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Assessment of spinal movement reduction by thoraco-lumbar-sacral orthoses

Peter J. van Leeuwen, MD; Renate P. Bos, Msc; José C. Derksen, Msc; Jaap de Vries, PhD, MD
Rehabilitation Center "Blixembosch", Eindhoven, The Netherlands, Roessingh Research and Development, Rehabilitation Center "Het Roessingh", Enschede, The Netherlands, Department of Biomedical Physics and Technology, Faculty of Medicine and Allied Health Sciences, Erasmus University Rotterdam, The Netherlands

Abstract—Bracing is a common modality in treating spinal fractures. Its objective is to reduce spinal movements and to stabilize the fracture. Until now, factual insight into the movement-reducing properties of Thoraco-Lumbar-Sacral Orthoses (TLSOs) has been missing. Two common TLSOs (e.g., Jewett and Voigt-Bähler) were tested for their movement-reducing properties in two small groups of healthy subjects. In the first study, maximal gross spinal movements, with and without a TLSO, were measured by means of a Portable Posture Registration Set (PPRS) in three different planes. In the second study, maximal segmental vertebral movements in the regions T10 to L4 were measured via X-rays. With few notable exceptions, wearing a TLSO, as measured by the PPRS and X-ray techniques, significantly reduced the segmental as well as gross spinal movements. However, the amount of movement reduction varied greatly from subject-to-subject and was sometimes small. Unfortunately, data are lacking on the amount of movement reduction that is clinically relevant.

Key words: *movement analysis, orthoses, spine, thoracolumbar fractures*

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Address all correspondence and requests for reprints to: Peter JCM van Leeuwen, Rehabilitation Center "Blixembosch", PO Box 1355, 5602 BJ Eindhoven, The Netherlands.

INTRODUCTION

The management of fractures in the thoracolumbar region of the spine is still controversial. Non-operative treatment was advocated until the late 1970s; however, with the increasing availability of more effective spinal instrumentation, there has been a change toward operative treatment. Comparison of both treatment modalities remains difficult because classification and follow-up measurements are not yet uniform (1–10).

Bracing is a common modality in treating spinal fractures. It allows early mobilization of patients with conservatively treated spinal fractures, where intrinsic stability is thought to be insufficient to withstand physiological load (1,3–5,7,9,11). Orthoses are also used to protect internal fixation during mobilization in the postoperative stage (1). The site of action of an orthosis needs to be located mainly on the thoracic (T12) and lumbar (L1 and L2) levels, because 63 percent of thoraco-lumbar-sacral fractures involve these vertebrae (6,8).

Thoraco-lumbar-sacral orthoses (TLSOs) are among the orthoses mentioned. These TLSOs have a rigid construction and, therefore, they should not only correct the posture but also reduce the mobility of the thoracolumbar spine (12). The orthosis is aimed at forcing the spine into a slightly hyper-extended alignment, thereby unloading the vertebral bodies. In clinical practice a reduction of the flexion-extension movement has also been noted.

No information exists, however, about the amount of movement reduction due to use of TLSOs. Research has already shown reduction in movement of the spine using thoracolumbar orthoses (13–20), but these studies were mainly focused on lower levels of the spine (14,15,18). The use of TLSOs is thought to lead to shorter hospital stay and diminished morbidity, facts which should make bracing cost-effective. To make the prescription of TLSOs more rational and justified, additional knowledge about the effects of these orthoses is necessary. Without these insights, prescribing a thoracolumbar orthosis may present a risk to the patient of malunion or nonunion of the vertebral fracture, or loss of reposition after internal fixation. This study intends to provide these insights.

To establish the mobility-reducing properties of thoraco-lumbar-sacral orthoses, analysis of the movement of the spine is necessary (21). A spinal fracture causes segmental problems. The TLSO is intended to shift the superencumbent load from the vertebral bodies, posteriorly, to place greater pressure on the transverse processes. This is only relevant in vertebral body fractures. Furthermore, the orthosis aims at reducing the mobility of the total spine as to unload the most vulnerable parts as much as possible. Two studies were carried out in order to determine the presumed restriction of movement due to the two currently applied types of thoraco-lumbar-sacral orthoses, e.g., the Jewett and the Voigt-Bähler orthosis.

