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Three-dimensional evaluation of lumbar orthosis effects on spinal behavior

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Abstract—The effects of the lumbosacral Lumbostab orthosis on intervertebral mobility, spinal geometry, and the geometrical deformations of discs have been investigated with a three-dimensional (3-D) reconstruction technique of the lumbar spine. Positions studied are neutral standing, maximal flexion, extension, left lateral bending, and left axial rotation. Results from this preliminary study indicate that the orthosis has a tendency to reduce vertebral mobility and discal deformations mainly at the upper segments (L1–L3), while it seems to increase vertebral displacements and discal deformations at the lower levels (L4–S1).

Key words: *biomechanical effects, discal deformations, lumbar orthosis, 3-D reconstruction, vertebral mobility.*

INTRODUCTION

Eighty percent of the population experiences severe low-back pain (LBP) once in their life (1,2). In fact, the problem of LBP remains at epidemic proportions. Expenditures for lost work time, medical diagnosis and treatment, worker's compensation, and so forth, resulting from back injuries are estimated at $16 billion per year (3). Bracing is one of the most common modalities of treatment used for a variety of conditions affecting the spine. While there is little strong scientific evidence that lumbar orthoses are clinically effective, retrospective studies have documented device acceptance and symptom improvement on 30–80 percent of wearers (4). The relief of LBP while wearing lumbar orthoses could be related to the limitation of spinal movements, to sitting and standing in better posture (5,6), or to the increase of intra-abdominal pressure allowing a proportion of the body load to be transmitted through the abdomen rather than the spine (7).

Several efforts have been made in the past to investigate the mechanical effects of spinal braces on the intervertebral motions (6,8–10), spine gross motions (11–13), myoelectric activities of trunk muscles (14–16), intra-discal pressures (15,17), and intra-abdominal pressures (15,17,18). Norton and Brown inserted pins into lumbar vertebra spinous processes and found small effects on intersegmental motions in flexion and extension (6). The authors stated that rigid braces increased motions in the lumbosacral segment, an observation later confirmed by a different study involving a similar technique to evaluate axial rotation (10). Using lateral radiographs, Fidler et al. investigated movements in flexion and extension and found greater reduction of vertebral mobility with a rigid orthosis than with an elastic corset (9). However, Axelsson et al. found that lumbar orthosis had little effect on intervertebral displacements when evaluated with a roentgen stereophotogrammetric technique (8). The influence of the orthosis on spinal gross motions was studied by Grew et al., who reported that rigid orthoses restricted

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spinal gross mobility more than an elastic brace (5). This was confirmed in a later study (12). However, Haig et al. reported that orthosis increased range of motion (ROM) of the trunk in flexion (11). Also, Parnianpour et al. observed that elastic orthosis had no effect on spinal ROM (13). Water et al. measured the myoelectric activities of several trunk muscles and found that the elastic brace had little or no effect, while the rigid orthosis increased myoelectric activities during rapid walking (16). Similar results were later obtained by other authors (14,15). The findings indicated that lumbar orthoses were inconsistently effective in reducing myoelectric activity, and, in many cases, signal levels were increased when the orthoses were worn. The influence of lumbar orthoses on intra-discal pressures was investigated by Nachemson et al., who found reduction of discal pressures with the orthosis (15,17). Morris et al. found that intra-abdominal pressures were unaffected by orthoses (18), and Nachemson et al. stated that intra-abdominal pressures were inconsistently affected by them (15,17).

The present study is an attempt to obtain data concerning the efficiency of a semirigid lumbar orthosis by means of a three-dimensional (3-D) reconstruction technique of the lumbar spine using biplanar radiographs (19). The study reports quantitative measurements of the effects of an orthosis on the intervertebral mobility, the global spine shape, and the disc geometrical deformations.

METHODS

A group of 28 young, nonimpaired volunteers participated in the study conducted at the Hôpital du Sacré-Coeur in Montreal. The group was composed of 12 men and 16 women with mean age, weight, and height of 24.8±4.9 years, 1.66±0.05 m and 54.0±7.5 kg, respectively. None had LBP or obesity; absence of these factors would optimize the work and efficiency of the lumbar orthosis. The radiographic experimental protocol of this investigation has been approved by the Research Ethics Committee of the hospital, and each subject was aware of the total amount of exposure.

