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ORIGINAL ARTICLE

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The effect of surgery and remodelling on spinal canal measurements after thoracolumbar burst fractures

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Abstract Bone fragments in the spinal canal after thoracolumbar spine injuries causing spinal canal narrowing is a frequent phenomenon. Efforts to remove such fragments are often considered. The purpose of the present study was to evaluate the effects of surgery on spinal canal dimensions, as well as the subsequent effect of natural remodelling, previously described by other authors. A base material of 157 patients operated consecutively for unstable thoracolumbar spine fractures at Sahlgrenska University Hospital in Gothenburg during the years 1980–1988 were evaluated, with a minimum of 5-years follow-up. Of these, 115 had suffered burst fractures. Usually the Harrington distraction rod system was employed. Patients underwent computed tomography (CT) preoperatively, postoperatively and at follow-up. From digitized CT scans, cross-sectional area (CSA) and mid-sagittal diameter (MSD) of the spinal canal at the level of injury were determined. The results showed that the preoperative CSA of the spinal canal was reduced to 1.4 cm^2, or 49% of normal, after injury. Postoperatively it was widened to 2.0 cm^2 or 72% of normal. At the time of follow-up, the CSA had improved further, to 2.6 cm^2 or 87%. The extent of widening by surgery depended on the extent of initial narrowing, but not on fragment removal. Remodelling was dependent on the amount of bone left after surgery. The study shows that canal enlargement during surgery is caused by indirect effects when the spine is distracted and put into lordosis. Remodelling will occur if there is residual narrowing. Acute intervention into the spinal canal, as well as subsequent surgery because of residual bone, should be avoided.

Key words Spinal canal · Burst fracture · Surgery · Remodelling

Introduction

Burst fractures of the thoracolumbar spine are frequently accompanied by retropulsion of bone fragments into the spinal canal, causing a reduction of the area available for the neurological structures [3, 7, 8,24]. These injuries are most often located at the thoracolumbar junction, and may be accompanied by neurological symptoms or even paraplegia [27]. Burst fractures can be unstable and require stabilizing treatment which often includes surgery [11, 21], conservative treatment sometimes may be an option [6, 17, 22, 23,25]. Case reports and minor series have previously reported that bone fragments in the spinal canal after thoracolumbar burst fractures tend to be reabsorbed, and that the canal area available for the nerve structures increases over time [5, 9, 13, 18, 20,26]. This contrasts with earlier statements recommending that such bone fragments should be removed, even when neurological deficit is not present [15,29].

The surgeon who faces a burst fracture with considerable amounts of bone fragments in the spinal canal in a neurologically intact patient may find it difficult to decide how to proceed. Should the chosen surgical procedure include decompression and fragment removal from the spinal canal in order to decompress the nerve structures or should its aims be limited to reduction, stabilisation and fusion of the spine. The following paper addresses this question by studying the effects of surgery and the effects of natural remodelling of the traumatically narrowed spinal canal in a long-term follow-up.

Materials and methods

Unstable injuries of the thoracolumbar spine have been treated operatively at the department of orthopedics, Sahlgrenska University Hospital, in Gothenburg, since 1977. During the years 1980 through 1988, 157 consecutive patients, 92 male and 65 female, mean age 32 years and median 28 years, were operated for such injuries. These patients constitute the base material for this study. The patients were followed prospectively and underwent conventional X-ray and computed tomography (CT) preoperatively, postoperatively and at follow-up, which lasted at least 5 years after injury. The median follow-up period was 7 (range 5–12) years. Data were collected concerning age, sex, level of injury, type of injury, presence of neurological deficits, surgical instrumentation and spinal canal intervention. Injuries were classified from plain radiographs and CT scans according to the Denis classification [10]. The present study includes the 115 cases in the base material where injuries were classified to be of the burst type. Of these 115 patients, 65 were men and 50 women, with a median age of 28 (14–68) years. For age distribution, see Table 1. Excluding five deceased patients, 110 were available for follow-up, of whom 109 attended (99%).

In all, there were 99 preoperative, 86 postoperative and 96 follow-up CT scans. Both pre- and postoperative CT scans were available for 81 patients, while postoperative as well as follow-up CT scans were available for 80 patients. A complete set of CT scans at all three occasions was present in 75 cases.

