Acta Orthopaedica et Traumatologica Turcica 51 (2017) 201–208

Contents lists available at ScienceDirect

Acta Orthopaedica et Traumatologica Turcica

journal homepage: https://www.elsevier.com/locate/aott

Analysis of complications following posterior vertebral column resection for the treatment of severe angular kyphosis greater than 100°

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A R T I C L E I N F O

Article history:
Received 19 July 2016
Received in revised form
26 February 2017
Accepted 27 February 2017
Available online 16 May 2017

Keywords:
Posterior vertebral column resection
Severe angular kyphosis
Complication
Neurological deficit
Neuromonitoring

A B S T R A C T

Objective: The aim of this study was to evaluate the complications, efficacy and safety of posterior vertebral column resection (PVCR) in severe angular kyphosis (SAK) greater than 100°.
Methods: The medical records of 17 patients (mean age 17.9 (range, 9–27) years) with SAK who underwent PVCR, were reviewed. Mean follow-up period was 32.2 (range, 24–64) months. Diagnosis of the patients included congenital kyphosis in 11 patients, post-tuberculosis kyphosis in 3 patients and neurofibromatosis in 3 patients. The sagittal plane parameters (local kyphosis angle, lumbar lordosis, sagittal vertical axis, pelvic tilt, sacral slope and pelvic incidence) were measured in the preoperative and the early postoperative periods and during the last follow-up on the lateral radiographs.
Results: The mean preoperative localized kyphosis angle was 121.8° (range, 101°–149°). The mean local kyphosis angle (LKA) was 71.5° at postoperatively evaluation ($p < 0.05$). Complications were detected in 12 patients (70.6%) with spinal shock in 4 patients, hemothorax in 3 patients, postoperative infection in 2 patients, dural laceration in 2 patients, neurological deficit in 2 patients (1 paraplegia and 1 root injury), the shifted cage in 2 patients and rod fracture in 2 patients. Neurological events occurred in six patients (35%) with temporary neurological deficit in 5 patients and permanent neurological deficit in 1 patient.
Conclusion: PVCR is an efficient and a successful technique for the correction of SAK. However, it can lead to a large number of major complications in SAK greater than 100°.
Level of evidence: Level IV, therapeutic study.

Introduction

Angular kyphosis is a spine deformity in the sagittal plane that may be present with various etiologies such congenital, neurofibromatosis and post-tuberculosis. Particularly, the severe forms may cause significant cosmetic problems in addition to psychosocial and self-esteem issues related to self-image. In our previous study, we found that the surgical treatment of kyphosis was uniformly associated with improved quality of life, after comparing two different groups (sharp and round) by showing patients their preoperative and postoperative clinical photographs. This shows that improvement in the surgical treatment of all kyphosis types provides a better quality of life for patients.[1] On the other hand, when the sagittal Konstam's angle was more than 90°, the patients had difficulty in movement later, they may acquire cardiopulmonary problems or can experience low back or costopelvic impingement pain, which can deteriorate the function of respiration and digestion due to compressive effects of the deformity on the abdomen and may cause neurological deficit that cause morbidity.[2,3] There is a need for complex and complicated surgery for their treatment such as vertebral column resection (VCR). VCR includes resection of one or more vertebral segments and can be implemented using either only posterior procedure or combined

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Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

http://dx.doi.org/10.1016/j.aott.2017.02.015
1017-995X/

anterior and posterior procedures. VCR provides correction of the sagittal and multiplanar deformity. In 1922, MacLennan first described VCR as a combined anterior and posterior procedure,[4] while Bradford firstly described it as a severe, rigid spinal deformity.[5] Boachie-Adjei and Bradford expanded the case series by reporting patients who had undergone VCR.[6] Suk et al were first to introduce the posterior vertebral column resection (PVCR) procedure.[7] Then, Lenke[8] started using the VCR procedure for the treatment of severe spinal deformities, specifically recommending only a posterior approach. PVCR is a demanding and difficult surgical procedure that requires advanced experience.