The semirigid lumbosacral Lumbostab from Médicus Laboratories was used for the experiments (**Figure 1**). The back frame and the abdominal support of the Lumbostab are made of the same flexible thermoplastic material: the use of thermoplastic for the front apron is to provide greater intra-abdominal compression; Velcro™ is used for strapping between the different components. The orthosis was custom-fitted to each subject by an experienced orthotist.

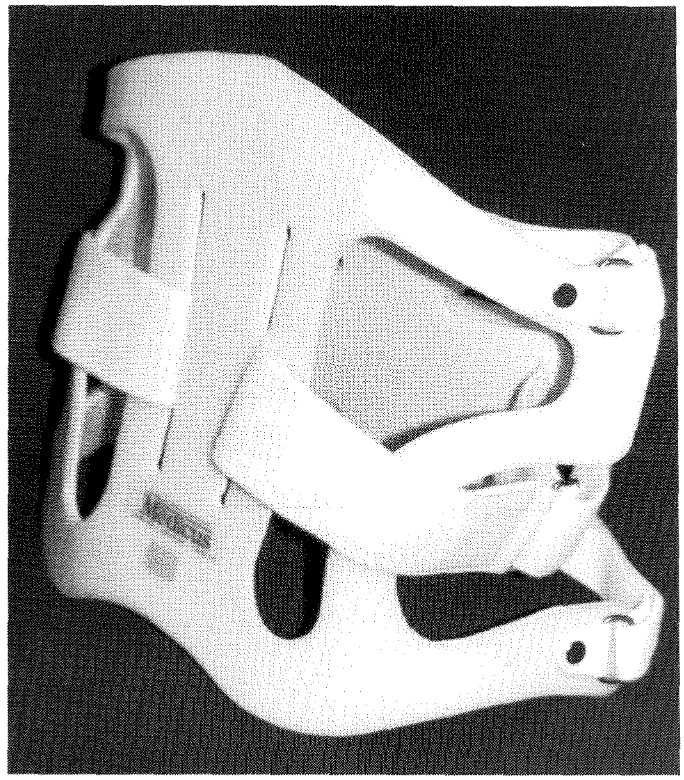

Figure 1.
The semirigid Lumbostab orthosis.

Positions studied were neutral standing, maximal flexion, maximal extension, maximal lateral bending to the left, and maximal torsion to the left. Each subject stood in a neutral position within a positioning device while antero-posterior (A-P) and lateral radiographs of the lumbar spine were taken simultaneously. Pairs of radiographs were also taken with the subject performing one of the above specified movements without the orthosis. The same radiographic sequence was repeated with the subject wearing the Lumbostab and performing the same movements, giving a total of eight radiographs for each individual. Thereafter, vertebral anatomic landmarks (the centroids of both inferior and superior endplates, top and bottom of both left and right pedicles, spinous process extremities, and 16 quasi-equidistant points identified on each singular endplate contour) were identified on the radiographs and digitized with a Calcomp system (**Figure 2**).

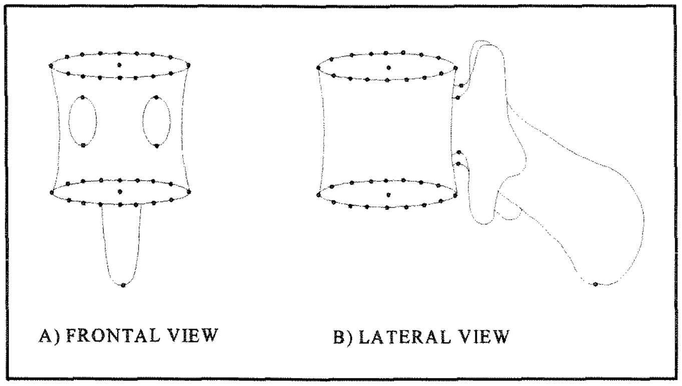

Figure 2.
Vertebral digitized landmarks on the frontal and lateral radiographs.