The surgical procedure (Table 2) usually employed double Harrington distraction rods with instrumentation and fusion from two levels above to two levels below the injury. Twenty-six patients with neurological deficits, in addition to reduction stabilization and fusion, underwent fragment removal, usually by impaction into the vertebral body (Table 3). Injured levels are shown in Table 4. Sixty-five percent were at T12 or L1. The dimensions of the spinal canal were assessed by calculating the cross-sectional area (CSA) and the mid-sagittal diameter (MSD). In each case, preoperative CT scans were selected at the level of maximum canal compromise. Care was taken to select scans from the same level of the injured vertebra at all three examinations. The selected scans were digitized using a video camera and computer system (Research Metrics, OrthoGraphics Inc., Salt Lake City, USA). From the digitized images the actual and the pre-injury CSA were traced and computed, as well as the actual and the pre-injury MSD. The pre-injury outline of the spinal canal was estimated by extrapolating the tracing following what was left of the normal boundaries of the canal [30].

The tracings were performed by the same investigator in all cases. Intraobserver error was 5.3 for CSA and 4.4 for MSD (percentage values), studied by duplicate measurements of 15 CT scans chosen at random.

The estimation of pre-injury CSA and MSD is a possible source of error. There are two commonly used ways to determine these measures from CT scans. One is the method applied in this work (tracing);the other is determination by calculating the corresponding mean measure from the uninjured levels above and below the injury (averaging). To compare the two methods, a separate study was performed in 17 cases in which both methods were applied.

Results of CSA and MSD are given in absolute values and percentages, comparing the available to the normal (pre-injury) value, in each CT scan. In some cases, an *operative effect* is calculated, as the difference between the initial available area and the available area at the postoperative CT scan. Similarily, a *remodelling effect* is calculated as the difference between the available area at the postoperative and the follow-up CT. Values are given as means and standard errors (±SEM). Statistical comparisons employ the *t*-test for paired and unpaired data. *P*-values less than 0.05 are considered statistically significant.

Table 1 Age at time of injury

Age	No. of patients	Percentage of patients
10–19	22	19
20–29	44	38
30–39	14	12
40–49	16	14
50–59	13	11
60–69	6	5
Total	115	100

Table 2 Instrumentation

	No. of patients
Harrington	111
Dick internal fixator	3
Louis plates	1
Total	115

Table 3 Fragment removal from the spinal canal

	No. of patients
Yes	26
No	89
Total	115

Table 4 Injured level

	No. of patients
T11	2
T12	21
L1	57
L2	14
L3	14
L4	4
L5	3
Total	115

Results

In the whole series, mean CSA after injury was 1.39 $cm^{2,}$ or 49% of normal. Surgery improved the mean CSA to 1.97 $cm^{2,}$ or 72%. At the follow-up investigation, the

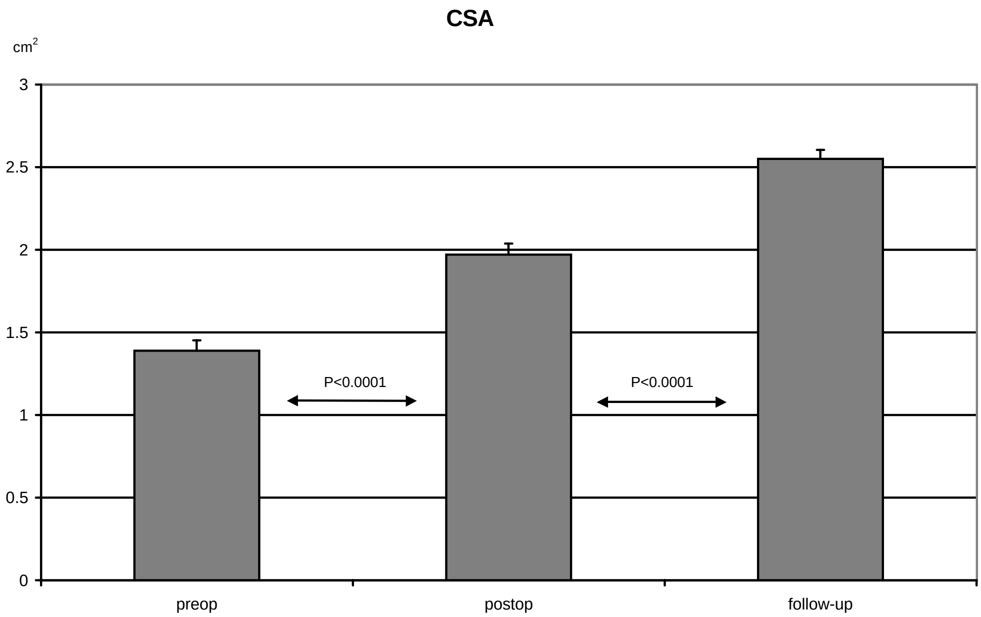


Fig. 1 Cross-sectional area (CSA) of the spinal canal preoperatively (*n*=99), postoperatively (*n*=86) and at follow-up (*n*=96), presented as mean and standard error (SEM). Statistics by paired *t*-test

