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ORIGINAL ARTICLE

Reducing kyphotic deformity by posterior vertebral column resection with 360° osteosynthesis in metastatic epidural spinal cord compression (MESCC)

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Abstract

Purpose Metastatic epidural spinal cord compression (MESCC) often requires anterior–posterior decompression and stabilization. To reduce approach-related complications, single-stage posterolateral vertebrectomy and 360° fusion is often performed. However, a sufficient reduction of kyphotic deformity through this approach has not been reported. The purpose of this study is to investigate the efficacy of kyphotic deformity reduction by this approach in MESCC.

Methods A retrospective analysis and chart review was performed for 14 consecutive patients who underwent a vertebrectomy and decompression from a posterolateral approach. Anterior mesh stabilization of the ventral column is used as hypomochlion for the posterior compression manoeuvre, which leads to reduction of the kyphotic deformity.

Results Pre-operative back pain was 7.2 on a visual analogue scale. Back pain was reduced to 4.4 at discharge and 2.0 at the latest follow-up with a mean follow-up of 12 months ($p < 0.001$). The Frankel score remains constant or improved from D to E. Radiological segmental kyphosis was corrected from a mean of 16° to 4°

($p < 0.001$) post-operatively with a loss of 3° at the final follow-up, but still with significant corrections compared with the pre-operative measurements ($p < 0.003$).

Conclusion Single-stage posterolateral vertebrectomy and reconstruction is a safe and less invasive approach that allows a sufficient reduction of hyperkyphosis and preservation of neurological function in patients with MESCC. This approach is an efficient alternative to anterior–posterior fusion with good pain reduction and improved sagittal profile.

Keywords Metastatic epidural spinal cord compression (MESCC) · Kyphotic deformity · Costotransversectomy · Thoracic stabilization

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Objective

Spinal metastases frequently cause metastatic epidural spinal cord compression (MESCC) due to anterior or bilateral tumour growth and additional instability [6].

MESCC is estimated to occur in between 5 and 10 % of patients with cancer, most commonly of the breast, prostate and lung, and in up to 40 % of patients who have pre-existing bone metastases outside of the spine [3, 36].

Due to the ventral aspect of the pathology and to avoid neurological deficits [27], a surgical procedure was developed to obtain a circumferential decompression [33] by an anterior approach with the opportunity for immediate stabilization [20, 38]. Frequently, this procedure has to be combined with a posterolateral decompression and circumferential fixation with a subsequent surgery through a posterior approach.

Approximately 60 % of MESCCs are located in the thoracic spine [2, 31]. However, the ventral approach to the

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upper and midthoracic region is particularly challenging [17]. Therefore, a single-stage posterior approach to decompress the ventral aspect of the spinal cord has become more popular due to its less invasive nature [1, 4, 5, 9, 43]. A biomechanical stable fast and safe reconstitution with preservation of neurological function and complete resection is achievable, but in contrast to the ventral approach, the possibility of kyphotic deformity reduction has been less frequently reported [1, 9, 10, 20, 43].

Panjabi et al. noted in their biomechanical analysis that abnormal thoracic kyphosis caused a mechanical response that further increased thoracic kyphosis and that an abnormal thoracic configuration created a vicious cycle of abnormal tissue loading [21, 29, 30]. Hato et al. found in a finite-element analysis of closing-opening correction osteotomy for angular kyphosis of vertebral fractures that the lack of correction leads to an increased stress on the vertebral column [21, 25]. From the biomechanical point of view, the advantage of correcting the kyphotic angle as close as possible to physiological alignment in the thoracolumbar spine is proven. Otherwise, it will lead to clinical complications such as progressive back pain, instrument failure, and neurological deterioration.

Therefore, we investigated the efficacy and feasibility of the previously described single-stage approach with special attention to the reconstruction of kyphotic deformity in patients with MESCC.

Materials and methods

Study inclusion criteria

The study included patients who underwent posterior vertebral column resection with 360° osteosynthesis in MESCC and spinal instability with segmental kyphosis between December 2012 and April 2014.

Spinal instability was diagnosed on the basis of radiographic findings (pathological fractures with posterior element extension) combined with level-specific pain patterns that had been described previously in the Spine Instability Neoplastic Score criteria evaluation [15].