These digitized landmarks were reconstructed in 3-D by a calibration procedure and the Direct Linear Transformation (DLT) algorithm based on a least-squares optimization process (20). The calibration procedure and the DLT implicitly compute the geometric parameters of the radiographic configuration for the A-P and lateral views. Then, with the geometric parameters, the DLT could reversely calculate the most probable intersection location between the rays connecting the image points on the radiographs to the X-ray source locations. The intersection location gives the optimized 3-D position of the object point projected on both films. Therefore, given the 2-D coordinates of the vertebral landmarks on both A-P and lateral radiographs and the DLT parameters, it is possible to reconstruct these anatomical landmarks in 3-D. Using this technique, the endplate center, the pedicle, and spinous process landmarks were so reconstructed. The 3-D reconstruction of the vertebral endplate contour was performed with a slightly different technique developed by Huynh et al (19). Essentially, this technique consists of modeling the endplate as an elliptical geometry based on the DLT algorithm and an iterative projection-reprojection process in order to reconstruct the true endplate 3-D contour. A graphical representation of the 3-D reconstructed lumbar spine is given in **Figure 3.**

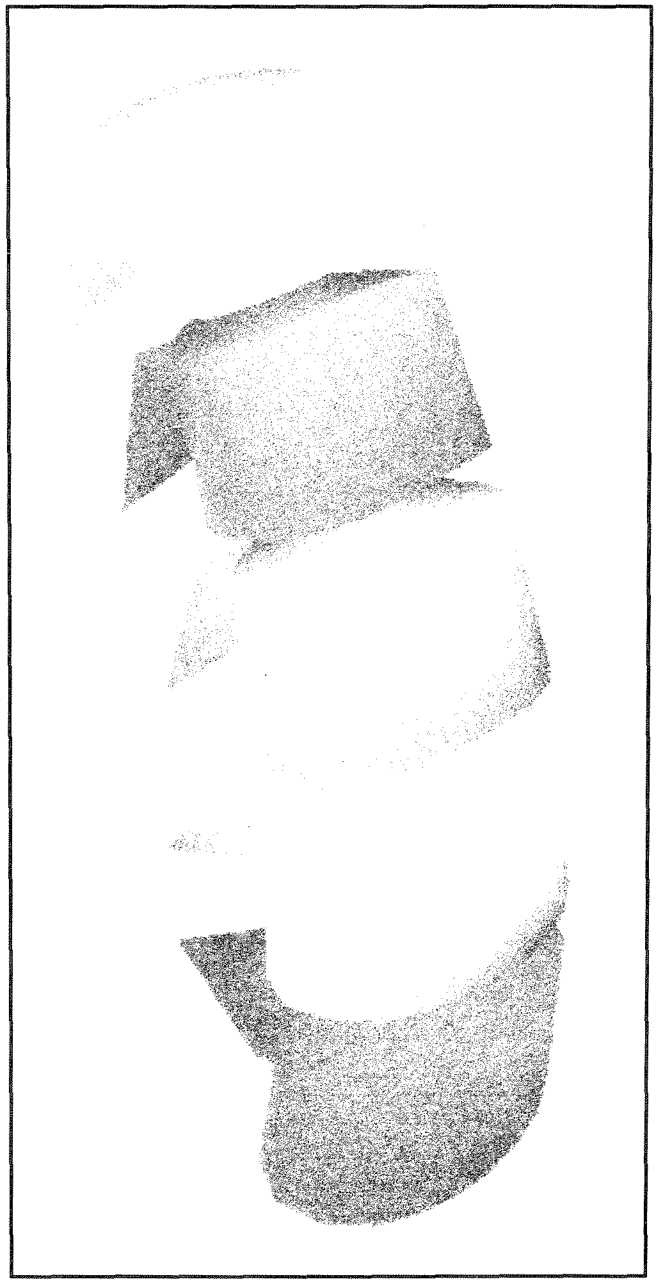

Figure 3.
3-D reconstruction of a lumbar spine.

By this method, the complete lumbar spine geometry was obtained in different positions with and without an orthosis. Clinical measurements have been developed in order to evaluate geometrical behavior of the orthosis on the lumbar spine. A local axis system was defined on each single vertebra in order to evaluate the geometrical relations between individual units. Thus, over the whole lumbar spine, the clinical measurements were defined with respect to these vertebral local axis systems. These measurements consist of intervertebral displacements, such as flexion-extension angles, lateral bending angles, axial rotations, A-P translations, and medio-lateral (M-L) translations. These intervertebral displacements were computed using the coordinates transformation method optimized by a least-squares technique. Essentially, given the 3-D coordinates of an object in two different positions, the method could compute the transformation matrix between the two positions that enclose the 6 degrees of freedom (3 rotations and 3 translations). Other measurements consisted of spinal lordosis (based on the Cobb technique), frontal imbalance, and discal deformations as defined below (see **Figure 4**):