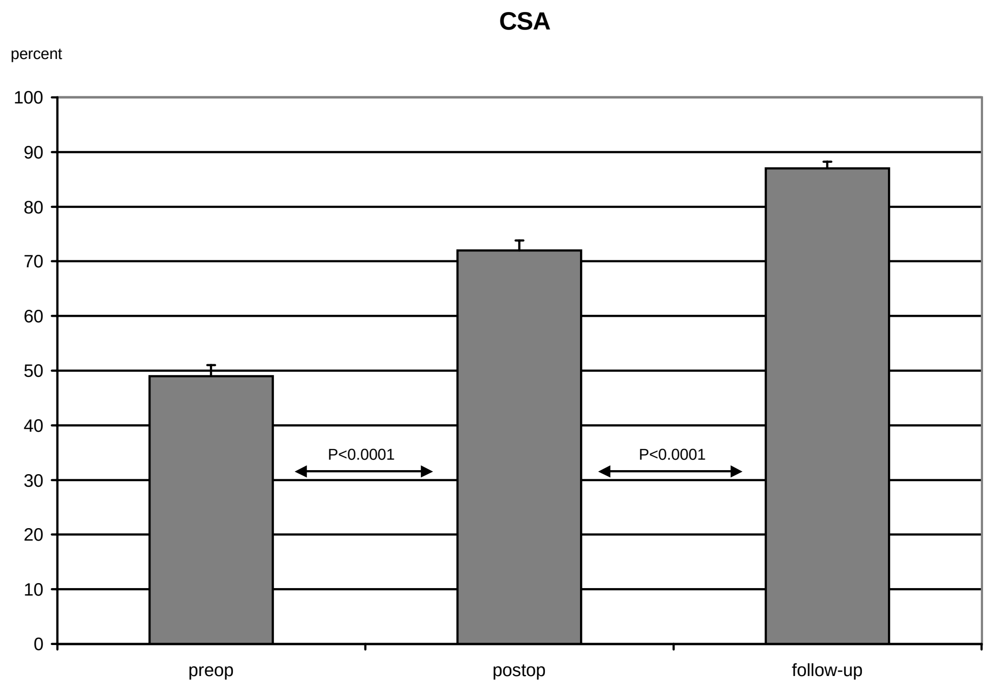


Fig. 2 CSA of the spinal canal, presented as mean ±SEM. Values are percentages of normal area, preoperatively (*n*=99), postoperatively (*n*=86) and at follow-up (*n*=96). Statistics by paired *t*-test

mean CSA had improved further, to 2.55 cm^{2,} or 87% of normal (Fig. 1, Fig. 2). MSD was 8.7 mm, or 60%, after injury and improved to 11.5 mm, or 79%, after surgery and then further to 13.7 mm, or 87%, at the follow-up (Fig. 3, Fig. 4). The mean operative effect was 0.60±0.067 cm^2 (*n*=81), and the mean remodelling effect was 0.60± 0.063 cm^2 (*n*=80).

Effects of spinal canal fragment removal

Patients with neurological symptoms were operated with fragment removal from the spinal canal. In these patients, the spinal canal area improved from 0.91 cm^{2,} or 34% of normal, to 1.91 cm^2, or 70%, after the surgical procedure. They then improved further over time, to 2.67 cm^2, or 90%, at the follow-up. In patients not operated with fragment removal, the canal area improved from 1.53 cm^2, or 54% of normal, after injury to 2.00 cm^2, or 72%, at the

Fig. 3 Mid-sagittal diameter (MSD) of the spinal canal, preoperatively (n=99), postoperatively (n=86) and at follow-up (n=96), presented as mean ±SEM. Statistics by paired t-test

