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ORIGINAL ARTICLE

R. B. Post
V. J. M. Leferink

Sagittal range of motion after a spinal fracture: does ROM correlate with functional outcome?

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R. B. Post (✉)
Department of Surgery,
University Hospital Groningen,
P.O. Box 30.001, 9700 RB Groningen,
The Netherlands
Tel.: +31-503-612876,
Fax: +31-503-614873,
e-mail: postrb@hotmail.com

V. J. M. Leferink
Department of Surgery,
Canisius-Wilhelmina Hospital,
P.O. Box 9015, 6500 GS Nijmegen,
The Netherlands

Abstract Literature regarding the effect of a spinal fracture and its treatment in terms of resulting spinal range of motion (ROM) is scarce. However, there is need for data regarding sagittal spinal ROM, since many patients who sustain a spinal fracture are concerned about the back mobility they will have after treatment. In addition, the relationship between ROM and impairment is not clear. The literature gives conflicting results. To study spinal ROM after a spinal fracture, we measured thoracolumbar ROM in operatively and non-operatively treated patients (n=76, average 3.7 years follow-up) as well as controls (n=41). In order to study the relation between ROM and subjective back complaints, we calculated the correlation between thoracolumbar ROM and scores derived from the VAS spine score and RMDQ. To assess impairment after a spinal fracture, we compared RMDQ and VAS scores between operatively and non-operatively treated patients and healthy controls. Operatively treated patients were found to have lower thoracolumbar ROM than controls (56.7° vs 70.0°, respectively; p<0.01). There was no difference between operatively treated and non-operatively treated patients (56.7° vs 62.7°, respectively); nor was a difference found between non-operatively treated patients and controls. Correlation between ROM and subjective impairment was very weak and only significant for ROM and RMDQ scores in the whole study group (rho= –0.25; p<0.01). Patients were more impaired than controls, there was no difference between operatively and non-operatively treated patients (VAS score 76.3 vs 72.6; RMDQ score 4.5 vs 4.4, respectively). We conclude that patients treated operatively for a thoracolumbar spinal fracture have a lower thoracolumbar ROM than controls. Spinal ROM, however, does not influence impairment. A spinal fracture results in impairment, no matter what therapy is chosen.

Keywords Spinal fractures · Thoracolumbar ROM · Functional outcome

Introduction

The effect of treatment of a spinal fracture on mobility of the spinal column and resulting range of motion (ROM) is uncertain. Literature about total spinal ROM after a fracture is scarce, as most studies address intersegmental ROM [5, 15, 17, 25]. The few studies available concerning spinal ROM after a spinal fracture reveal conflicting results. Axelsson et al. found, in patients treated with a posterolateral fusion for spondylolysis or facet joint arthritis, that the sagittal lumbar ROM increased after a fusion, probably due to relief of protective muscle spasm [1]. Dodd et al. found that spinal ROM does not return to normal after Harrington rod removal in patients treated operatively for a thoracolumbar fracture [8]. In a study by Junge et al.,

sagittal spinal ROM was found to be normal 2.5 years after operative treatment for a thoracolumbar spinal fracture [9].

There is need for data on spinal ROM in patients treated for a thoracolumbar spinal fracture. In order to study how a spinal fracture and its treatment affect spinal ROM, we measured sagittal thoracolumbar ROM in operatively and non-operatively treated patients. For comparison, ROM was also measured in a control group consisting of healthy volunteers.

As the ROM after a spinal fracture is still uncertain, little is known about the influence of the resulting spinal ROM on the patient's overall functional outcome, measured in terms of subjective impairment. Poitras et al. stated that thoracolumbar ROM is poorly to moderately related to functional disabilities [24]. Nattrass et al. found that there was no relationship between ROM and impairment [23]. In contrast, a study by Cox et al. reports a significant correlation between sagittal lumbar ROM and impairment [3]. In order to assess the relationship between subjective impairment and spinal ROM, and to reveal whether operative and non-operative treatment result in different impairment rates, we asked participants to fill in two questionnaires, the Visual Analogue Scale (VAS) spine score and the Roland-Morris Disability Questionnaire (RMDQ).