Patients also had to have at least one neurological sign or symptom (including pain) and were required not to have been paraplegic for longer than 24 h before study entry to improve neurologic deterioration [13]. The MESCC was restricted to a single thoracic area, which included only one vertebral body. Patients with certain radiosensitive tumours (e.g., lymphomas, leukaemia, and germ-cell tumours) and without extensive neurological deficits were excluded. The hyperkyphosis was defined as a pathologic accentuation of this normal curvature compared to cranial and caudal

segments. In the case of plasmocytoma, single vertebral destruction is often osteolytic. This may produce mechanical instability with the risk of secondary fractures combined with kyphosis and spinal cord compression. Neurologic deterioration should be avoided in these cases, and therefore, these indications with kyphotic deformity already present were also included. Overall, a multidisciplinary tumour board involving specialists in radiology, oncology, pathology, and spinal surgery had to give the patient a minimal survival time of at least 2 years. The decision to treat the patient surgically was influenced by common scoring systems for the pre-operative evaluation of metastatic spine tumour prognosis [38, 39] to understand life expectancy and quality [7, 12].

Prospective documented medical records were retrospectively reviewed. For pain quantification, the visual analogue scale (VAS) was used [37]. Long-term outcome assessment was conducted with the Oswestry Disability Index (ODI), as described by Fairbank [11]. Long-term functional outcome was assessed using the Frankel score [18]. General well-being and activities of daily life were assessed by Karnofsky performance status [24]. The fusion rate was divided into five grades: grade 0, no healing; grade 1, minimal consolidation of bone graft; grade 2, bone graft consolidation; grade 3, bridging callus; and grade 4, bridging callus with trabeculations.

Segmental shortening of the spine was calculated from the height of the two adjacent vertebral bodies. The mean height was equalized to the supposed height of the affected vertebral body before metastatic involvement and was set in relation to the height between the two adjacent endplates after surgical treatment.

Technique

The single-stage posterolateral approach with posterior corpectomy and 360° decompression of the neuronal structures as well as anterior and posterior stabilization is shown in Fig. 1, and was previously described [9]. For sagittal alignment reconstruction, complete tissue removal was required to prevent spinal cord compression during the procedure and create enough space for re-lordosation. This mobilization of the upper against the lower levels simplifies re-lordosation during the reconstruction manoeuvre and avoids implant failure.

Once resection of the vertebral body and adjacent discs was complete, the length and width of the cavity were measured using fluoroscopy and compared with the pre-operatively measured height and width dimensions on the CT/MRI-scan. Two length-adjusted mesh cages were created and filled with cancellous bone from the iliac crest. None of the locally excised bone was used for grafting.
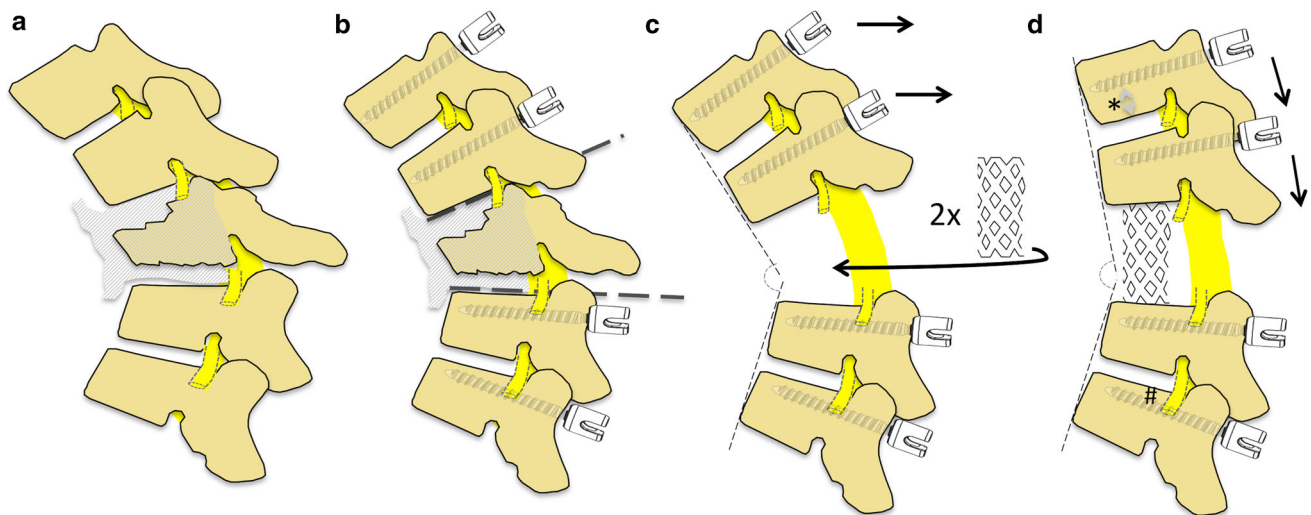
Fig. 1 Schematic illustration of the surgical procedure. **a** The involved vertebral body with metastatic spinal cord compression (*grey*) and kyphotic deformity is shown. (**b**) The vertebrectomy with resection of adjacent discs. The temporary rod to avoid distraction is not shown. The titanium mesh cage is applied in the decompression cavity without distraction manoeuver (**c**), which provides the opportunity to perform the correction manoeuvre using the mesh as a hypomochlion and re-lordose by consecutive compression through the screw-rod system (**d**). The live operative procedure is performed with two mesh cages, as shown in (**c**)