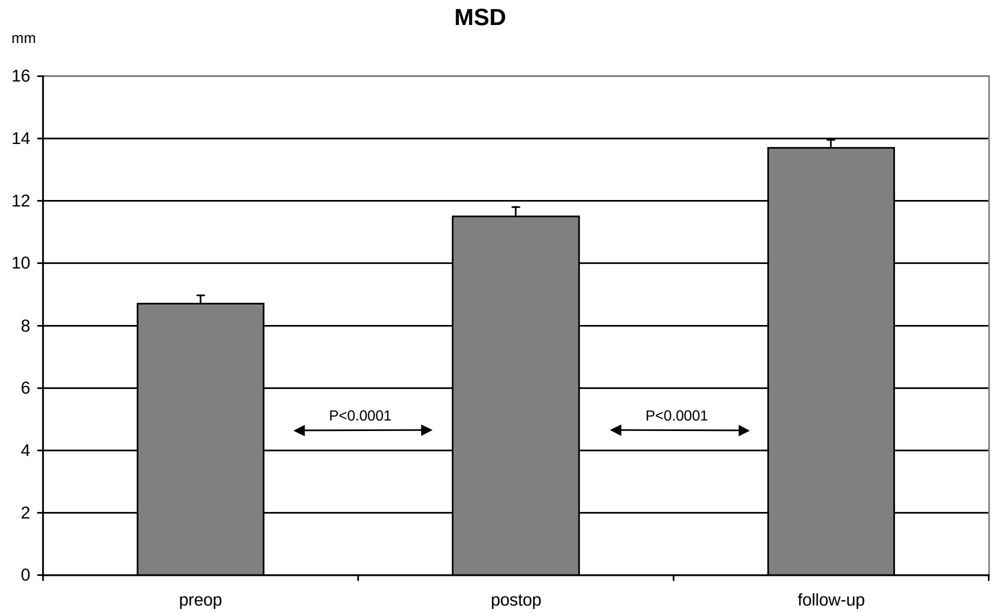
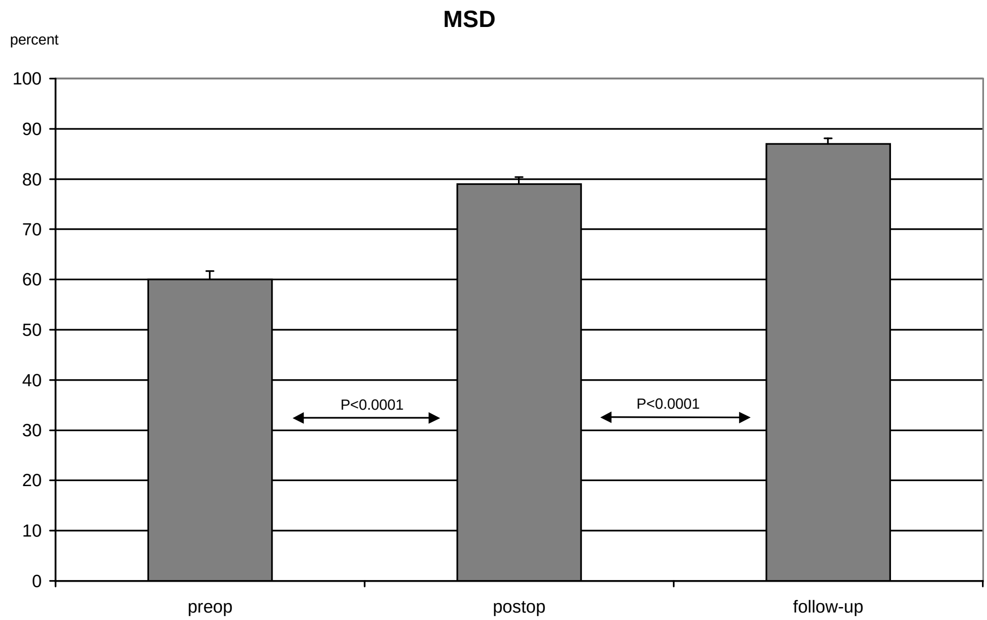


Fig. 4 Mid-sagittal diameter (MSD) of the spinal canal, presented as mean ±SEM. Values are percentages of normal diameters, preoperatively (n=99), postoperatively (n=86) and at follow-up (n=96). Statistics by paired t-test



postoperative investigation, and 2.52 $cm^{2,}$ or 86%, at the follow-up investigation (Fig. 5). MSD values for patients operated with fragment removal were 6.6 mm, or 47%, 11.4 mm, or 79%, and 14.0 mm, or 87%, after injury, after surgery and at follow-up respectively, while the values for patients with only stabilising surgery were 9.3 mm, or 64%, 11.5 mm, or 79%, and 13.6 mm, or 87%, respectively (Fig. 6). The group with fragment removal showed a higher operative effect than the group with surgical reduction and fusion only (0.95 vs 0.48 cm^2, P=0,0017, unpaired t-test, Table 5). The postoperative result was, however, the same for the two groups (1.91 vs 2.00 cm^2, NS).