The research objective of both the first and second study is to determine the extent of movement reduction of the thoraco-lumbar spine when TLSOs are used. However, study one addresses gross spinal movements in maximal flexion and extension, lateral bending and rotation, while study two determines the effect on segmental mobility in maximal flexion and extension.

METHODS

Subjects

Eleven subjects, total, were included in the studies. Subject inclusion criteria were: male, volunteer, less than 40 y of age, no history of back disorders, and a normal pattern of spine movements on clinical examination. Exclusion criteria were: a history of back pain within the last 3 y, a history of stomach, abdominal, heart or lung disorders that would interfere with wearing a TLSO. The subjects were also excluded if their body fat percentage was more than 30 and if they had allergies to plaster materials (22). The criteria were chosen to prevent bias due to gender, fitting differences in those who were overweight, and movement aberrance due to back problems or older age.

The first study included 6 healthy male subjects with an average age of 31 y. The second study was performed on a different sample of 5 healthy male subjects with an average age of 35 y. **Table 1** contains characteristics of the subjects.

Table 1.
Subject characteristics: averages (ranges).

	Study 1		Study 2	
Age (yr)	30.6	(24.9-38.9)	34.8	(31.1-39.7)
Length (m)	1.85	(1.76-1.96)	1.77	(1.74-1.79)
Weight (kg)	82.3	(70-109)	69.6	(68-72)

Because the studies took place at different points in time, it was not possible to conduct simultaneous studies on the same subject sample.

Orthoses

The TLSOs tested were: a modular hyperextension orthosis according to Voigt-Bähler (**Figure 1**), and a hyperextension orthosis according to Jewett (**Figure 2**).

Although the construction of the Voigt-Bähler orthosis has an abdominal band to connect the sternal and the symphysal pressure-pads there is no attempt made to increase abdominal pressure. The Jewett orthosis leaves the abdomen completely free. Both TLSOs theoretically work according to the three point principle which applies pressure on bony prominences (11,12). The points of pressure are the sternum, os pubis anterior and the thoracolumbar junction posterior.

Both TLSOs are ready-made, modular systems and are available in several sizes. A qualified orthotist can easily adjust them to personal requirements. All TLSOs were fitted by the same well-trained orthotist several days before the measurements in order to give the subjects an opportunity to get used to the orthoses.

Measurement Instruments

First Study

Gross spinal movements were measured non-invasively using the Portable Posture Registration Set,

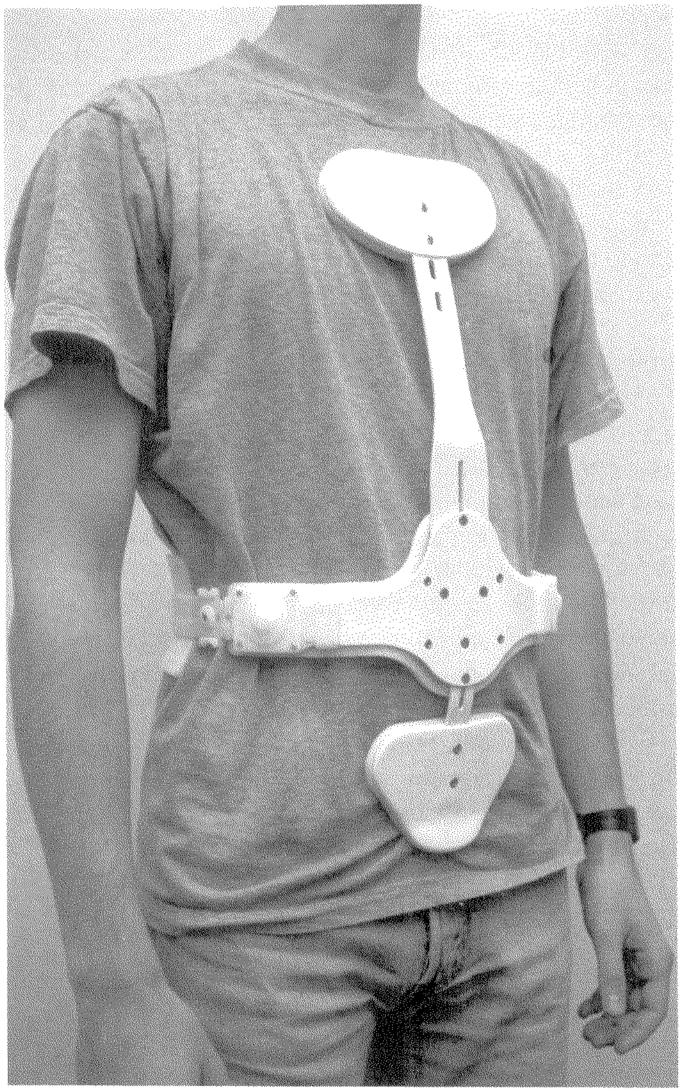

Figure 1.
Volunteer with a Voigt-Bähler brace.