The following questions were studied:

1. Is there a difference in sagittal spinal ROM between operatively treated patients, non-operatively treated patients and controls?
2. Do the average VAS and RMDQ scores differ between operatively treated patients, non-operatively treated patients and controls?
3. Does sagittal spinal ROM correlate with subjective impairment, measured by the RMDQ and VAS?

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Spinal fracture between T1 and L5	Pathological fracture
Age at follow-up between 18 and 60 years	Total paraplegia
Time since injury at follow-up >1.5 years	Psychiatric illness
Capable of understanding the Dutch language	A3.3 fracture with implant in situ

Materials and methods

Patients

Between January 1996 and December 2000, 254 patients with a fracture of the thoracolumbar spine were treated at the traumatology department of the University Hospital Groningen. One hundred and ten patients (mean age 38.0 years) were treated operatively; 144 (mean age 42.4 years) were treated non-operatively. 153 (60%) patients (74 treated operatively, 79 non-operatively) met the inclusion criteria (Table 1). Patients operated on for an A3.3 fracture with the implant still in situ were not included, because the implant would influence the paravertebral measurement.

From the 153 included, 125 randomly selected patients (82%) were sent a letter in which the aim of the study was described. Four to 8 days later, an investigator telephoned patients to ask them to participate. Twelve patients were lost to follow-up; 14 could not be reached. Twelve refused, giving such reasons as "not interested" or "no time." Eleven patients missed several appointments. In total, 76 (38 treated operatively, 38 non-operatively) participated in the study (response rate: 76/125=61%; follow-up: 76/254=30%). Respondents did not differ from non-respondents for age, gender and time since injury.

For both groups, the participating patients did not differ from the non-participating patients for age, gender and time since injury. The control group consisted of 41 healthy volunteers (without a history of back surgery or medically treated back complaints) from a normal population of hospital personnel. The three groups did not differ from each other for age, gender and number. Average time from injury to follow-up was 3.7 years (range 1.7–6.4 years). Time since injury was significantly shorter for non-operatively treated patients ($p<0.01$). The non-operatively treated group consisted of more type-A fractures and fewer type-B and type-C fractures, according to the comprehensive classification (CC) [19] than the operatively treated group (Table 2).

Treatment

Operative treatment consisted of fracture reduction and fixation by means of dorsal instrumentation with the Universal Spine System (Synthes, Oberdorf, Switzerland), combined with transpedicular cancellous bone grafting and dorsal spondylodesis as described by Daniaux and Dick [4, 6, 7]. Fracture reduction was obtained by indirect manipulation using pedicle screws as levers. Cancellous bone was taken from the dorsal iliac crest and put in the reduced vertebral body transpedicularly [4]. The facet joints at the level of the traumatized disc were opened and the cartilage was removed. Cancellous bone was packed around the joints at the dorsolateral side [2]. No ventral operations, discectomies or laminectomies were performed.

Postoperatively, all patients were transferred to a rehabilitation center. They were allowed to walk after about 10 days in a simple reclination brace, worn for 9 months, after which the implants

Table 2 Study-group patient descriptions (n=117): age, gender, fracture level, follow-up and type of fracture (according to the CC [19]; *nc* not classified)

Treatment	n	Age (years): mean, (SD), range	Gender (M:F)	Fracture level	Follow-up (years): mean, (SD), range	Type of fracture			
						A	B	C	nc
Operative	38	40.5 (12.0) 21–59	25:13	T9–L5	4.1[a] (1.1) 2.5–6.4	23	10	3	2
Non-operative	38	40.6 (11.3) 23–59	22:16	T4–L5	3.3[a] (1.2) 1.7–5.6	31	2	1	4
Controls	41	39.1 (10.5) 23–60	28:13	–	–	–	–	–	–

[a]Difference significant: $p<0.01$

were removed. Three months later, patients were instructed to resume all former activities. A more detailed description of the operative technique was published previously [14].