Earlier studies have demonstrated that PVCR in patients with severe spinal deformity provided excellent outcomes.[9–11] However, the surgical treatment of severe angular kyphosis (SAK) in some literature had proven to be of high risk complications.[12,13]

Hypothesis of our study showed whether or not PVCR procedure has high risk complications for the treatment of SAK greater than 100°. Complications were analyzed in detail.

Patients and methods

In our study, we retrospectively reviewed 17 patients (7 males and 10 females) with SAK who underwent a PVCR between the year 2011 and 2014. Patients excluded from the study had a history of pedicle subtraction osteotomy (PSO) and other surgical treatments for angular kyphosis and round kyphosis. Clinical records were reviewed for demographic data and etiology of the lesion, and Frankel grades of neurological status were evaluated. The mean age of the patients was 17.9 (range: 9–27) years preoperatively. Diagnosis of the patients included congenital kyphosis in 11 patients, Pott's kyphotic deformity in three patients and neurofibromatosis in three patients. Seven patients had previous surgeries (five had posterior growth arrest, one had posterior fusion and one had tethered cord) (Table 1). During the examination, lower extremity motor and sensorineural status, deep tendon reflexes and pathologic reflexes were assessed and the findings were noted according to Frankel grading system. The patients were sub-grouped based on the etiology of SAK. Flexibility for SAK was assessed on hyperextension bolster lateral radiographs. All participants had pure kyphosis, which was confirmed on the posteroanterior and lateral radiographs. Local kyphosis angle, lumbar lordosis, cobb angle of curve of the spine in coronal plane, pelvic tilt, sacral slope, pelvic incidence and sagittal vertical axis measurements were processed preoperatively, postoperatively and during follow-up radiographs by DICOM medical imaging software (Nemaris Inc, New York, NY).[14] All parameters were measured by the first author. Preoperatively, all patients for planning for surgery were evaluated with standing posteroanterior and lateral 36-in radiographs, three-dimensional computed tomography and magnetic resonance tomography combined, especially to understand the patho-anatomy of apical region in SAK before surgery.

For statistical analysis of the radiographic measurements, we used SPSS 11.5 (Lead Technologies, Inc., Chicago, IL, USA). Wilcoxon's signed-rank test was used for the comparison of local kyphosis angle, sagittal vertical axis, lumbar lordosis and deformity correction. P values of <0.05 were accepted as significant.

Surgical technique

Only posterior procedure was performed on all patients (Figs. 1, 2 and 4). The patients underwent surgical procedure by two different surgical teams in our clinic. The location of the PVCR was preferred at the apex of the deformity in all patients. After standard posterior exposure, pedicle screws were placed using a free-hand technique as segmental, except for the resected levels. After wide laminectomy, transverse processes and bilateral foraminotomies at PVCR level were performed, we put temporary rod on one level above screw and one level below screw of the PVCR level. We could sacrifice nerve roots and could resect rib heads to facilitate exposure in the thoracic spine. Subperiosteal dissection was done on the lateral wall of the vertebral body. Discs above and below the planned resection level, the pedicles and the vertebral body of planned resection level were removed by using osteotomes or high-speed burr. We used curette, Kerrison rongeur and pituitary forceps to remove bone tissue under the spinal cord, thus minimizing trauma to it. The temporary rod was placed to the other site and started to work on the opposite site. The resection carried on similarly on the opposite side. The discs and endplates of the neighboring vertebrae were cleaned off any remaining cartilage to hinder pseudarthrosis. We aimed to do correction by resecting the least amount of vertebral column for the surgical treatment of SAK. A high-speed drill was used in all the stages of corpectomy to prevent from neurological deficit. We performed VCR on more than one-level when spinal cord was being compressed by the cephalad and the caudal parts of adjacent segment to VCR. After the PVCR was applied, the gap of vertebral body/bodies was filled with a titanium mesh cage (16 patients) or expandable cage (one patient). Autologous bone graft was inserted into the cage. The correction was gradually performed by doing compression on rod.