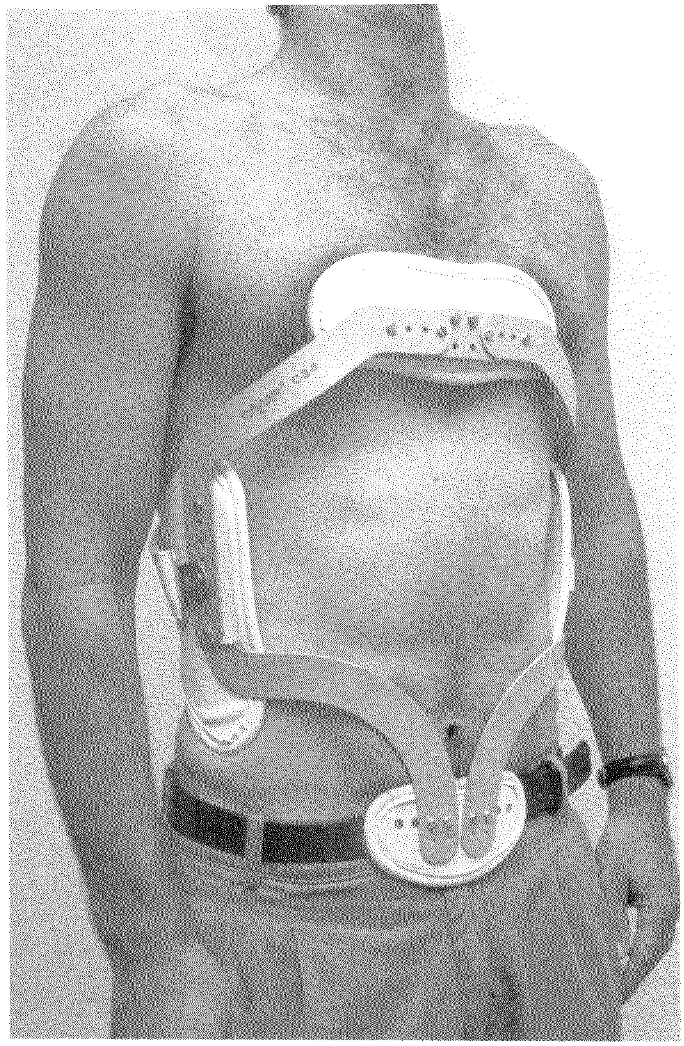

Figure 2.
Volunteer with a Jewett brace.

PPRS(23), developed at Erasmus University, Rotterdam, which is able to measure movements in different planes simultaneously. The measurements were continuous and data were collected using a portable data recorder, with a sample rate of 16 Hz. **Figure 3** shows the PPRS.

Postural change has two aspects: change of the position and change of the shape of the spine. The position of the trunk was measured in degrees by an inclinometer. The inclinometer was fixed on the skin at the level of L1 and measures the movements in the sagittal plane, forward and backward inclination.

The shape of the spine was non-invasively measured in sagittal, frontal and transverse planes by measuring the sagittal curvature, lateral flexion and torsion, respectively. Combined sagittal curvature and lateral flexion was established by measuring the change in length of the skin in mm. Two helical springs were connected at one end to a strain gauge-type force transducer. The accuracy of this device is 3–4 percent of the full range of 11 cm. For further details on the sensors see Snijders and van Riel (23). The helical springs were adjusted at both sides of the spine, with the top ends of the springs fixed at T9 level and the caudal end at the level of L4. Since most of the torsion in the thoracolumbar spine takes place in the thoracic part (68 percent), the thoracic spine was chosen for measuring the torsion (24). The torsionmeter is based on single turn