Non-operative treatment was initialized in our hospital and continued in a rehabilitation center or the outpatient clinic. Therapy consisted of bed rest, sometimes on a Stryker frame, for a maximum of 6 weeks, followed by mobilization with a reclination brace for 9 months, combined with physiotherapy. Most A1 and A2 fractures (according to the CC [19]) were treated with a short period of bed rest, followed by functional treatment without a brace.

Measurement

We used the SpinalMouse (Idiag, Volkerswill, Switzerland), a computer-aided device, for measuring sagittal spinal ROM and the intersegmental angle in a non-invasive manner (Fig. 1). The device is connected via an analog–digital converter to a standard PC. Manually guided along the back of a subject, the system records the outline of the spinal column in the sagittal plane. To measure spinal ROM, the SpinalMouse is run paravertebrally along the spinal column from C7 to the rima ani (S3). The local angle or inclination relative to a perpendicular line is given at any position by an internal pendulum connected to a potentiometer. The ROM of each segment (i.e., intersegmental ROM) is computed, from which the relative parts of ROM for thoracic spine, lumbar spine and sacral spine/hip are computed. A more detailed description has been accepted for publication (R.B. Post and V.J.M. Leferink, 2004, Arch Orthop Trauma Surg).

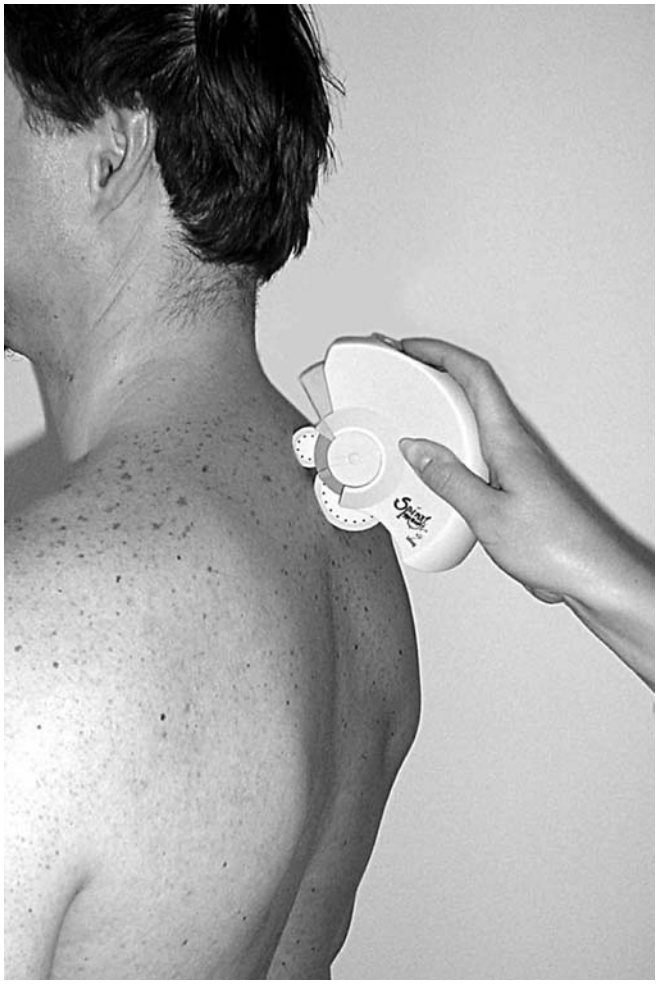

Fig. 1 The SpinalMouse is run paravertebrally from C7 to S3

We measured thoracolumbar ROM (T1/2–L5/S1) by adding thoracic ROM to lumbar ROM. Two investigators in succession (R.B.P. and V.J.M.L.) measured the patient's back. Participants were asked to bend and extend as far as possible, with their knees straight, without "warming up." In this manner, two measurements were obtained from each patient. The ROM we used was the average thoracolumbar ROM obtained from the two measurements.

With regard to subjective impairment, we asked participants to fill in two questionnaires measuring back pain and restrictions: the RMDQ and the VAS spine score (VAS). The RMDQ is a health status measure designed to be completed by patients to assess physical disability due to low back pain. It is self-administered and takes less than 5 min to complete [27]. Total scores can vary from 0 (no disability) to 24 (severe disability). The RMDQ has been used extensively and was found to be a sensitive, reliable and valid instrument [12, 13, 16, 27, 28]. In this study the Dutch version of the RMDQ was used [26].