The mesh cages were placed into the cavity on each side with fluoroscopic guidance. Due to the implantation of one mesh cage on each side, only a small space was necessary. To perform the re-lordosation manoeuvre, dorsal structures (i.e., facet joints, lamina, and partial pedicles) had to be removed in order to create enough space. The implanted mesh cages acted like a hypomochlion around the re-lordosation (Fig. 1). Length-adjusted rods precontoured to the former anatomic shape were finally fixed and step-by-step shortening was performed under fluoroscopic control with gentle manual palpation of the spinal cord. To avoid loosening or even break out of the screws due to a relatively high force on the screws during the step-by-step shortening and reconstruction of sagittal alignment, the caudal segments were fixed and the cranial segments were converged stepwise to the caudal segments because of higher counter bearing. Cranial pull-out of the screws can thus be avoided (Fig. 1d *,#). Neuroforaminal exits were checked to avoid nerve root entrapment. A posterior spondylodesis was performed at all levels. Standard wound drainage and stepwise suture closures of the fascia and skin completed the procedure (see Fig. 2).

Follow-up

Further oncology therapy was performed as determined by the interdisciplinary tumour board. Patients received early physiotherapeutic mobilization and required no extended post-operative bed rest.

Post-operative radiographs and clinical data were obtained after surgery, before discharge, and during follow-up visits that took place 3, 6, and 12 months after surgery, and annually after the first year.

Follow-up time was calculated from the time of surgery until the date of the last follow-up. Statistical analysis was carried out using Wilcox test for paired data. A significant difference between the groups was assumed when $p < 0.05$. Statistical Product and Service Solutions software version 15.0.1 (SPSS Inc., Chicago, IL) was used for computed analysis.

Results

A significant reduction of hyperkyphosis and preservation of neurological function could be observed in all 14 patients [8 male (57.1 %) and 6 female (42.9 %)].

The pre-operative Tomita Scores were evaluated with a mean of 4.1 (range 2–7), the Tokuhashi Score had a mean of 9.5 (range 8–11), and the Spinal Instability Neoplastic Score mean was 12 (range 10–14). The mean pre-operative Karnofsky performance status scale was 75 pre-operative (range 50–100) and 80 at latest follow-up (range 60–100).

The mean age at surgery was 63.6 years (range 51–78 years). The mean surgical time was 278 ± 64 min (Table 2). The mean follow-up time was 12 months (range 3–21 months).

Histological diagnoses of the primary tumours are shown in Table 1. The most common tumour types were plasmacytoma (35.7 %, $n = 5$), breast cancer (21.4 %, $n = 3$), and renal cell carcinoma (14.2 %, $n = 2$, patients #6 and #11, treated with pre-operative embolization).

Fig. 2 Exemplary documentation of patient # 4: **a** pre-operative CT-Scan in the lateral plane showing a severe deformity with 20° kyphosis, **b** sagittal pre-operative T2 MRI-Scan with compression of the spinal cord with metastatic destruction of the vertebral bodies, **b** pre-operative T2 MRI-Scan with intra-spinal mass in the axial plane causing stenosis of the spinal cord and acute walking ataxia at the patient's clinical examination, **d** post-operative axial CT-Scan with decompression and two mesh grafts in place, **e** post-operative CT-Scan in the sagittal plane showing the reconstruction of the spine and the reduction of kyphotic deformity (4°). A.p. X-ray and lateral X-ray showing the reconstruction and improved kyphotic deformity in the follow-up examination (**f**, **g**)

Anatomic localization as well as the length of decompression (shortening of the treated segment in comparison with the supposed height of the affected vertebral body before metastatic involvement) and instrumentation are shown in Tables 1 and 3.