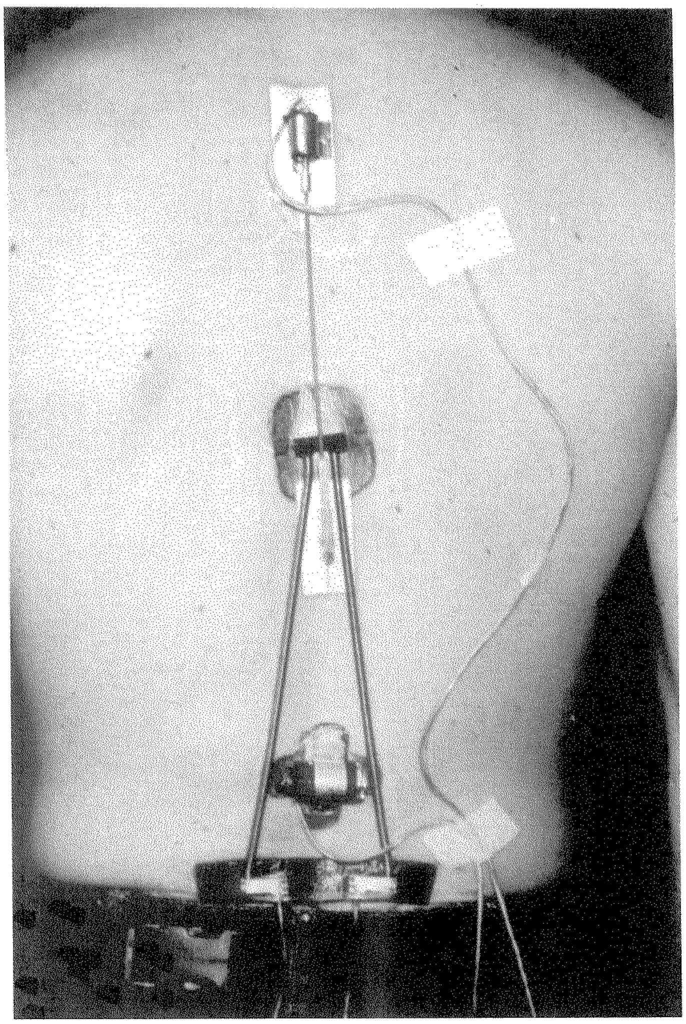

Figure 3.
The Portable Posture Registration Set applied to a volunteer.

potentiometers and measures the movements of the spine in the transverse plane. For practical reasons it could only be positioned to measure torsion from T3 to T9.

Because of the size of the inclinometer, space was created in the cushioning of the dorsal part of both orthoses, so the equipment could be applied and move freely underneath the orthoses. Because the frame of the orthoses remained intact, we presumed that these alterations did not interfere with the biomechanical properties of the orthoses (test-retest results, with and without the PPRS, did not differ from each other). The application of the equipment to the back of the subjects was done by one person, using bony landmarks and palpation to detect the correct sensor locations. For each subject, the upright posture was recorded upon which the device was then calibrated.

Second Study

Segmental vertebral mobility was measured by using lateral radiographs. A standardized technique of producing lateral radiographs of the thoracolumbar region T10–L4 in both maximum flexion and extension was used. The distance between the X-ray tube and the plate was fixed, so the anthropometric data of the subjects had to be within narrow limits (**Table 1**). Six radiographs were made, centered on the L1 vertebra, for each subject.

Investigation Procedure

First Study, PPRS

The subjects performed a standardized movement protocol. It included flexion/extension (in order to measure sagittal inclination as well as curvature) and left and right lateral flexion and rotation (in order to measure the torsion) in a standing position. Hip flexion was not controlled. All movements were supervised by the same person and were done maximally. Regarding the extent of the movement-reducing properties of the TLSOs, maximally performed trunk movements are most relevant (16). All examined movements were repeated twice in order to determine the intra-subject variation. Measurements were done on two consecutive work days. On each day, two measurements were made: one while wearing a TLSO, and one while not wearing a TLSO. The movement protocol was always performed in the same order; however, it was determined at random which type of TLSO and which condition (with versus without orthosis) was tested first. After the measurements, two sets of data without an orthosis (on consecutive working days) and one set of data with either TLSO (on the same day) were available.

Second Study, X-ray

All subjects performed a maximal flexion and a maximal extension from a standing position. Hip flexion was not controlled. Both positions were studied, first without TLSO, then with the Voigt-Bähler orthosis, and finally with the Jewett orthosis. Each volunteer acted as his own control. To minimize excessive radiation, off-centered radiographs were not repeated.