1. Spinal lordosis is defined by the angle formed between two lines perpendicular to the spinal curve and passing through the centers of L1 superior endplate and L5 inferior endplate, respectively. The spinal curve was modeled with a second order polynomial, fitted by least squares through the endplate centers.
2. Frontal imbalance is defined by the angle between the line passing through the endplate centers and the vertical gravitational line. The line, which passes by the endplate centers, was also fitted through the points with the least squares technique.
3. Discal stretching indicates the maximal elongation of the intervertebral disc given by the longest 3-D distance separating two adjacent endplates along their contours. As each endplate contour was modeled by a set of 20 equidistant points, it was possible to compute the longest 3-D distance between each pair of corresponding points.
4. Discal squeezing indicates the maximal compression of the intervertebral disc, which is given by the shortest 3-D distance separating the two adjacent endplates along their contours. As each endplate contour was modeled by a set of 20 equidistant points, it was possible to compute the shortest 3-D distance between each pair of corresponding points.
5. A-P and M-L shifting refers to horizontal elongation of the disc in the A-P and M-L planes, respectively. The shifting is given by the longest projected (2-D) distance between pairs of corresponding points on adjacent endplates, respectively, in those planes.
6. Torsional shearing indicates the angular deformation of the intervertebral disc with respect to the vertebral transverse plane. The shearing is given by the angular difference, in the transverse plane, between two adjacent vertebral endplates.

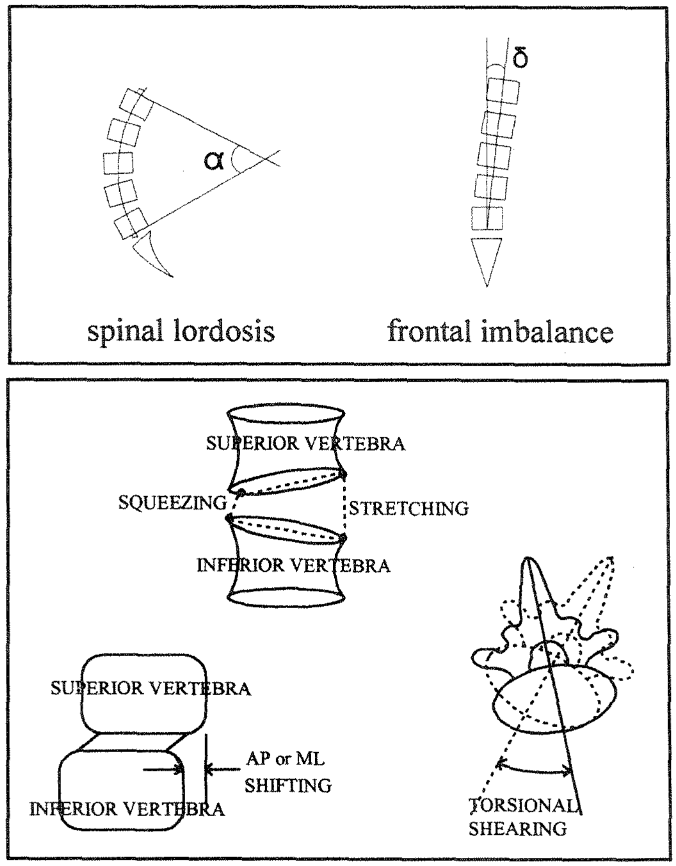

Figure 4.
Clinical measurements of the global spine geometry (top). Geometrical deformations of the intervertebral discs used as clinical measurements (bottom).

RESULTS

Lumbostab Effects on the Intervertebral Displacements

The Lumbostab orthosis affected principal vertebral displacements in maximal flexion, extension, left lateral bending, and left axial rotation.

In flexion, the orthosis tends to reduce A-P translation at all anatomical levels and A-P rotation mainly at L1-L4 (**Figure 5**). Maximum reductions of vertebral displacements are 8 mm in translation and 5° in rotation. The extension motion is characterized by negligible effects on A-P translations and rotations at almost all levels (**Figure 6**). However, the Lumbostab seems to increase intervertebral rotation at the lumbosacral joint (9°).