The VAS spine score, developed for use with spinal fracture patients, asks the patient to rate the functional outcome in 19 items on an analogue 10 cm visual scale. The patient's perception of pain and restriction in activities related to back problems is measured. Higher scores represent better results, recalculated to percentages of the maximum score (0–100%). In previous studies, it has proved to be a reliable and valid instrument [11, 16].

Statistical analysis

Statistical analysis was done with SPSS version 10 (SPSS, Chicago). Comparison of VAS and RMDQ scores and ROM between groups was done by means of one-way ANOVA (posthoc Bonferroni). Correlation was computed by means of Pearson's correlation coefficient r. RMDQ and VAS scores for the total study group did not show a normal distribution, so correlation between VAS scores and RMDQ scores and ROM for the total group was tested non-parametrically, by means of Spearman's rho. Significance was accepted at 0.05.

Results

ROM

Operatively treated patients had lower thoracolumbar ROM than did controls (56.7° vs 70.0°, $p<0.01$). There was no difference found between operatively and non-operatively treated patients (56.7° vs 62.7°, $p=0.429$) or between non-operatively treated patients and controls (62.7° vs 70.0°, $p=0.210$) See Table 3.

Table 3 Thoracolumbar ROM (°; mean, SD and range) in operatively and non-operatively treated patients and controls

Treatment	Mean	SD	Range
Operative	56.7[a]	16.3	25.0– 88.5
Non-operative	62.7	19.7	16.5–105.5
Controls	70.0[a]	16.7	38.5–108.0

[a]Difference significant: $p<0.01$

Table 4 VAS and RMDQ scores in operatively and non-operatively treated patients and controls

Treatment	VAS: mean, (SD), range	RMDQ: mean, (SD), range
Operative	76.3[a] (23.3) 21.6–100.0	4.5[a] (5.2) 0–17.0
Non-operative	72.6[b] (22.9) 22.8–100.0	4.4[b] (4.3) 0–12.0
Controls	92.8[a,b] (9.2) 50.2–100.0	0.5[a,b] (1.4) 0– 7.0

[a]Difference significant: $p<0.001$
[b]Difference significant: $p<0.001$

Table 5 Correlation between ROM, VAS score and RMDQ score in separate groups and total study group

Treatment	Correlation with ROM	
	VAS	RMDQ
Operative	r =–0.001 (p=0.99)	r =–0.19 (p=0.25)
Non-operative	r =0.12 (p=0.50)	r =–0.23 (p=0.18)
Controls	r =0.16 (p=0.35)	r =–0.10 (p=0.54)
Whole study group (Spearman)	rho=0.16 (p=0.08)	rho=–0.25 (p=0.007)[a]

[a]Difference significant: $p<0.01$

VAS and RMDQ scores

Comparison of VAS and RMDQ scores showed that the mean VAS score in operatively and non-operatively treated patients was less than the mean VAS score of controls ($p<0.001$). VAS scores did not differ between operatively and non-operatively treated patients (p=1.000). Operatively as well as non-operatively treated patients had a higher mean RMDQ score than did controls ($p<0.001$). Mean RMDQ scores did not differ between operatively treated patients and non-operatively treated patients (p=1.000) See Table 4. A Spearman's rho of –0.85 ($p<0.001$) was found for correlation between VAS score and RMDQ score for the whole study group.

Correlation between ROM and VAS, RMDQ

A significant correlation was found between ROM and RMDQ score for the whole study group (Spearman rho= –0.25, $p<0.01$). None of the other correlation coefficients was significant (Table 5).

Discussion

This study was designed to evaluate sagittal spinal ROM of patients who sustained a thoracolumbar spinal fracture, as well as to study functional outcome and the relation between sagittal ROM and functional outcome.