The flexion and extension radiographs were analyzed as follows. The L2 vertebra of the flexion radiograph was superimposed on the L2 vertebra of the extension radiograph. Along the left edge of the upper radiograph, a line was drawn on the radiograph underneath. Then, the L1 vertebra were superimposed, and, in the same manner, a line was drawn on the bottom radiograph. The angle between these lines represented the segmental mobility at the L1–L2 level. The segmental mobility at other levels was measured in the same way. The gross spinal movement was computed by a summation of the separate values on the different segmental levels.

Reproducibility of this method was examined by Tanz (20), who found the error to be within 2°. The intra-observer variation of the present study was assessed as follows. One person measured the radiographs several times with an interval of several weeks. The difference did not exceed 1°.

Statistics

First and Second Study

Test-retest reliability of the PPRS data was assessed by calculating the intra-class correlation coefficient between the data without TLSO, on two consecutive days, for the same subject. For further analysis, we used the mean of the first and second measurement. Test-retest reliability could not be assessed in the X-ray study, because only one measurement per circumstance was done.

The X-ray and PPRS study each reproduce absolute measurement data in cm or degrees. For reasons of comparability, the results of both studies were converted into percentages of movement reduction due to the orthoses.

A one-tailed, non-parametric, paired samples test—the Wilcoxon signed ranks test—was used to determine if there was a difference between the plus/minus orthosis conditions in either segmental or gross spinal movements. Differences between the two orthoses themselves were assessed by the two-tailed Wilcoxon signed ranks test.

Finally, a two-tailed Mann-Whitney test was used to assess the differences between corresponding results of the two studies on the group level. Because the two studies consisted of two different subject samples, it was not possible to calculate the correlation coefficient.

A probability value (p) ≤ 0.05 was considered significant.

RESULTS

First Study

Table 2 reports the correlation coefficients and p-values on the test-retest measurements without orthosis. As can be seen, the correlations for the torsionmeter and the inclinometer were high.

Table 2.
Correlation coefficients (p-values) of test-retest PPRS data without orthosis on consecutive days.

	Type of motion	Correlation (p-values)
Sagittal	Inclination (°)	0.7608 (p=0.079)
	Sagittal curvature (mm)	0.9456 (p=0.004*)
Transverse	Torsion (°)	0.7742 (p=0.436)
Frontal	Lateroflexion (mm)	0.8778 (p=0.021*)

*=significant with p<0.05.

Table 3 shows the absolute values of the sagittal movements (measured in degrees by the inclinometer and in mm change of length by the helical springs).**Table 4** shows the absolute values of the torsion and lateral movements. Also the percentage of movement reduction achieved by the orthoses is mentioned.

Technical problems were the cause of the few missing values in **Tables 3 and 4**. Except for one subject (sub-

Table 3.
Results of the gross spinal movement measurements by PPRS and percentage of movement reduction due to the TSLOs in the sagittal plane (inclinometer and helical springs).

	Inclination			Sagittal curvature		
	W	V	J	W	V	J
A	114.0	89.0 (-21.9)	87.0 (-23.7)	120.5	47.0 (-61.0)	33.0 (-72.6)
B	110.0	72.0 (-34.5)	80.0 (-27.3)	107.5	44.0 (-59.1)	41.0 (-61.9)
C	120.5	78.0 (-35.3)	99.0 (-17.8)	84.0	48.0 (-42.9)	51.0 (-39.3)
D	116.0	94.0 (-19.0)	82.0 (-29.3)	93.5	45.0 (-51.9)	50.0 (-46.5)
E	127.0	90.0 (-29.1)	98.0 (-22.8)	113.5	20.0 (-82.4)	64.0 (-43.6)
F	124.0	80.0 (-35.5)	81.0 (-34.7)	77.5	22.0 (-71.6)	--

Inclination in degrees (percent reduction); Sagittal curvation in mm (percent reduction); W=without orthosis; V=Voight-Bähler; J=Jewett; missing data caused by technical problems with the measurement equipment.

Journal of Rehabilitation Research and Development Vol. 37 No. 4 2000

Table 4.
Results of the gross spinal movement measurements by PPRS and percentage of movement reduction due to the TSLOs in the frontal and transverse plane (inclinometer and helical springs).