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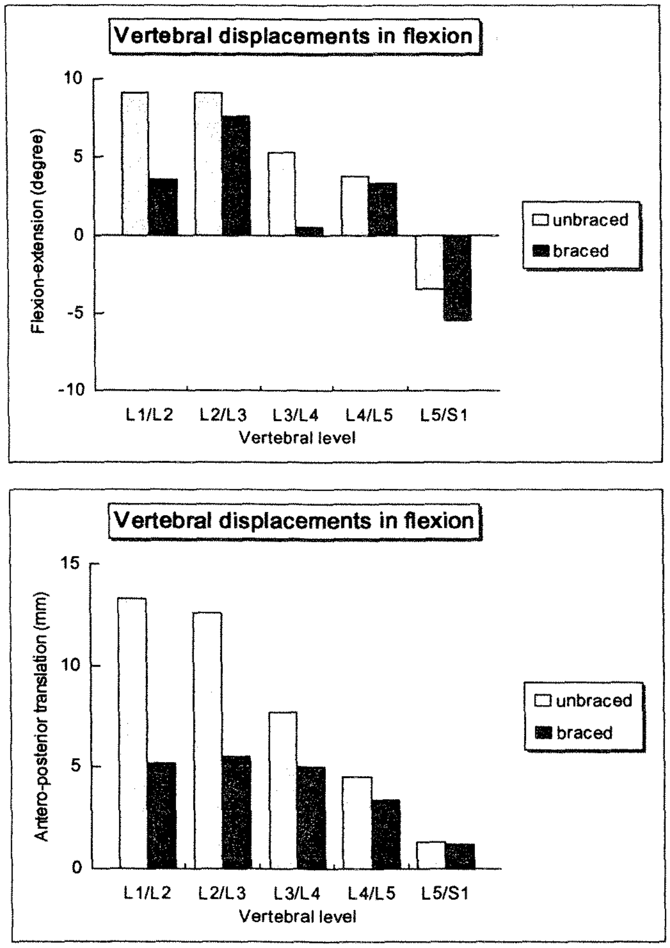

Figure 5.
Lumbostab effects in the maximal flexion.

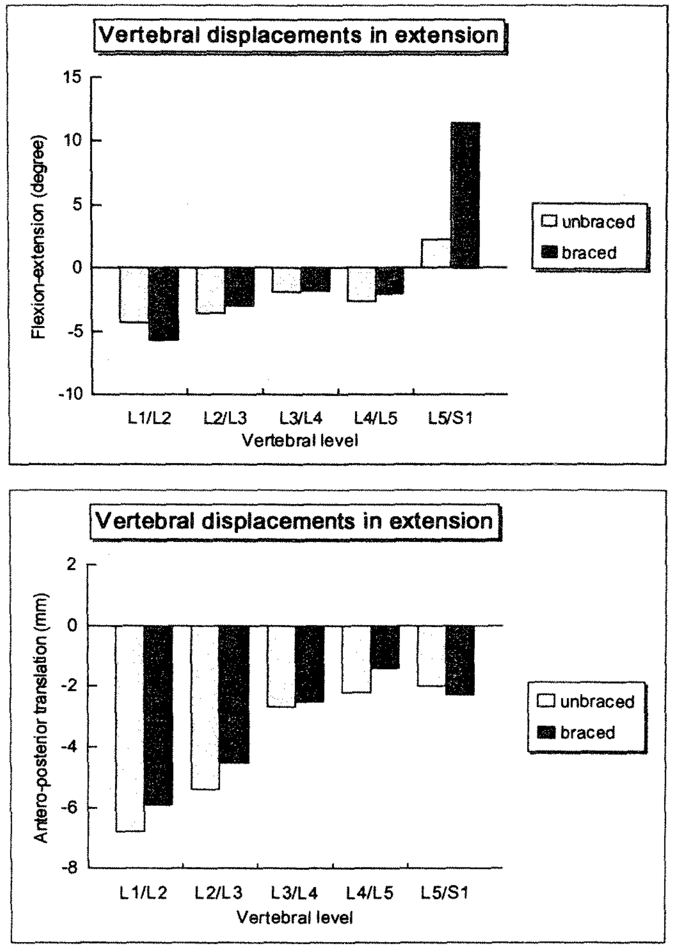

Figure 6.
Lumbostab effects in the maximal extension.