During surgery, we routinely monitored the spinal cord. The surgical intervention was continued whether or not returning to baseline data for spinal cord monitoring. When spinal cord function impairment occurred during the surgical procedure, that is, lost neurogenic motor evoked potentials (NMEPs), intraoperatively, we would stop the surgical intervention and place a temporary rod and then wait for return of NMEPs, since the spinal cord could be damaged if we don't quit the surgery. Before the surgical intervention ended, we performed all standard strategy steps (we checked for technical problems, metabolic or electrolyte imbalance, low body temperature, hypotension, anemia, residual compression on spinal cord and the position of all screws) to improve the signal loss. Mean arterial pressure and hematocrit were raised to preoperative level. The spinal distraction or compression was released. Intraoperative steroid injection was done. Methylprednisolone was given as bolus half of 30 mg/kg. If the patient did not have any neurological deficit postoperatively, we did not continue medical treatment. Then, if these maneuvers did not restore intraoperative neuromonitoring, Stagnara wake-up test was performed. However, if intraoperative neuromonitoring still did not normalize to the same values as before surgery, we ended the surgical intervention and after a temporary rod was placed, the incision was closed.[15] Afterwards, if neurological deficit continued postoperative period, we gave the patients the remaining methylprednisolone dose. Then, we continued with infusion at 5.4 mg/kg/h for 23 h. Finally, methylprednisolone dose was tapered off. If patients did not have neurological deficit after they woke up, they generally underwent a second operation 2 weeks later.

All patients were braced for 6 months after surgery. Measurements of deformity magnitude and balance were made on 36-in. Standing anteroposterior and lateral radiographs were obtained for follow-up after surgery. Follow up sessions were scheduled 2 weeks, 1, 3, 6, 12 and 24 months postoperatively.

Results

The average follow-up period was 32.2 (range: 24–64) months. The PVCR were performed at T5 level in one patient, T7 level in two patients, T8 level in two patients, T9 level in two patients, T10 level in two patients, T12 level in seven patients and L1 level in one patient. Thirteen of these procedures were performed in a single

Table 1
Patient demographics.

	Sex	Age (years)	Preoperative history	Preoperative neurological status	Preoperative local kyphosis angle (°)	Diagnosis	Corpectomy level	Number of resected vertebral bodies	Intraoperative estimated blood loss (ml)	Duration of surgery (hour)	Complication
1	F	26			127	Post-tbc	T9	2,5	1600	7	Spinal shock
2	F	18	Released tethered cord in 7 years old		122	Congenital	2	1,5	2800	7	Dural laceration, unilateral progressive paraparesis
3	F	15			110	Congenital	T12	1	1600	4	Subluxation of the spinal column
4	F	20		Paraparesis	118	Post-tbc	T12	2,5	2000	8	Hemopneumothorax and superficial wound infection, ARDS
5	F	12		Paraparesis	101	Congenital	T12	2	2600	6	Spinal shock
6	F	15	Syringomyelia and local posterior apical fusion	Paraparesis	125	Congenital	T10	1	1800	5	Spinal shock, dural laceration and rod fracture
7	F	21	Released tethered cord in 6 years old and local posterior apical fusion		118	Congenital	L1	1	3500	8	Rod fracture
8	F	14	Syringomyelia, local posterior apical fusion, released tethered cord in 7 years old		149	Congenital	T12	1	3130	7	Deep wound infection and the shift of cage
9	F	14	Local posterior apical fusion and released tethered cord in 4 years old		104	Congenital	T8	1	3550	8	
10	M	22			130	Congenital	T10	1	1800	6	Hemopneumothorax
11	M	16	Local posterior apical fusion		110	Congenital	T12	1	2200	6.5	
12	M	9			123	Congenital	T12	2	1600	6	
13	M	20	Rod fractures after posterior fusion	Paraparesis	130	Neurofibromatosis	T9	2	1600	6	Paraplegia
14	M	18	Syringomyelia	Paraparesis	132	Neurofibromatosis	T8	1	2060	6	Hemopneumothorax and spinal shock
15	M	24	Syringomyelia	Paraparesis	106	Post-tbc	T5	2	2880	8	Cage migration
16	F	27	Syringomyelia	Paraparesis	127	Congenital	T7	2	2200	7	
17	M	13	Diplomyelia		138	Neurofibromatosis	T7	1	1800	6.5	