	Lateroflexion			Torsion		
	W	V	J	W	V	J
A	36.0	35.0 (-2.8)	33.0 (-8.3)	18.0	5.0 (-72.2)	--
B	70.0	69.0 (-1.4)	40.0 (-42.9)	24.0	--	37.0 (+54.2)
C	37.5	32.0 (-14.7)	36.0 (-4.0)	28.0	20.0 (-28.6)	--
D	55.5	45.0 (-18.9)	44.0 (-20.7)	39.5	26.0 (-34.2)	12.0 (-69.6)
E	65.0	32.0 (-50.8)	43.0 (-33.8)	25.0	18.0 (-28.0)	18.0 (-28.0)
F	37.0	18.0 (-51.4)	--	30.0	13.0 (-56.7)	8.0 (-73.3)

Lateroflexion in mm (percent reduction); Torsion in degrees (percent reduction); W=without orthosis; V=Voight-Bähler; J=Jewett; missing data caused by technical problems with measurement equipment.

ject B, transverse plane), all movements were reduced by wearing a TLSO. **Table 5** shows that the reductions in the range of movements in the sagittal and frontal planes were statistically significant.

Table 5.
P-values of the Wilcoxon signed ranks test according to differences between situations with and without orthosis (one tailed) and between the two orthoses (two tailed), with regard to PPRS evaluation.

Plane	Type of motion	V-W	J-W	V-J
Sagittal	Flexion/extension (°)	0.0139*	0.0139*	0.4618
	Flexion/extension (mm)	0.0139*	0.0216*	0.5879
Transverse	Torsion (°)	0.0216*	0.1367	0.1797
Frontal	Lateroflexion (mm)	0.0137*	0.0216*	0.8927

V=Voight-Bähler; J=Jewett; W=without orthosis; *=significant with $p<0.05$.

No differences were found between the orthoses. There was no significant reduction in the movements in the transverse plane (torsion) with the Jewett orthosis. The torsion measurements generally showed less consistency and were less reproducible than most other measurements. Furthermore, subject B had an increase in the movement in the transverse plane while wearing the Jewett orthosis compared to when not wearing it, influencing the group results.

Second Study

Table 6 presents the absolute data of the X-ray study at segmental levels and the percentage movement reduction in the sagittal plane due to the orthoses. Some radiographs were off-centered; therefore, some values could not be determined by the normal procedure. Instead, the missing data were calculated by means of both interpolation and extrapolation. The values in question are presented in brackets.

Nearly all levels and all subjects showed a reduction of sagittal movement while wearing an orthosis compared to not wearing one. Subject E, however, shows an increase in mobility at the T11–T12 and T12–L1 levels while wearing the Jewett orthosis. Looking at the separate radiographs, the orthosis seemed to increase the range of extension on subject E. Subject D also showed a slight increase in the range of extension at the T11–T12 level while wearing the Voigt-Bähler orthosis and at the L3–L4 level while wearing the Jewett orthosis. In the case of subject D, the values in question (**Table 6**)were extrapolated.

Table 7 shows the probability values (p-values) of a one-tailed Wilcoxon signed ranks test on the differences measured at each segmental level between the conditions with and without orthosis. Also, the two-tailed test results of the potential difference between the two types of orthoses are presented.

As can be seen, the difference between the two conditions (with versus without orthosis) is statistically significant at all segmental levels with the exception of T11–T12 in both the Voigt-Bähler and Jewett orthosis and T12–L1 in the Jewett orthosis. Again, these exceptions can be explained by the measurements on subjects D and E, showing an increase in mobility at these levels as mentioned in the previous paragraph. The difference between the two conditions on the overall Range of Motion of the trunk from T10–L4 is statistically significant for both orthoses.

Table 6.
Degree (percentage) of movement reduction in sagittal plane due to the TLSOs according to X-ray evaluation.