Effects of initial traumatic narrowing

Patients who underwent surgical reduction and fusion, without surgical decompression and fragment removal, were assigned to one of two groups: one comprising those with less than 50% of normal spinal canal area (on admission), and the other, those with an area of 50% or more. The first group (severe narrowing) had a mean preoperative area of 1.03 cm^2. Mean postoperative enlargement of the canal was 0.76 cm^2, resulting in a mean postoperative area of 1.77 cm^2, and a long-term follow-up area of 2.37 cm^2. The second group (less severe narrowing) had a

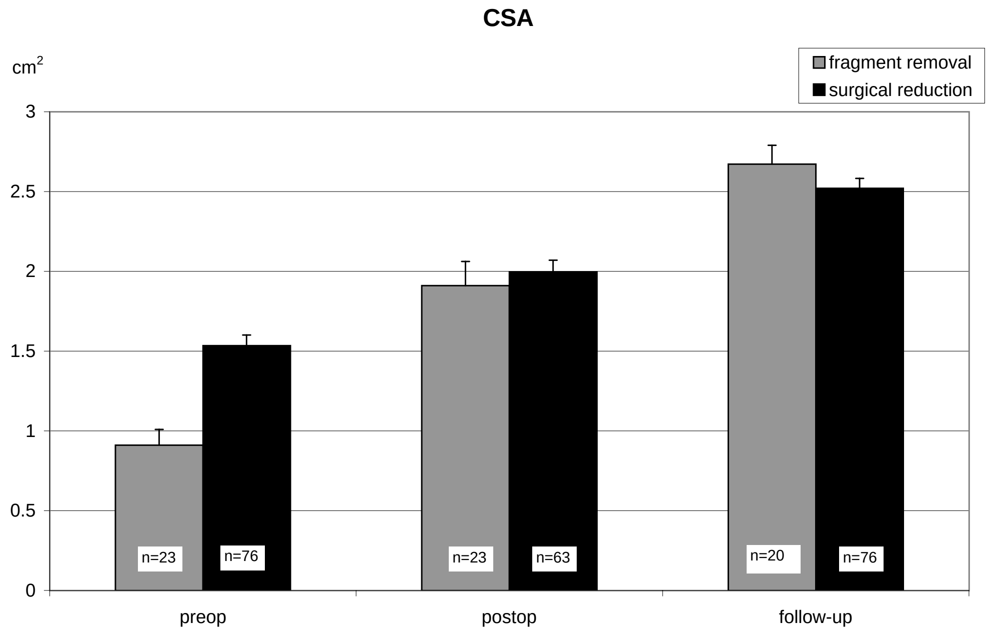


Fig. 5 Cross-sectional area (CSA) split by fragment removal (mean ±SEM). For fragment removal group: $P<0.0001$ preop. vs postop.; $P<0.0001$ postop. vs follow-up. For indirect surgical reduction group: $P=0.0004$ preop. vs postop.; $P<0.0001$ postop. vs follow-up. Statistics by paired *t*-test