Fig. 1. This patient was 20 years old with severe angular kyphosis due to spinal tuberculosis. She was operated at single stage. Intraoperative and postoperative views of posterior vertebral column resection were resected. Hemopneumothorax occurred in this patient who underwent corpectomy in T12 level. She was drained by inserting of a chest tube. Infection superimposed on hemopneumothorax in this patient. This table turned into acute respiratory distress syndrome (ARDS). After receiving the treatment in an intensive care unit by chest surgery, the patient fully recovered after 40 days.

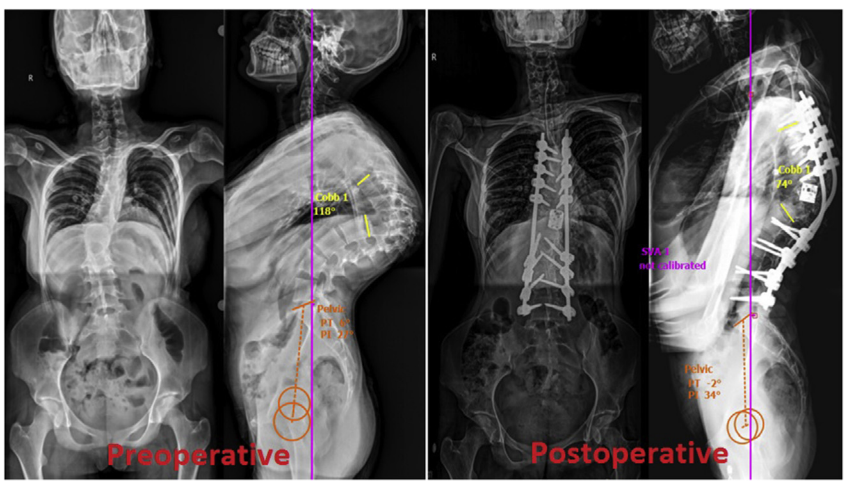

Fig. 2. Preoperative and postoperative anteroposterior and lateral radiographies of a patient with post-tbc kyphosis in Fig. 1.

stage with the remaining four treated with a two-stage procedure. The average number of resected vertebral bodies was 1.5 (range: 1–2.5). There were nine one-level, one and a half-level, five two-level, and two and a half-level resections. The average intraoperative estimated blood loss for all patients was 2280 (range: 1600–3550) ml. The mean duration of surgery was 6.6 (range: 4–8) hours. The average hospitalization after surgery was 24.3 (range: 8–54) days. The data of the patient demographics are presented in Table 1. The data of the sagittal parameters results are presented in Table 2.

According to Frankel classification grading system, the neurological status of the patients was Frankel E in 10 patients (58.8%), Frankel D in five patients (29.4%) and Frankel C in two patients (11.8%) preoperatively. During follow-up period, the neurological status of the patients was Frankel E in 12 patients (70.6%), Frankel D in three patients (17.6%), Frankel C in one patient (5.9%) and Frankel A in one patient (5.9%).

Preoperative localized kyphosis angle was 121.8° (range: 101°–149°). The mean local kyphosis angle (LKA) was corrected to 71.5° (the mean correction amount of LKA = 58.7%) at post-operatively evaluation ($p < 0.05$).

While neurological events occurred in six (35%) of the seventeen patients, complications occurred in 12 (70.6%) of the 17 patients.

The resulting neurologic complications were temporary neurological deficit (five patients) and permanent neurological deficit (one patient). Five patients (29%) lost NMEP intraoperatively while working around the spinal cord. Four patients experienced spinal shock during corpectomy. They underwent level T8, T9, T10 and T12 corpectomy respectively. Before the surgical intervention was stopped, we performed all standard strategy steps. Four patients were out of spinal cord shock in average 16 (range: 10–22) days (temporary neurological deficit) (Fig. 4). As a result, we performed two-stage procedure on four patients. One patient that had undergone level T7 corpectomy developed paraplegia. NMEPs were lost from both legs. Previously, the surgical intervention was stopped and lost signals were turned after 20 min but did not reach their preoperative levels. Later, we continued the operation since the corpectomy was ending but NMEPs were lost again, and were not regained postoperatively. The patient woke up with paraplegia. The patient did not improve during the 2 years follow-up period (permanent neurological deficit).