On average, the patients reported pre-operative back pain of 7.2 on the VAS (range 4–10) with a reductions to 4.4 (range 2–6) at discharge and 2.0 (range 0–5) at the latest follow-up ($p < 0.005$).

On ODI at latest follow-up, 35.7 % of the patients scored minimal disability (0–20 %), 50.0 % reported moderate disability (21–40 %), 14.3 % had severe disability (41–60 %), and there were no reports of complete disability at the last follow-up. Initial ODI was not

Table 1 Histological data of all patients, resected vertebra, and extent of instrumentation

Patient	Age	M/f	Tumour	Resected vertebral body (T)	Highest instrumented vertebra (T)	Lowest instrumented vertebra (T)	Period of follow-up (month)
1	51	M	CUP	3	2	4	13
2	56	M	Plasmacytoma	11	9	L1	18
3	53	F	Plasmacytoma	5	4	6	15
4	78	F	Breast cancer	5	3	7	4
5	63	F	Breast cancer	3	1	5	10
6	57	M	Plasmacytoma	11	9	L1	16
7	77	F	Renal cell carcinoma	9	7	9	21
8	62	M	Pulmonary cancer	3	1	5	6
9	64	M	Renal cell carcinoma	8	6	11	3
10	77	F	Breast cancer	2	C5	5	6
11	62	M	Plasmacytoma	11	9	L1	13
12	56	M	Gist	8	7	9	16
13	74	F	Rectal cancer	12	10	L2	15
14	61	M	Plasmacytoma	3	1	5	11

m male, *f* female, *CUP* cancer of unknown primary, *gist* gastrointestinal stromal tumour, *T* thoracic vertebra, *C* cervical vertebra, *L* lumbar vertebra

Table 2 Operative data with the duration of surgical procedure, blood loss, and clinical data with pre- and post-operative neurologic outcome score according to Frankel [18], post-operative Frankel Score is concordant to follow-up, all follow-up data were raised at latest follow-up

Patient	Operation time (min)	Blood loss (ml)	Pre-operative Frankel Score	Post-operative Frankel Score	Pre-operative Karnofsky	Karnofsky at follow-up	SINS Score	ODI at follow-up
1	340	1800	D	E	100	100	13	35
2	320	5000	E	E	80	70	14	44
3	210	1500	E	E	100	100	10	14
4	380	1000	D	E	50	70	13	20
5	240	2000	E	E	90	90	11	45
6	340	6100	E	E	80	80	13	14
7	210	3300	E	E	70	80	11	36
8	200	800	E	E	80	90	13	18
9	220	800	D	E	80	80	12	28
10	380	2800	E	E	70	70	11	33
11	240	1200	E	E	60	60	12	18
12	350	1500	E	E	60	70	12	24
13	260	1800	E	E	70	90	13	33
14	260	2000	E	E	60	70	10	35

observed. The Frankel score improved from D to E (three patients) or was equal comparing pre- and post-operative scores. No neurological deterioration could be detected. The data are presented in Table 2.

No cases required further revision surgery due to persistent instability or neurological complications. No cases of chest drain placement, pulmonary complication or brace immobilization were encountered.

Radiographic data

Radiological segmental kyphosis was corrected from a mean of 16° (range 8°–26°) to 4° (1°–6°) ($p < 0.001$) post-operatively with a mean subsequent loss of 3° at the final follow-up ($p < 0.003$) according to the technique of Cobb [8] (Table 3). The angle was measured by CT-scan. However, the segmental kyphosis correction was still significant. The

Table 3 Radiometric data with pre- and post-operative kyphosis (two days after surgery) and kyphosis at follow-up and the percentage of segmental shortening

Patients	Kyphosis pre-op	Kyphosis post-op	Kyphosis follow-up	Shortening (%)	Length after shortening (cm)	Extend of fusion
1	26	4	5	65	0.8	1
2	12	5	16	39	1.8	2
3	21	6	12	63	0.9	3
4	20	4	6	46	1.2	n.a.
5	15	5	7	53	1	1
6	10	4	7	30	2	2
7	11	3	4	43	1.7	2
8	15	1	6	32	1.7	n.a.
9	8	1	1	13	2.1	n.a.
10	10	6	9	38	1.3	n.a.
11	21	7	7	29	2.1	3
12	9	4	10	26	1.9	2
13	26	1	8	23	2	2
14	17	6	9	18	1.8	3

n.a. not available

mean segmental shortening to the healthy segment was 0.94 cm on average (range 0.3–1.6 cm). In the radiological follow-up examinations, 20.0 % of the patients achieved a grade 1 bony fusion, 50.0 % had a grade 2, and 30.0 % reached a grade 3. No grade 0 healing was detected. No signs of screw loosening were observed (Table 4).