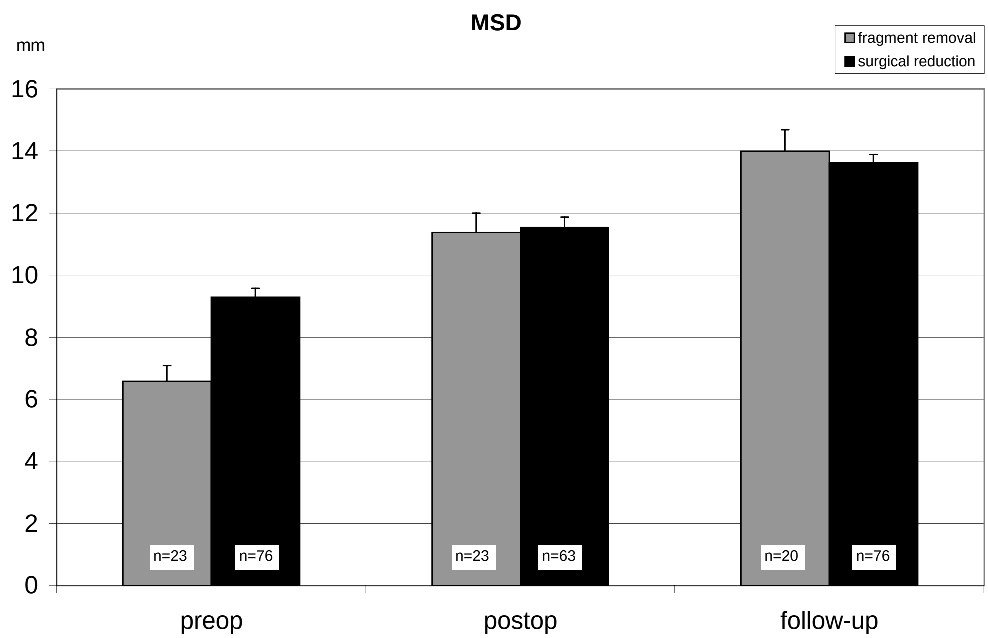


Fig. 6 Mid-sagittal diameter (MSD) split by fragment removal (mean ±SEM). For fragment removal group: $P<0.0001$ preop. vs postop.; $P=0.0028$ postop. vs follow-up. For indirect surgical reduction group: $P<0.0001$ preop. vs postop.; $P<0.0001$ postop. vs follow-up. Statistics by paired *t*-test

mean preoperative area of 1.83 cm^2, a mean postoperative area of 2.13 cm^2 and a long-term follow-up area of 2.63 cm^2. Postoperative widening in this group (0.31 cm^2) was significantly less than in the first group ($P=0.0006$, less severe vs severe, unpaired *t*-test, Fig. 7 and Table 5). Within the group with severe narrowing, the effect of additional decompression and fragment removal was tested. This combined procedure widened the canal by 1.066 cm^2. Without decompression and fragment removal, canal widening was 0.755 cm^2. The difference proved not to be significant (Table 5).

Effects of spinal level

Splitting the material according to the injured level, for the levels T12 through L3, showed no significant differences between the levels regarding the effects of surgery and the remodelling effect. Other levels were operated in too small numbers to allow statistical evaluation.

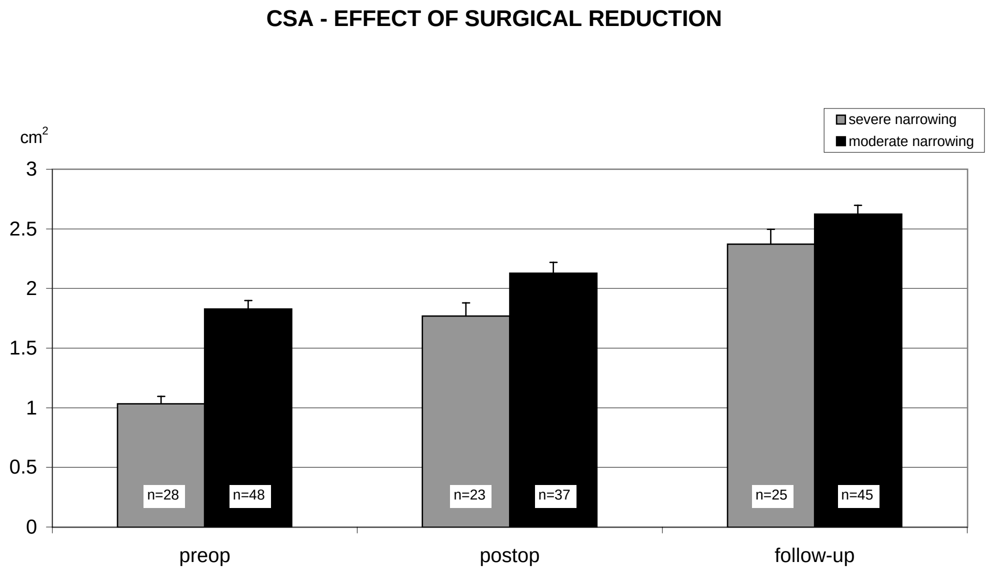


Fig. 7 CSA in cases operated with indirect surgical reduction only, split by severity of initial narrowing (mean ±SEM). Severe group: *P*<0.0001 preop. vs postop. and postop. vs follow-up. Moderate group: *P*=0.0004 preop. vs postop. and *P*<0.0001 postop. vs follow-up. Statistics by paired *t*-test