One patient had unilateral progressive paraparesis in the lower extremity, postoperatively. We assessed the patient with three-dimensional computed tomography and found that a screw got through the spinal canal and touched the spinal cord at right L1. The screw was taken out 2 days later. Afterwards, the deficit was

Fig. 3. This patient was 24 years old with severe angular kyphosis due to spinal tuberculosis. This patient was operated at single-stage. Severe cage migration occurred in this patient who underwent corpectomy in T5 level.

resolved 2 weeks after surgery (temporary neurological deficit). At the same time, the dura was damaged same level but BOS leakage was localized and it healed spontaneously postoperatively follow-up period.

Hemopneumothorax occurred in three patients (Fig. 1). Those patients underwent Level T8, T10 and T12 corpectomy respectively. Hemopneumothorax was drained by inserting a chest tube through the patients' chest walls. One patient developed an infection that turned into acute respiratory distress syndrome (ARDS). After the patient underwent a chest surgery and received treatment in an intensive care unit, she completely recovered after 40 days. At once, the patient had superficial wound infection, the infection was treated by taking antibiotics only.

Two patients (12.5%) had cage migration in our study. During follow-up period, Revision surgery was not necessary for these patients (Fig. 3). Two rod fractures and one implant failure occurred in three patients. The first patient with pseudarthrosis had a unilateral left rod fracture 18 months after the surgery. The second patient with pseudarthrosis had a bilateral rod fracture 6 months after the surgery. Rods were replaced and they were supported with one additional rod laterally. The pseudarthrosis region was debrided and decorticated. It was grafted with cancellous allograft chips and demineralized bone matrix resulting in pain-free solid fusion after 6 months. This patient had BOS leakage from corpectomy level. The treatment for dural tear directly was repaired with Prolene suture and adipose tissue was placed over the area of the dural leak. The third patient had an implant failure due to loosening of screw/rod connection after 1 month from the initial procedure, and at once, the patient had deep wound infection. The rods and loosened screws were replaced and the patient was supported with one additional rod. The infection was treated by debridement and antibiotic treatment.

Subluxation of the spinal column at T12 level occurred in one patient. Dural buckling was restricted after the rod was placed. The spinal cord was not compressed by the cephalad and the caudal parts of adjacent vertebra to PVCR and NMEPs were not deteriorated. The patient awoke with normal spinal cord function.