Discussion

This study found that the application of a posterior vertebral column resection with 360° osteosynthesis in MESCC constitutes a relatively fast, safe, and adequate surgical procedure, as described by others [1, 4, 5, 9, 43]. In contrast to others, we could further demonstrate that a significant reduction of kyphotic deformity is realizable.

Radiation therapy remains the first-line therapy in many patients with metastatic spinal tumours with confirmed effectiveness in avoiding neurological deterioration and long-term tumour control in patients without epidural compression [28]. However, decompression is indicated in patients with spinal metastases who have high-grade epidural compression (MESCC) with or without neurological deficit and three-column instability. One indication in this kind of patients is a fracture with spinal instability, spinal cord compression resulting from retropulsion of bony elements into the spinal canal. A second and different pathology is a metastatic mass lesion growing into the spinal canal mainly from anterolateral. In clinical results, both pathologies drive in the same result: a 360° decompression and stabilization in the established and described techniques [1, 4, 5, 9, 43].

Table 4 The presence of fusion and extent of fusion grading scales used to evaluate CT images

Grade	Presence of fusion	Extent of fusion
0	No healing	0 % (not healed)
1	Minimal consolidation of bone graft	1–25 % (healed)
2	Consolidation of bone graft	26–50 % (healed)
3	Bridging callus	51–75 % (healed)
4	Bridging callus with trabeculation	76–100 % (healed)

A prospective clinical trial of direct decompressive surgical resection and stabilization with radiotherapy vs. radiotherapy alone for MESCC from Patchell et al. revealed a significant difference in the ability of surgical patients to walk compared to those treated by radiotherapy alone (84.0 vs. 56.9 %, $p = 0.001$) [31]. A meta-analysis conducted by Lee [26] also supported this finding.

Even without existing neurological deficits, the preservation of neurological function in three-column destruction, progressive deformity and pain may be considered for stabilization procedures.

Therefore, Fisher et al. have proposed the Spinal Instability Neoplastic Score (SINS), which encompasses the location of the tumour, the character and type of pain related to movement, the quality of the bone, spinal alignment, vertebral collapse and involvement of the posterior elements [15]. SINS is valuable in deciphering which patients require a stabilization procedure partially independent of the histological type (i.e., plasmocytoma as hematologic neoplasm with primary systemic treatment options if, for example, progressive deformity occurs) [16].

Stabilization can be achieved via anterior or posterior approaches. However, in the cases of a necessary resection of more than 50 % of the vertebral body diameter, a reconstruction of the vertebral body is usually required, as the maximal load is transmitted through the anterior column [40]. This can be achieved by an anterior approach as described by Harrington [20]. The advantage of this approach is that in addition to the complete ventral decompression, it provides an excellent opportunity for deformity correction, which is, in terms of hyperkyphosis, not explicitly described in sole dorsal stabilization procedures in MESCC.

However, this anterior approach frequently has to be combined with a posterolateral decompression and circumferential fixation via a subsequent surgery through a posterior approach and is accompanied by additional approach-related complications, such as reduction of vital capacity due to manipulation of pleura and temporary lung collapse [42]. It is also important to note that the regular anterior approach is technically very demanding above T 5 or 6 [19], depending on patient anatomy. Pure dorsal approaches, as described in this study and in previous publications, allow access to the entire thoracic vertebral column [9].

To avoid a two-stage procedure, many authors have performed a single-stage posterior or a posterolateral approach [1, 4, 5, 9, 43]. The surgical technique, as well as the indication of three-column tumour decompression and dorsal instrumentation via a single-stage dorsal or dorsolateral approach, is similar in the majority of published series [1, 4, 5, 9, 23, 43].

Amankulor, Bilsky, and Wang et al. recommended a surgical approach for MESCC with vertebral body involvement through a transpedicular resection of the vertebral body with anterior reconstruction using polymethyl methacrylate (PMMA) and Steinman pins (4,43, and 2). Studies suggest that PMMA reconstruction provides good mechanical stability and possible intrinsic antineoplastic properties [10, 32].

Eicker, Eleraky, Hofstetter, and Jandail modified this technique using expandable cages or titanium mesh cages with the advantage of less artefacts in follow-up imaging by magnetic resonance imaging (MRI) in comparison with the ferromagnetic artefacts produced by the Steinman pins and better ossification [9, 10, 22, 23].