Our results show that operatively treated patients have a lower thoracolumbar ROM than do controls. ROM did not differ significantly between non-operatively treated patients and controls; nor was there a significant difference in ROM between operatively treated and non-operatively treated patients. In these series the only statistically significant difference in ROM was found between operatively treated patients and controls. The differences between the other groups were not significant. An explanation could be found in, e.g., the power. The only conclusion possible based on these findings, however, is that operatively treated patients have lower ROM than do controls. Only a few studies regarding this issue have been published, making it difficult to compare our results with literature.

In a study by Junge et al. sagittal spinal ROM was found to be normal after mono-segmental operative treatment of a spinal fracture [9]. ROM was measured by means of finger-to-floor distance (11.6 cm) and the Schober technique (10:13.9 cm), as well as a clinical examination. Finger-to-floor distance, however, measures gross mobility of the trunk, which is mainly composed of hip movement [20, 30]. Consequently, finger-to-floor distance does not seem to be a valid tool for measuring thoracolumbar ROM. The Schober technique [29], although popular, has some important deficiencies: spinal extension and movement in the upper lumbar/lower thoracic region are not assessed [22]. Although Junge states that ROM was within normal range, he did not mention the normal values for either method. Reported values of 111° for flexion and 37° for extension seem to us values representing total trunk mobility, which does not represent thoracolumbar mobility [9].

In contrast to Junge, a recent study (concerning functional outcome of operatively treated patients) reports decreased thoracolumbar ROM 3 years after injury [10]. Thoracolumbar ROM was measured by finger-to-floor distance (11.6 cm) and the Schober technique (13.2 cm), as well as the Ott technique. No normal values for these methods were reported. As pointed out before, the first two methods do not represent true thoracolumbar mobility. The Ott technique consists, according to the author, of measuring the lengthening of a 30 cm distance, caudal to C7 in maximal spinal flexion [10]. However, no literature could be found regarding this technique, so it is not clear that it is reliable and valid for measuring thoracolumbar ROM. Taking into account the limitations of the papers discussed above, it is difficult to compare our results to literature. On the other hand, considering thoracolumbar ROM in *normal* subjects, a striking difference was found between our results and values reported in the literature (Mellin: 106°, Louis: 133°) [18, 21].

Why operatively treated patients have lower sagittal thoracolumbar ROM than controls is unknown. In our opinion, it seems unlikely that a single fusion is responsible for a decline in thoracolumbar range of motion. Fear of re-fracture or pain might be a possible explanation, as recently mentioned by Cox et al. [3]. Psychological aspects, for example the impact an operation implies, may lead to less functional use of the back post-traumatically,

which might result in decreased ROM. Another explanation for the lower ROM could be in the invasiveness of the operation, which results in scar tissue formation.

Evaluation of subjective impairment reveals that patients are impaired after a spinal fracture. Both operatively treated patients and non-operatively treated patients have a higher mean RMDQ score than do controls, as well as lower mean VAS scores. Both indicate more impairment. Scores between operatively treated and non-operatively treated patients did not differ. These data indicate that a spinal fracture, regardless of its treatment, results in subjective impairment that is similar for both types of treatment. However, it should be taken into account that average time since injury was shorter for non-operatively treated patients than for operatively treated patients, possibly biasing results.

In literature, a VAS score of 66 is reported for patients treated operatively for a spinal fracture at a follow-up of 23 months. A control group achieved scores of 92 [11]. For the control group, these data are comparable with our results, whereas operatively treated patients in our study achieve higher VAS scores. A possible explanation is our longer follow-up. Recently, Leferink et al. studied functional outcome in patients treated operatively for a thoracolumbar burst fracture. In his study, a mean RMDQ score of 4.0 was found, together with a mean VAS score of 79 [16]. Our results were obtained from a different group of patients, but are comparable. Kraemer et al. found a mean RMDQ score of 15.6 after a follow-up of 3.8 years, in patients treated operatively as well as non-operatively for a thoracolumbar burst fracture [12]. As in our study, there was no difference in RMDQ scores between operatively and non-operatively treated patients.

Correlation between RMDQ and VAS was found to be good (rho= –0.85). Only one published study reports correlation between these two questionnaires, in which a correlation of –0.72 was found [16].