Concerning left lateral bending, reductions on intervertebral displacements occur at the upper levels (L1–L3), while some increases have been found at the lower segments (L4–L5), as shown in **Figure 7.** Mean reductions observed are about 3 mm in lateral translations and 3° in frontal rotations at L1–L3 to increases of 1 mm and 2° at L4–L5. Concerning torsion movement, the Lumbostab seems to have inconsistent effects, varying from reduction to amplification, on the vertebral mobility (**Figure 8**). The same tendency is observed for the lateral bending movement even if the orthosis tends to increase this motion at L5–S1. Generally, increases and reductions vary between 0–2° for the lateral bending for all levels. For the M-L translation, the Lumbostab tends to reduce vertebral mobility at the upper levels (L1–L4) between 1 to 5 mm.

Lumbostab Effects on the Global Spine Shape

Table 1 presents the effects of the Lumbostab orthosis on the lumbar lordosis and frontal imbalance in different positions.

The results seem to indicate that the orthosis increases the lordotic curve in flexion (4°) and left lateral bending; whereas, in extension and left axial rotation, the lordosis angle has been reduced (4°). For the frontal imbalance, the orthosis shows increases in flexion; whereas, reductions occur in extension, left lateral bending, and left axial rotation.

Lumbostab Effects on Disc Geometrical Deformations

The orthosis affected discal deformations in various ways. In flexion (**Table 2**), the Lumbostab has a

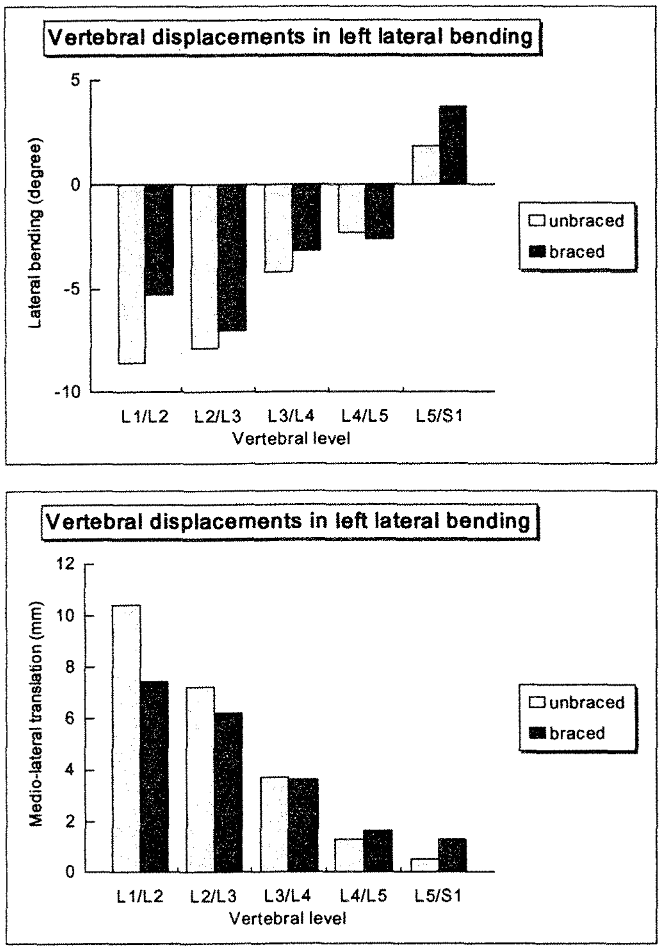

Figure 7.
Lumbostab effects in the maximal lateral bending to the left.