Common in all publications is the missing characterization of the correction of hyperkyphotic deformity. Usually described is only the preservation of a pre-operative existing deformity without progression in follow-up examination [2, 4, 9, 22].

Eleraky et al. [10] reported a slightly improved lordosis for expandable cages compared to PMMA reconstruction after a single-stage lumbar posterolateral approach, which did not reach significance. In contrast, this study supports that further deterioration and implant failure can be prevented with sufficient decompression and stabilization as well as hyperkyphosis reduction with reconstruction of the sagittal alignment.

Our described technique combined the idea of sufficient correction of a pathologic hyperkyphosis with the reduced invasiveness of a single-stage dorsal approach. A mean radiological proven segmental kyphosis correction of 12° was performed. This may reduce back pain and lead to lower hardware failure rates. From clinical point of view, this can also be detected in the improvement of quality of life [7, 12, 14, 26, 34].

One reason for the possible correction of deformity in the presented study is the opportunity of segmental shortening without neurological deterioration. According to Tomita, column shortening can be characterized into three phases: Phase 1 (safe range) involves spinal shortening within one-third of the vertebral segment, which is characterized by no deformity of the dural sac or the spinal cord. Phase 2 (warning range) has spinal shortening between one-third and two-thirds of the vertebral segment, which is characterized by shrinking and buckling of the dural sac and no deformity of the spinal cord. Phase 3 (dangerous range) is when spinal shortening occurs in excess of two-thirds of the vertebral segment, which is characterized by spinal cord deformity and compression by the buckled dura [41].

The results of this study showed a mean shortening of 37 % with seven cases of Phase 1 shortening and seven cases of Phase 2 shortening, with a maximum of 65 %. No neurological deterioration could be detected directly after surgery or on follow-up.

Second, a stepwise compression of the anterior titanium mesh between the vertebral body was performed, using the mesh as a hypomochlion. This procedure results in a reduction of kyphotic deformity with an accompanied compression and therefore, fixation of the implanted cages. This leads on to anterior vertebral column stability with low loss of correction on follow-up and no hardware failure.

Amankulor et al. also described a low rate of symptomatic hardware failure in patients with MESCC undergoing posterior decompression and instrumentation of 2.8 % [2]. His patient population had a limited life expectancy. Surgery was indicated regardless of the number of spinal column metastases or pathology. In this work, risk factors were detected for symptomatic hardware failure: iatrogenic chest wall destabilization after rib resection, construct lengths spanning six or more contiguous vertebral segments, and women with MESCC. In addition, the work of Quraishi [35] described lower complication rates in patients with lower epidural spinal cord compression (ESCC).

In this study, none of the patients had an iatrogenic chest wall destabilization due to a modified costotransversectomy with avoidance of the additional anterior approach.

Furthermore, instrumented segments were always less than six levels, and the women in this study were in three of six cases patients with breast cancer with good prognosis compared with other tumour entities.

In addition to hardware failure, Akeyson et al. described in his group of patients a mean survival time of 29 weeks and a total of 13 complications in 25 patients [1]. Four of these complications were each cerebrospinal fluid fistulas or migration of hardware. In the present series, pedicle instrumentation was performed instead of Luque rectangle, which leads to higher primary stability. In combination with the compression/shortening technique, hardware failure could not be detected during the mean follow-up time of 12 months. In addition, no dural tear or fistula was detected.

In the work of Fehlings et al., two patients required a second spinal surgery: one for progressive neurologic deficits as a result of a spinal hematoma and one for screw malposition [14].

In the presented series with subselected patients (expected survival time above 2 years, not being paraplegic for longer than 24 h before study entry), the bias is obvious, but characterizes exactly the patients in which this procedure should be used.

Limitations

The limitations of this study include its retrospective nature and the relatively short follow-up time. Consequently, we were unable to account for other medical conditions that may have confounded the results. The small sample size as well as patient selection might have contributed to a certain selection bias.

Conclusion

Adequate tissue removal, custom tailored relative small titanium cages, and a stepwise reduction of the kyphotic deformity led to significant kyphotic correction 2 days after surgery as compared to the pre-operative measure. Although the kyphotic deformity slightly increased over the follow-up period, the degree of kyphotic deformity remained significant less than pre-operatively. In addition, patients reported sustained pain relief and there were no neurological deterioration post-operatively.

Compliance with ethical standards

This work is completed under compliance with Ethical Standards.

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