Another issue is whether ROM influences impairment. We found weak correlation between RMDQ score and ROM for the whole study group (rho= –0.25). Negative rho indicates that an increase in ROM is accompanied by a lower score on the RMDQ, indicating less impairment. However, correlation was very weak and correlation for separate groups was not significant, either. Consequently, it seems unlikely that ROM influences impairment. There is a growing amount of literature concerning the relationship between ROM and impairment. Poitras et al. found that kinematic variables, including thoracolumbar ROM, correlate moderately to poorly to disability, and do not appear to be a valid measure of disability [24]. In a study by Nattrass et al. no relationship was found between lumbar ROM (measured with a long-arm goniometer and dual inclinometer) and impairment measured by the Oswestry Disability Index and the Waddell Disability Index [23]. These findings support our data that ROM is of no (or minor) influence on impairment. However, Nattras measured lumbar ROM, whereas in our series thoracolumbar ROM was measured. In contrast, a study by Cox et al. reports a significant correlation (r=0.52) between ROM and impairment measured by the Quebec Back Pain Disability Questionnaire [3]. The author states that simple parameters of the functional examination, such as ROM, are strongly correlated with the cognitive state. For example, fear will influence (voluntary) ROM [3].

A limitation of this study is that the average time since injury was shorter for non-operatively treated patients than for operatively treated patients, which makes these two groups not completely comparable. The shorter follow-up might have affected the results in some way. Another issue to keep in mind is the response rate, which might have biased results.

Conclusions

Sagittal thoracolumbar ROM 4 years after operative treatment of a spinal fracture seems to be lower than the thoracolumbar ROM of healthy individuals. It is unclear why operative treatment of thoracolumbar fractures might result in lower spinal ROM. Further research should be done in this field.

Patients who sustained a spinal fracture are more impaired than healthy controls. ROM does not seem to influence this impairment, however. Both kinds of treatment (operative vs non-operative) apparently result in similar impairment rates.

References

1. Axelsson P, Johnsson R, Stromqvist B, Arvidsson M, Herrlin K (1994) Posterolateral lumbar fusion. Outcome of 71 consecutive operations after 4 (2–7) years. Acta Orthop Scand 65:309–314
2. Blauth M, Bastian L, Jeanneret B, Knop C, Moulin P, Müller-Vahl H, Schmidt U, Schratt HE, Wippermann B (1998) Wirbelsäule. In: Tscherne H, Blauth M (eds) Tscherne Unfallchirurgie, vol 3. Springer, Berlin Heidelberg New York, pp 314–320 and pp 333–338
3. Cox ME, Asselin S, Gracovetsky SA, Richards MP, Newman NM, Karakusevic V, Zhong L, Fogel JN (2000) Relationship between functional evaluation measures and self-assessment in nonacute low back pain. Spine 25:1817–1826