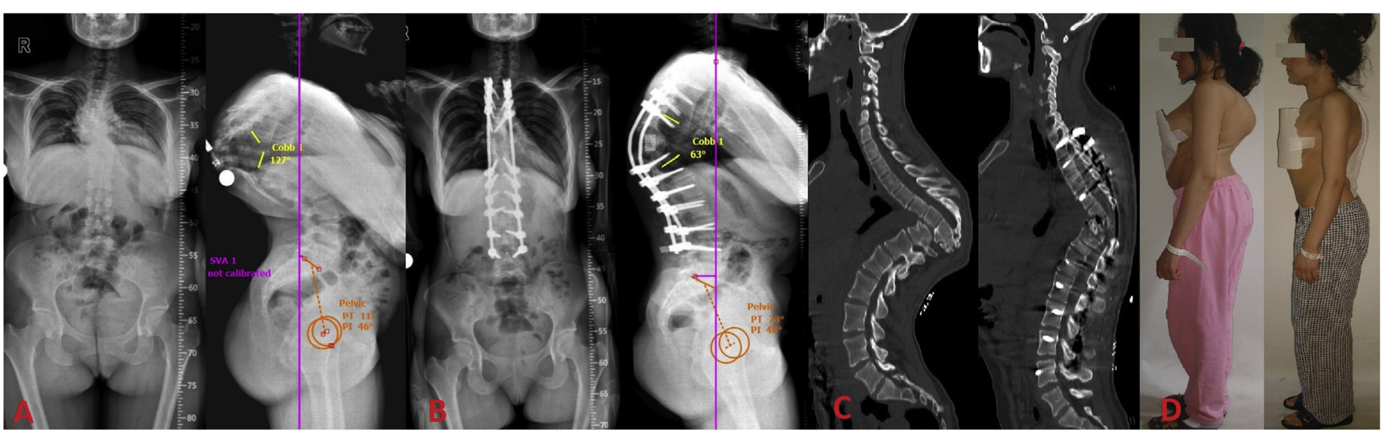

Fig. 4. This patient was 26 years old with severe angular kyphosis due to post-tbc SAK. This patient was operated at two stages due to spinal shock. A and B- The patient had his preoperative and postoperative anteroposterior and lateral radiographies, C- Preoperative and postoperative sagittal CT images and D- preoperative and postoperative lateral photographs.

Table 2
Radiographical data of the patients.

	Preoperative	Postoperative	The last follow-up
The mean local kyphosis angle (LKA) (°) = degree	121.8° (range, 101°–149°)	50.3° (range, 10°–80°) ($p < 0.05$) (The mean corrected LKA = 71.5° = 58.7%) ($p < 0.05$)	51.2° (range, 10°–84°) ($p > 0.05$)
The mean lumbar lordosis (LL) (°)	84° (range, 67°–98°)	63.5° (range, 43°–81°) ($p < 0.05$)	64.8° (range, 52°–80°) ($p > 0.05$)
The mean sagittal vertical axis (SVA) (mm)	32.6 mm (range, −29 to 160)	15.4 mm (range, −43 to 36) ($p < 0.05$)	15.6 mm (range, −45 to 29) ($p > 0.05$)
The mean pelvic incidence (PI) (°)	41.8° (range, 29°–83°)	41.2° (range, 27°–80°) ($p > 0.05$)	39.8° (range, 27°–78°) ($p > 0.05$)
The mean sacral slope (SS) (°)	30.9° (range, 9°–63°)	32.1° (range, 11°–73°) ($p > 0.05$)	30.7° (range, 15°–68°) ($p > 0.05$)
The mean pelvic tilt (PT) (°)	10.7° (range, 0°–34°)	9.1° (range, 0°–30°) ($p > 0.05$)	8.8° (range, 0°–24°) ($p > 0.05$)

Discussion

In SAK, the spinal cord is very close to the sharp edge at the posterior part of apical vertebral body. The long-standing mechanical compression and/or stretching of the spinal cord by this sharp edge of vertebral body may lead to paraparesis or paraplegia. McMaster et al detected neurologic injury development due to spinal cord compression in 11 of the 112 patients (approximately 10%) and congenital kyphosis (seven cases were Type 1 kyphosis) whose mean kyphosis angle was 111°.[16] Similarly, Winter et al reported a ratio of 12% paraparesis development in their series (all Type 1 kyphosis).[17] Meaning risk of the neurologic deficit is predictably high in severe congenital kyphotic deformities.[16–18] The literature indicates development of paraplegia in advanced (late stage) post-tubercular kyphotic deformity due to spinal cord compression.[19–22] Paraplegia or paraparesis is uncommon in spinal deformities with underlying neurofibromatosis; however, SAK with neurofibromatosis may result in worsening of neurologic deficit by either compression or stretching effect on spinal cord.[23,24] Winter et al have reported six paraparesis in 33 SAK cases (range: 80°–180°) with neurofibromatosis during follow-up period without surgery.[25] These data demonstrate that regardless of etiology, the incidence of developing neurologic deficit is considerably high in untreated SAK cases.[26,27] In conclusion, these cases must be treated.

