that the overall displacement across all testing conditions would be double when two levels are included.

As a measuring point, the load application point at the top of the specimen was chosen. We believe this to be a good measure of the overall stiffness of the system. The intact axial displacements indicated a maximum motion of about 2.5 mm for 600 N of compressive load. This is consistent with the literature, where axial disc stiffnesses of 500–1000 N/mm have been reported (White and Panjabi 1990). For a three-disc complex with these stiffnesses, one would expect maximum axial motion to range from 1.8 to 3.6 mm (e.g., $3 \times 600/500 = 3.6$ mm). Moreover, as the conditions remained the same throughout the testing in all four configurations, changes in axial displacement are bound to represent changes in the fixed segments, whereas the displacement of the one free segment above remains the same in all phases.

One limitation of any in vitro study is the lack of muscular activity. Regarding the results of our study, additional stabilization of the segments supplied with the fixator would require continuous activity of the spinal musculature. This is hardly true in vivo, and would not, as such, affect the overall axial displacement.

Our findings are consistent with those reported in the literature. In their study on the in vivo effect of external fixation using the RSA method, Axelsson et al. (1996) claimed significant changes due to ESF in all directions. However, they included no statistical analysis of their data and such analysis shows that, in the vertical direction, the ESF did not stabilize significantly (paired t-test: $p = 0.2$; Wilcoxon test: $p = 0.3$). Loosening of the ESF did not increase the motions (paired t-test: $p = 0.1$, Wilcoxon test: $p = 0.1$). In their study, the anterior-posterior translations were reduced due to the ESF ($p < 0.05$). Thus, our results are, in fact, consistent with those of Axelsson et al.

Further, our results are similar to those of Stalder et al. (1996), who also showed that the external spinal fixator has a very low axial stiffness. They concluded that the effect of isolated segmental distraction in pain relief has probably been overestimated. Our study broadens our knowledge by showing increased lumbar spine flexibility after fixator distraction.

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