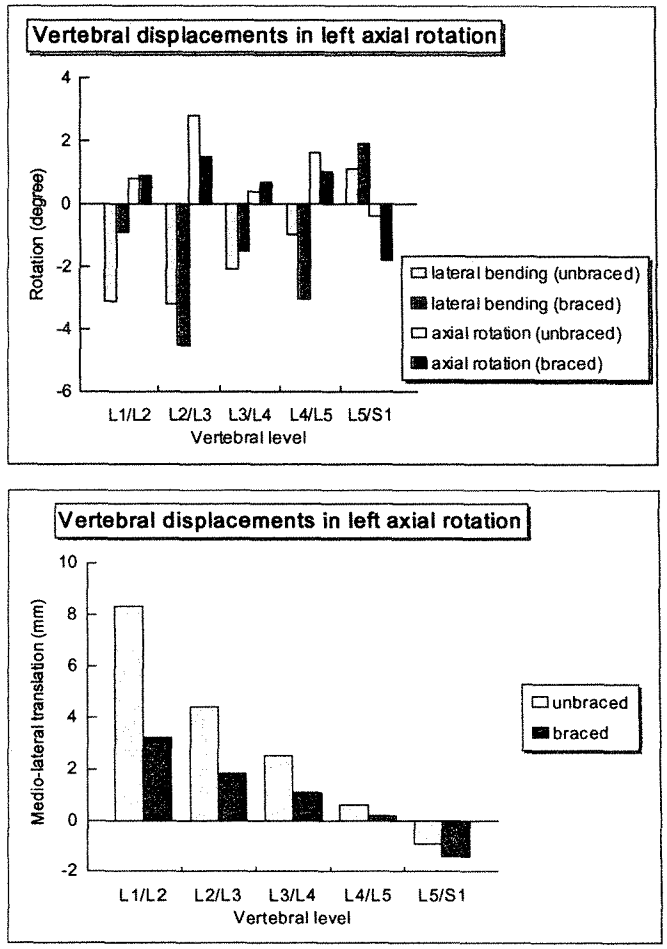

Figure 8.
Lumbostab effects in the maximal axial rotation to the left.

tendency to squeeze vertebral discs, resulting in a slight reduction of discal stretching and increase of discal squeezing (3 mm). In addition, the Lumbostab tends to increase discal shifting at L3–L5 in both frontal and lateral views (2 mm).

In extension (**Table 3**), the orthosis seems to push apart adjacent vertebrae, as opposed to the flexion movement. This tendency results in a small amplification of stretching and reduction of squeezing at different levels. In addition, slight reductions of discal shearing also occur (2°). In left lateral bending (**Table 4**), the orthosis seems to have negligible effects on discal stretching, squeezing, and shifting, while slight reductions occur in discal shearing at lower levels. Finally, in left axial torsion (**Table 5**), disc frontal and A-P shifting are slightly reduced with the orthosis at L1–L4, while discal shearing is amplified at L3–L5 levels.

DISCUSSION

The results obtained in this study have been compared to others and we have found some similarities and differences in the effects of semirigid and rigid orthoses. Thus, on the vertebral mobility in flexion, the semirigid orthosis has a tendency to reduce vertebral mobility similarly to the rigid braces evaluated in the past by Fidler et al. (9). In extension, both the Lumbostab and the rigid braces tend to increase vertebral displacements at the lumbosacral segment (6). In axial torsion, the Lumbostab is found to have inconsistent effects similar to those of rigid braces, varying from reduction to increase of movement between adjacent levels (10). In general, our results indicate that the Lumbostab orthosis has a tendency to

Table 1.
Effects of the Lumbostab on the global spine geometry.

Position	Lordosis (°)	Reduction of Lordosis (°)	Frontal Imbalance (°)	Reduction of Frontal Imbalance (°)
Flexion (n=6)	23.5±13.9	4.2±8.3*	0.5±6.3	2.6±5.3*
Extension (n=7)	44.3±14.1	0.6±6.5	0.8±3.5	1.7±3.8
Lateral bending to the left (n=7)	33.8±10.8	0.4±4.1*	7.5±9.5	0.5±3.2
Axial rotation to the left (n=7)	33.2±4.3	1.6±2.0	2.4±3.0	1.3±3.6

All measurements = Mean ± SD; * indicates an amplification.

Table 2.
Lumbostab effects on discal deformations in maximal flexion.

Level	N	Stretching	Squeezing	M-L Shifting	A-P Shifting	Torsional Shearing
L1/L2	5	1.0±2.0	2.7±5.2*	0.0±1.3	0.0±2.2	0.5±3.6*
L2/L3	5	0.1±1.4	0.3±1.2*	0.0±2.1	0.6±1.3*	0.9±2.2
L3/L4	6	1.6±2.8*	1.3±1.8	0.3±0.4*	2.3±3.2*	0.9±2.5*
L4/L5	6	0.8±2.3	03.±2.2*	0.3±0.6*	1.1±3.0*	0.3±2.9

M-L = medio-lateral; A-P = antero-posterior; measurements in mm ± SD; shear in ° ± SD; * indicates an amplification.

Table 3.
Lumbostab effects on discal deformations in maximal extension.

Level	N	Stretching	Squeezing	M-L Shifting	A-P Shifting	Torsional Shearing
L1/L2	7	0.7±1.6*	0.5±0.9	0.6±0.9*	0.9±1.0*	1.8±2.8
L2/L3	7	0.5±0.9*	1.1±1.3	1.0±0.8*	1.1±1.5*	0.2±3.0*
L3/L4	7	1.0±1.2	0.0±0.8	0.2±0.4*	0.2±0.5*	0.6±2.4
L4/L5	7	0.4±1.5*	0.3±0.8	0.0±1.1	0.5±1.2*	0.1±1.7

M-L = medio-lateral; A-P = antero-posterior; measurements in mm ± SD; shear in ° ± SD; * indicates an amplification.