Region	O	Subj A	Subj B	Subj C	Subj D	Subj E
T10-11	**W**	4.0	1.0	[3.5]	[3.5]	6.0
	V	1.0	1.0	[1.5	[1.0	1.0
		(-75.0)	(-0.0)	(-57.1)]	(-71.4)]	(-83.3)
	J	0.0	1.0	1.0	[1.0	3.0
		(-100.0)	(-0.0)	(-71.4)	-(71.4)]	(50.0)
T11-12	**W**	10.0	3.0	2.0	2.0	1.0
	V	5.0	2.5	2.0	[2.5	1.0
		(-50.0)	(-16.7)	(-0.0)	(+25.0)]	(-0.0)
	J	4.0	3.0	0.0	1.0	6.0
		(-60.0)	(-0.0)	(-100.0)	(-50.0)**	(+500.0)
T12-L1	**W**	8.0	10.0	11.0	8.0	1.0
	V	7.0	2.0	4.0	1.0	1.0
		(-12.5)	(-80.0)	(-63.6)	(-87.5)	(-0.0)
	J	6.0	6.0	8.0	1.0	9.0
		(-25.0)	(-40.0)	(-27.3)	(-87.5)	(+800.0)
L1-L2	**W**	16.0	15.0	18.0	8.0	14.0
	V	9.5	5.0	1.0	5.0	7.0
		(-40.6)	(-66.7)	(-94.4)	(-37.5)	(-50.0)
	J	10.0	14.0	10.0	5.0	4.0
		(-37.5)	-(6.7)	(-44.4)	(-37.5)	(-71.4)
L2-L3	**W**	20.0	16.0	17.0	10.0	14.0
	V	12.0	7.0	4.0	5.0	5.0
		(-40.0)	(-56.3)	(-76.5)	(-50.0)	(-64.3)
	J	8.0	4.0	6.0	5.0	3.0
		(-60.0)	(-75.0)	(-64.7)	(-50.0)	(-78.6)
L3-L4	**W**	17.0	16.0	20.0	9.0	14.0
	V	11.0	7.0	8.0	7.0	7.0
		(-35.3)	(-56.3)	(-60.0)	(-22.2)	(-50.0)
	J	14.0	9.0	[9.5	[9.5	6.0
		(-17.6)	(-43.8)	(-52.5)]	(-5.6)]	(-57.1)
Total	**W**	75.0	61.0	71.5	40.5	50.0
	V	45.5	24.5	20.5	21.5	22.0
		(-39.3)	(-59.8)	(-71.3)	(-46.9)	(-56.0)
	J	42.0	37.0	34.5	22.5	31.0
		(-44.0)	(-39.3)	(-51.7)	(-44.4)	(-38.0)

Region=spinal region; O=orthosis; Subj=subject; T=thoracic; L-lumbar; W=without orthosis; V=Voight-Bähler; J=Jewett; values in square brackets were extrapolated due to off-centered radiographs. **square bracket is not "welcome" on this spot.

There was no two-tailed significant statistical difference in the flexion/extension range between the two orthoses, at any segmental level. The total range of motion between the two orthoses also did not differ significantly.

Comparing X-ray and PPRS

The Mann-Whitney test results in **Table 8** show no significant differences between the results of the sagittal curvature measurements of the PPRS study and the range of motion assessed by the X-ray study. The test, however, does indicate a difference between the flexion/extension measurements in degrees by the PPRS inclinometer and the range of motion assessed by the X-ray study.

DISCUSSION

The present study addresses maximal flexion and extension in healthy subjects. We assume that patients will fall at least within the borders of movement reduc-

Journal of Rehabilitation Research and Development Vol. 37 No. 4 2000

Table 7.
P-values of the Wilcoxon signed ranks test according to differences between situations with and without orthosis (one tailed) and between the two orthoses (two tailed), with regard to the X-ray evaluation.

Region	V-W	J-W	V-J
T10-11	0.0340*	0.0328*	1.0000
T11-12	0.2071	0.2326	0.6858
T12-L1	0.0328*	0.2501	0.1408
L1-2	0.0220*	0.0220*	0.2693
L2-3	0.0211*	0.0206*	0.1975
L3-4	0.0220*	0.0398*	0.0796
Total	0.0220*	0.0220*	0.1380

Region=spinal region; T=thoracic; L=lumber; V=Voight-Bähler; J=Jewett; W=without orthosis; *=significant with $p<0.05$.

Table 8.
P-values of the Mann-Whitney test according to the differences between PPRS and X-ray data.

Plane	Type of motion	J	V
Sagittal	Inclination (°)	0.0062*	0.0062*
	Sagittal curvature (mm)	0.3472	0.3613

J=Jewett; V=Voight-Bähler; *=significant with $p<0.05$.

tion that healthy subjects achieve. We tested the TLSOs in extreme situations and, even then, movement reduction was achieved. Because healthy subjects were studied, we cannot pass judgements regarding when these TLSOs are indicated for a given injury or pathology and when they are not. Furthermore, we chose rather strict inclusion criteria (e.g., only male subjects, body fat percentage 30) to prevent bias in this respect). This means that one should be especially careful in extrapolating the results to other populations. On the other hand, certain effects of TLSOs (e.g., reminder function; see discussion further on) can be considered more or less independent of the applied inclusion criteria.