VCR includes resection of one or more vertebral segments and can be implemented using either only posterior procedure or combined anterior and posterior procedures. VCR provides correction of the sagittal and multiplanar deformity. VCR was first described in 1922 by MacLennan as a combined anterior and posterior procedure.[4] In the modern era of spinal deformity surgery, VCR was firstly described by Bradford.[5] Boachie-Adjei and Bradford expanded case series by reporting patients who had undergone VCR.[6] For more than half a century, VCR was used for correction of severe spinal deformities.[7,8,28] Whatever the etiology for SAK, the surgical treatment of severe angular kyphotic deformities has always been demanding and may cause major complications. Suk and Lenke[7,8] developed PVCR procedure to reduce operating time, amount of blood loss and possible major complications. PVCR provides manipulation in every direction under simultaneous control of both the anterior and posterior sites of the spinal column and provides better correction than the other types of osteotomies. But, PVCR is a technically demanding procedure, with possible risks of major complications.[9,29] PVCR has certain advantages such as; shorter operating time, less blood loss, single exposure and anesthesia and the possibility of avoiding or minimizing pulmonary complications during anterior thoracic exposures. But it also has certain disadvantages. For example; you must work for along time by touching around spinal cord, pleura and vascular structure during resection of vertebral body and/or ribs; thus, causing dural tear, neurological deficit, pleural tear and vascular injury. It is also not possible to see all the body parts so, you sometimes must perform blind resection. Therefore, dural tear may occur at the anterior area of dura. This area is difficult to repair.[29,30]

Suk et al[7] presented the results of PVCR of 70 patients with spinal deformity. Twenty-four patients (34%) had complications: six patients had hematomas, five patients had implant failures, five patients had hemopneumothoraxes, four patients had nerve root injuries, two patients had complete cord injuries and two patients had infections. Lenke et al[8] reported that only PVCR technique and cage placement were done on 43 patients with severe spinal deformity. Forty (93%) procedures were performed to the cephalad of L2. A signal of NMEPs was not received in seven patients during correction intraoperatively. But, baseline signal values were improved in patients after necessary surgical intervention. It was determined that two patients had nerve root deficit postoperatively. Later, recovery of neurological deficit occurred in two patients. As a result, there was no neurologic deficit in this study. Ozturk et al[9] reported five major complications that included two postoperative infection, two dural laceration and one hemopneumothorax in five out of the 44 patients who severe deformity and underwent PVCR. There were no neurological complications, postoperatively, although the etiologies of all cases reported congenital. But, three patients developed motor evoked potential (MEP) changes intraoperatively. Intraoperative changes were detected in neuromonitor device related to translation due to neurological intact after surgery in all patients. Demirkiran et al[29] reported that only PVCR was carried out on nine of the 26 patients with congenital kyphoscoliosis. These patients did not encounter any neurological and vascular complications, but the mean kyphotic angle was corrected to 30.1° by the surgeon. In this study, PVCR group patients had moderate degree kyphosis (preoperative the mean kyphosis = 57.2°). None of the PVCR group patients had undergone a previous spinal procedure. Although the PVCR group did not have severe kyphotic segment and previous spinal surgery, they encountered various complications (two dural tears, one pneumonia and one screw pullout).

Several recent articles have demonstrated that PVCR may lead to major complications, especially neurological injuries.[3,31,32] For example, Wang et al[31] evaluated the efficacy and safety of PVCR for 24 patients with congenital SAK. These patients had an average segmental kyphosis 87.3° preoperatively. Four patients (17%) faced major complications (neurological deficit about 8%) postoperatively. Another study performed by Sacramento-Domínguez et al[32] showed that PVCR was performed on 98 patients with complex spinal deformity that have various etiologies and average localized kyphosis 104° preoperatively. Major complications occurred in 46 patients (47%) (neurologic in 25 patients (25.5%)) postoperatively. In our study, average localized kyphosis was 123° preoperatively. Complications occurred in 12 out of the 17 patients (70.6%). Neurologic complications occurred in six of these patients (35%). Average localized kyphosis was 123° preoperatively. If we take into consideration those studies, we can see that as the severity of spinal deformity increases, the risk of complications increase. Consequently, we can say that the indication of PVCR should be an alert for SAK and other treatment options should be considered for the surgical treatment of SAK.