4. Daniaux H (1982) Technik und erste Ergebnisse der transpedikulaeren Spongiosaplastik bei Kompressionsbruechen im Lendenwirbelsaulenbereich. Acta Chir Austr 43 [Suppl]:79
5. Dekutoski MB, Conlan ES, Salciccioli GG (1993) Spinal mobility and deformity after Harrington rod stabilization and limited arthrodesis of thoracolumbar fractures. J Bone Joint Surg Am 75:168–176
6. Dick W (1987) The "fixateur interne" as a versatile implant for spine surgery. Spine 12:882–900
7. Dick W, Kluger P, Magerl F, Woersdorfer O, Zach G (1985) A new device for internal fixation of thoracolumbar and lumbar spine fractures: the "fixateur interne." Paraplegia 23:225–232
8. Dodd CA, Fergusson CM, Pearcy MJ, Houghton GR (1986) Vertebral motion measured using biplanar radiography before and after Harrington rod removal for unstable thoracolumbar fractures of the spine. Spine 11:452–455
9. Junge A, Gotzen L, von-Garrel T, Ziring E, Giannadakis K (1997) Die monosegmentale Fixateur interne – Instrumentation und Fusion in der Behandlung von Frakturen der thorakolumbalen Wirbelsäule. Indikation, Technik und Ergebnisse. Unfallchirurg 100:880–887
10. Knop C, Fabian HF, Bastian L, Blauth M (2001) Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. Spine 26:88–99
11. Knop C, Oeser M, Bastian L, Lange U, Zdichavsky M, Blauth M (2001) Entwicklung und Validierung des VAS-Wirbelsäulenscores. [Development and validation of the Visual Analogue Scale (VAS) Spine Score]. Unfallchirurg 104:488–497
12. Kraemer WJ, Schemitsch EH, Lever J, McBroom RJ, McKee MD, Waddell JP (1996) Functional outcome of thoracolumbar burst fractures without neurological deficit. J Orthop Trauma 10: 541–544
13. Leclaire R, Blier F, Fortin L, Proulx R (1997) A cross-sectional study comparing the Oswestry and Roland-Morris Functional Disability scales in two populations of patients with low back pain of different levels of severity. Spine 22:68–71
14. Leferink VJM, Zimmerman KW, Veldhuis EFM, Vergert EM, Duis HJ (2001) Thoracolumbar spinal fractures: radiological results of transpedicular fixation combined with transpedicular cancellous bone graft and posterior fusion in 183 patients. Eur Spine J 10: 517–523
15. Leferink VJM, Nijboer JMM, Zimmerman KW, Veldhuis EFM, Vergert EM, Duis HJ (2002) Thoracolumbar spinal fractures: segmental range of motion after dorsal spondylodesis in 82 patients: a prospective study. Eur Spine J 11:2–7
16. Leferink VJM, Keizer HJE, Oosterhuis JK, van der Sluis CK, Duis HJ (2003) Functional outcome in patients with thoracolumbar burst fractures treated with dorsal instrumentation and transpedicular cancellous bone grafting. Eur Spine J 12:261–267
17. Lindsey RW, Dick W, Nunchuck S, Zach G (1993) Residual intersegmental spinal mobility following limited pedicle fixation of thoracolumbar spine fractures with the fixateur interne. Spine 18:474–478
18. Louis R (1983) Surgery of the spine: surgical anatomy and operative approaches. Springer, Berlin Heidelberg New York, p 70
19. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. Eur Spine J 3:184–201
20. Mayer TG, Tencer AF, Kristoferson S, Mooney V (1984) Use of noninvasive techniques for quantification of spinal range-of-motion in normal subjects and chronic low-back dysfunction patients. Spine 9:588–595
21. Mellin G (1986) Measurement of thoracolumbar posture and mobility with a Myrin inclinometer. Spine 11:759–762
22. Miller MH, Lee P, Smythe HA, Goldsmith CH (1984) Measurements of spinal mobility in the sagittal plane: new skin contraction technique compared with established methods. J Rheumatol 11:507–511
23. Nattrass CL, Nitschke JE, Disler PB, Chou MJ, Ooi KT (1999) Lumbar spine range of motion as a measure of physical and functional impairment: an investigation of validity. Clin Rehabil 13:211–218
24. Poitras S, Loisel P, Prince F, Lemaire J (2000) Disability measurement in persons with back pain: a validity study of spinal range of motion and velocity. Arch Phys Med Rehabil 81:1394–1400
25. Rohlmann A, Neller S, Bergmann G, Graichen F, Claes L, Wilke HJ (2001) Effect of an internal fixator and a bone graft on intersegmental spinal motion and intradiscal pressure in the adjacent regions. Eur Spine J 10:301–308
26. Roland M, Fairbank J (2000) The Roland-Morris Disability Questionnaire and the Oswestry Disability Questionnaire. Spine 25:3115–3124
27. Roland M, Morris R (1983) A study of the natural history of back pain. I. Development of a reliable and sensitive measure of disability in low-back pain. Spine 8:141–144
28. Roland M, Morris R (1983) A study of the natural history of low-back pain. II. Development of guidelines for trials of treatment in primary care. Spine 8: 145–150
29. Schober P (1937) Lendenwirbelsäule und Kreuzschmerzen. Munch Med Wochenschr 84:336–338
30. Winter RB, Carr P, Mattson HL (1997) A study of functional spinal motion in women after instrumentation and fusion for deformity or trauma. Spine 22:1760 – 1764