The present research confirms the positive clinical experience with TLSOs in reducing spine mobility. A significant reduction of gross spinal movement from T10–L4 was accomplished by the TLSOs included in this research, except for the movement in the transverse plane. **Tables 3 and 6** (total) show that the movement reduction in the sagittal plane varies from 42.9–82.4 percent (sagittal curvature), 17.8–35.5 percent (sagittal inclination) and 38.0–71.3 percent (X-ray, sagittal plane). The movement reduction in the frontal plane varies from 1.4–51.4 percent (**Table 4**). The movement reduction in the transverse plane varies from 28.0–73.3 percent (**Table 4**). The amount of movement reduction clearly differs by subject and by type of TLSO, and sometimes is quite small, especially in the frontal plane. It should be noticed that, in one subject, the spine mobility in the transverse plane even increased when wearing a TLSO. The TLSOs did not significantly differ from each other in mobility reducing properties.

The range of flexion/extension at segment level as measured in the X-ray study was significantly reduced by both TLSOs, at all levels, with the exception of the T11–T12 and T12–L1 level, where it occurred with the Jewett orthosis only. This can be explained by the fact that the orthosis in two subjects had an excessive extending effect which could have led to an increased mobility at the aforementioned segments. Again, the amount of movement reduction varies by subject and by type of orthosis. The effect of both orthoses also did not significantly differ from each other at segmental level.

The literature on the conservative treatment of spinal fractures by bracing does not provide any information about the amount of spine movement reduction that is needed for optimal healing conditions. As stated in the introduction, the efficacy of a TLSO needs to be directed mainly at the T12, L1 and L2 levels. Despite the positive effect of the TLSOs in reducing the gross and segmental movements of the spine, at the critical levels of T11–T12 through T2–T3, not all levels show a statistically significant movement reduction (**Table 7**).

Looking at the divergent results, we question if the application of one of the TLSOs included in this research can be justified in the treatment of vertebral fractures in the thoracic/lumbar region. It should, however, be borne in mind that the present study was performed on healthy subjects. Also, the reminder function of wearing a TLSO may play a part. We assume that patients with a thoracic or lumbar vertebral fracture who are treated with a TLSO will probably not perform maximal spinal movements, due to pain, stiffness and carefulness. To be sure, we recommend first examining this assumption by recording the movements of the spine in healthy subjects during representative activities of daily life. Later, the same investigation can be done in patients.

With respect to the choice of an adequate measurement instrument, segmental vertebral mobility as well as gross spinal movements can be measured accurately using the X-ray technique (13,20). In spite of the detailed information the X-ray technique can provide, there are disturbing disadvantages. The X-ray technique can only be used in laboratory, as opposed to functional, conditions. Furthermore, the obtained information is limited to two planes, sagittal and frontal. In order to compare different situations and/or different interventions, several measurements have to be made. This will lead to an unacceptable X-ray exposure.

The non-invasive, portable measuring instrument (PPRS) seems a reasonable alternative. PPRS measurements of gross spinal movements can be done in three planes, under functional conditions. The PPRS inclination data in the sagittal plane, however, show significant differences from the X-ray data (**Table 8**). Apparently this is not the correct parameter. The shape of the spine, as measured in mm changes of length of the skin by the helical springs, appears to more closely reflect spinal motion. This could be expected because the inclinometer only measures one angle, at L1, which is the result of a combination of change of shape and position of the spine. Hip movements strongly influence the spinal position of the spine. The helical springs, on the other hand, measure along the entire lower back from T9 to L4 and provide accurate information purely about the change of shape of the lower spine. This may well explain the significant difference between the inclinometer versus the X-ray measurements and the non-significant difference between the helical springs versus X-ray measurements (**Table 8**). With respect to the movements in other planes, comparative data are missing in this study.

Comparing the pros and cons of both measurement instruments, the PPRS is recommended as a potential measurement system for research under functional conditions. The validity of the PPRS system, however, should further be sorted out by applying both techniques on the same subjects, preferably patients.

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