Table 5 Cross-sectional area improvement after surgery in different groups, presented as mean ± standard error (SEM). Statistics by unpaired *t*-test

Group	Mean operative effect cm^2	SEM	Significance
All patients (*n*=81)	0.603	0.067	
Moderate narrowing (*n*=40)	0.307	0.073	P<0.0001
Severe narrowing (*n*=41)	0.892	0.092	
Fragment removal (*n*=21)	0.953	0.160	P=0.0017
Indirect surgical reduction only (*n*=60)	0.481	0.065	
Severe narrowing±fragment removal (*n*=18)	1.066	0.173	P=0.0952 (NS)
Severe narrowing±indirect surg. reduction (*n*=23)	0.755	0.088	
Indiriect surg. reduction±severe narrowing (*n*=23)	0.755	0.088	*P*=0.0006
Indirect surg. reduction±moderate narrowing (*n*=37)	0.310	0.079	

Effects of early surgery

Patients operated 3 days or less after the injury had a mean improvement after surgery of 0.65±0.086 cm^2 (*n*=49). Surgery later than 3 days after injury gave a mean improvement of 0.53±0.109 cm^2 (*n*=32). There was no significant difference between those operated early or later (unpaired *t*-test). Nor did subdividing according to fragment removal or initial canal narrowing reveal any significant differences (unpaired *t*-test).

Determination of pre-injury measurements

In a separate study of 17 cases, we compared the two different techniques of determining the pre-injury CSA and MSD of the spinal canal from CT scans after a burst fracture. A tracing of the normal preoperative area on a CT scan was compared to measurement of the area on the non-injured levels above and below, and calculating the average of these areas. The tracing method gave a mean normal CSA of 2.785±0.129 cm^{2,} while the averaging method gave a mean CSA of 2.342±0.087 cm^2. The difference is statistically significant (*P*=0.0001). The corresponding determination of MSD resulted in 14.86± 0.61 mm with the tracing method, and 16.16±0.36 mm with the averaging method (*P*=0.005).

Discussion

The thoracolumbar burst fracture is a common spinal injury – 73% of our surgically treated thoracolumbar spine fractures were of this kind. Approximately one out of four burst fractures is associated with major neurologic deficit, because of the bone fragments compressing the nerve structures. Treatment of this injury, whether by nonoperative or operative methods, has been debated for a long time in the literature. In the present material, we chose to operate cases that we considered unstable, i.e. when the anterior and middle column support was substantially compromised [10]. The aim of surgical treatment, usually with double Harrington rods lordotically contoured, was to achieve reduction of the deformed spine by restoration of normal lordosis and normal height of the compressed vertebra and to obtain initial stability, reduce pain and allow early mobilisation of the patient. The goal was further to decompress the spinal canal, indirectly by postural reduction or directly by fragment removal.

In several articles, the biomechanics involved in the indirect reduction of the fragments retropulsed into the spinal canal have been described [4, 19, 28,31]. It has been shown that distraction is the main force of reduction [14, 19,30], but restoration of normal lordosis will also create space in the spinal canal [12]. Such indirect reduction of the burst fractures caused a mean improvement in the spinal canal area, in our series, from 49% to 72% of normal (from 1.4 to 2.0 cm^2). It has traditionally been believed that fragment removal from the spinal canal, in order to increase the available area for the nerve structures, is more effective in this respect, than postural reduction alone. This has been the basis of our policy of intervening in the spinal canal if the patients have neurological symptoms after a burst fracture. Our results do not, however, support this view. We demonstrated that postural reduction is more effective in enlarging a severely narrowed spinal canal (available area <50%) than a less severely narrowed canal (available area >50%), viz. 0.76 versus 0.31 cm^2 increase in spinal canal area. Within the severely narrowed canals, it made no difference whether surgical fragment removal had been performed or not (Table 5). The end result after surgery was fairly consistent, irrespective of fragment removal and irrespective of the severity of the initial canal narrowing. The average postoperative area of the canal was between 1.8 and 2.1 cm^2.