Table 4.
Lumbostab effects on discal deformations in maximal lateral bending to the left.

Level	N	Stretching	Squeezing	M-L Shifting	A-P Shifting	Torsional Shearing
L1/L2	7	0.3±1.1	0.1±1.0*	0.0±0.8	0.0±0.1	0.2±1.7*
L2/L3	7	0.8±1.1	0.2±1.1	0.0±2.5	0.0±0.7	0.8±1.9
L3/L4	7	0,.2±1.0*	0.2±1.0	0.0±3.2	0.2±0.4*	1.1±1.1
L4/L5	7	0.2±2.1	0.2±2.0*	0.1±0.3*	0.1±0.3*	0.6±1.5

M-L = medio-lateral; A-P = antero-posterior; measurements in mm ± SD; shear in ° ± SD; * indicates an amplification.

Table 5.
Lumbostab effects on discal deformations in maximal axial rotation to the left.

Level	N	Stretching	Squeezing	M-L Shifting	A-P Shifting	Torsional Shearing
L1/L2	7	1.2±1.4	0.9±1.4*	0.7±1.1	0.2±1.5	0.1±1.3*
L2/L3	7	0.2±1.2	0.0±1.8	0.2±1.0	0.3±1.0	0.8±3.0
L3/L4	7	0.2±0.9*	0.2±1.2	0.4±0.7	0.4±0.7	0.3±1.9*
L4/L5	7	1.0±0.7	0.9±1.5*	0.2±0.3*	0.2±0.3*	0.6±1.7*

M-L = medio-lateral; A-P = antero-posterior; measurements in mm ± SD; shear in ° ± SD; * indicates an amplification.

reduce intervertebral motions at the upper segments (L1–L3), while increasing them at the lower levels (L4–S1). In addition, it has a tendency to straighten up the global spine shape, probably as a result of an increase of abdominal pressure, therefore reducing spinal lordosis and frontal imbalance in most positions (17,18). Concerning the discal deformations, in flexion, the Lumbostab has a tendency to squeeze vertebral discs. This phenomenon has also been observed in the past, where wearing a brace or orthosis might increase discal pressure from 10 to 20 percent (15). In full extension, the Lumbostab has a tendency to relieve spinal squeezing, as observed by Nachemson et al. on a different orthosis (15). In left lateral bending, the Lumbostab seems to have negligible effects on the reduction of discal deformations. Finally, in left axial torsion, discal squeezing occurs with the Lumbostab, as shown by the reduction of discal stretching and increase of discal squeezing. These last results are in contradiction with those from Nachemson et al. who found discal decompressions with an orthosis (15).

In general, the results obtained in this study are in agreement with those already published (7,15); however, it is difficult to make accurate comparisons, because different evaluation techniques have been used and different lumbar supports have been investigated (biomechanical effects vary considerably from one orthosis to another). Lumbar disc squeezing could be reduced when wearing an orthosis in some positions, but in others, discal squeezing could be increased with a support. In addition, general findings suggest that the Lumbostab is mainly effective at the upper levels and less so at the lower segments in the reduction of intervertebral mobility and discal deformations. This phenomenon might be related to the fact that the orthosis is conceptually short and has a limited area of contact at the lumbosacral segment, leading to the presence of unproductive effects at the lumbosacral segment. However, this study has demonstrated that a semirigid orthosis could produce effective controls on vertebral displacements and discal deformations at specific areas. Work is in progress to design a new generation of lumbar orthoses that would have dynamic control of the whole lumbar spine.

CONCLUSION

The biomechanical effects of the lumbosacral Lumbostab orthosis have been investigated with a 3-D *in vivo* and personalized reconstruction technique on 28 nonimpaired subjects. The results show that the Lumbostab has a tendency to reduce intervertebral mobility and discal deformations at L1–L3 but to increase them at L4–S1. A new orthosis design is being developed in order to control the lumbar spine dynamically. The 3-D reconstruction technique and clinical measurements presented in this paper represent accurate tools for an *in vivo,* 3-D evaluation of the geometrical behavior of orthoses on the lumbar spine.

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