It has also traditionally been believed that surgery within the first days after a burst fracture injury allows better fragment removal than more delayed surgery. This was a finding reported by Willén [30]. In our material, we found no difference between cases operated within 3 days after injury compared to the cases operated later. This may be due to the fact that there were very few cases in the Willén study (6 and 5 cases, as opposed to 49 and 32 in this study, in the early and late operated groups, respectively). Also, the studies do not include entirely the same patient material. The Willén study includes all unstable thoracolumbar injuries, while our study only considers burst fractures.

Irrespective as to whether the canal was enlarged by direct fragment removal or by postural reduction, there was encroachment left after surgery caused by remaining bony fragments in the spinal canal. The fate of this bony narrowing over time has been studied by other authors in case reports or smaller series, and it has been shown that the canal area increases over time [5, 9, 13, 18, 20,26]. This natural remodelling effect of the spinal canal is confirmed in our study. The natural remodelling effect over a time of 7 years (median) was of the same magnitude as the surgical canal widening effect, namely 0.60 cm^2. The natural remodelling seemed to end at a mean spinal canal area of approximately 2.5 cm^2, which is in the vicinity of the normal area of the spinal canal. This was true irrespective of whether the patient had additional surgical removal of fragments.

Eleven out of 80 patients showed no natural remodelling at all. Analysis revealed that their mean available area postoperatvely was 2.4 cm^2. This contrasts with the 69 out of 80 patients who demonstrated natural remodelling. Their mean area postoperatively was 1.9 cm^2. Thus, it seems that remodelling will occur only if there is substantial remaining bone in the spinal canal, provided the spine is stabilized and fused over the injured segments. Bohlman [2] has suggested that narrowing of the spinal canal may cause *subsequent* neurological symptoms due to compression of the neural structures. This does not seem probable in view of the resorption of fragments seen in this study. In our series, we did not see a single patient with deterioration of neurological symptoms over the observation time. Nor did any patient develop new symptoms. All patients with incomplete spinal injuries regained all or part of their neurologic functions. Thus, in our opinion, a residual moderate spinal canal narrowing after surgery does not imply the need for further surgery, as suggested by some authors [1,16]. Further, it seems that surgical decompression and fragment removal should be avoided in all cases of burst fractures, since this procedure has no additional effect compared to the effect of surgical reduction and fusion alone. Nor does late “acute” surgery imply a need for fragment removal or anterior procedures, since there is no difference in the canal clearing effect if the patient is operated within 3 days after injury or later.

The method of determining the CSA and MSD by tracing reconstruction at the injured level has the theoretical advantage that the normal area is estimated at the actual injured level in every case. This eliminates one source of variation, namely the individual variation between levels. However, it introduces a systematic error. Pre-injury MSD determination by reconstruction from the CT scan showing the injury yields a slightly smaller value than determination of MSD by averaging the measurements from the adjacent levels (14.9 vs 16.1 mm), while CSA determination yields a larger value by reconstruction compared to the average of adjacent levels (2.78 vs 2.34 cm^2). This difference between the two methods was also observed by Sjöström et al. [26]. They demonstrated that the overestimation by the reconstructive method correlated with a high degree of accuracy with regard to the widening of interpeduncular distance frequently seen in burst fractures [30]. This implies that the percentage values of available CSA in our study is underestimated. This underestimation is somewhat higher at the initial measurement than at the postoperative and the follow-up measurements, since the spreading of the pedicles is reduced during the distraction procedure [30]. This probably explains why Sjöström et al. [26] found a remaining canal narrowing of only 2% at follow-up, while we in our series found the end result to be slightly over 10%. In absolute values, however, the end result at follow-up was approximately 2.5 $cm^{2,}$ which is beyond the normal area of 2.34 cm^2 that we found by way of the average method. It seems that the remodelling process continues until the spinal canal area reaches the normal range. The MSD measurements though, do not quite reach normal (13.7 mm vs 16.2 mm given by the average method), implying that the shape of the canal, at the end, is somewhat wider and more shallow in the frontal plane. This is well in line with what could be expected bearing in mind the remaining spreading of the pedicles.

Conclusions

The widening of spinal canal area produced by indirect surgical reduction of the spine is confirmed. This effect is dependent on the amount of initial canal narrowing. Fragment removal, per se, does not seem to produce superior results as compared to indirect surgical reduction alone.

The natural remodelling of a narrowed spinal canal after a burst fracture, previously described by others, is confirmed. It will occur if there is bone left in the spinal canal, and it continues until the canal area reaches the normal range.

The end result after a burst fracture is a somewhat wider and more shallow spinal canal.

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