Generally, we have performed PVCR for the surgical treatment of SAK greater than 90° in our clinic, but while performing closing wedge vertebral osteotomy for congenital kyphosis less than 90°. In our previous study,[33] we found that closing wedge osteotomy with posterior instrumented fusion is an efficient method of surgical treatment in terms of sagittal balance restoration and deformity correction in patients with congenital kyphosis less than 90°. The mean local kyphosis angle of patients was 67.7° (range: 42°–88°). Major complications occurred in three patients (30%). The first patient with pseudarthrosis had a bilateral rod fracture, the second patient had an implant failure due to loosening of screw/rod connection and the third patient had junctional kyphosis. Nevertheless, none of the patients had any neurological deficit or deep infection. In this study, the number and type of major complications was not high due to moderate deformity and easier osteotomy techniques according to PVCR, but there was increase in the number and types of complications.[33] The patients who underwent PVCR had preoperative problems such as, spinal cord pathology, paraparesis or had previously had a spinal surgery. The PVCR was performed by two different surgical teams. Kim SS et al[34] analyzed the incidence and risk factors of complications on 152 patients following performing a posterior vertebral resection (de-cancellation and PVCR) for spinal deformity (different etiologies). The complication rate of PVCR was 39.5%. There was temporary neurologic deficit in 21 patients (13.8%) and permanent neurologic deficit in five patients (3.3%). They concluded that risk factors of complications in patients who had preoperative neurologic deficit and preoperative kyphosis 22 times higher than those who had no prior deficits. Two important risk factors of postoperative neurologic deficit were obtained, the first was preoperative neurologic deficit and the second was resection of two or more vertebrae. Patients with two risk factors had 29 times higher neurologic complication rate.

In our study, we could have implemented over correction for SAK and therefore our patients came across many complications during or after PVCR procedure. Over correcting the SAK can lead to major complications. But, there is not a consensus on the optimal amount of correction necessary. During PVCR, neurological complications may occur due to different reasons. First, direct neurological injury may occur during bone resection around spinal cord or deformity correction. For this reason, there are necessary meticulous and experienced team of surgeons. Second, the use cage for anterior support during restoration after removing deformed anterior column. We must properly regulate its size and location. For example, the spinal cord and nerve roots can either get elongated or shortened and buckled. As well they can compress on tissues like the spinal cord and vessels. Third, the subsidence of mesh cage can occur during follow-up period depending on changes in the size of the angular kyphotic angle.[35] Fourth, subluxation of the spinal column.[9] And fifth, damage in spinal cord related to ischemia due to more touching and pressing of the spinal cord during surgery.[3]

In our study, five patients lost NMEP data while we were working around the spinal cord. Spinal cord was performed to retract and to press during bone resection. Vertebral translation occurred in one patient who did not end up losing any NMEP data. All patients had thinner spinal cord as a result of both direct compression and tension related to posterior sharp edge of middle vertebral column in kyphotic segment. Many patients had neurologic complications, due to several reasons. The first was spinal cord pathologies (some patients had syringomyelia that may occur due to the direct compression of kyphotic bone segment). The second reason was, preoperative neurologic deficit (some patients had paraparesis). We gently should retract from touching the spinal cord and should be more careful to prevent neurological events. Third was ischemia. We frequently should rest to spinal cord and should be more sensitive. The fourth reason was iatrogenically related to adhesions around spinal cord, mainly patients with post-tbc SAK had dural adhesions around bone tissues. In addition, if the patient has previous spinal surgery, there is the risk of dural adhesion. We should be more careful during the resection of bone in such cases. Neurological deficit has not been improved in one patient during intraoperative period, because we continued the bone resection in this patient despite losing NMEP data. We should wait for the normalization of the NMEP signal. In addition, we must have a well-trained neuromonitoring team and an anesthesia team.

Hemothorax is related to many factors during surgical procedure such as; central venous line insertion, incorrect placement of screws and hooks by penetrating to the thorax, the penetration of ribs to thorax during thoracoplasty, iatrogenically inducing the injury of intercostal or internal mammary arteries and their branches, during thoracoplasty or releasing the pleurae from the vertebrae after posterior correction of spinal deformity.[36,37] In this study, hemothorax iatrogenically occurred in three patients during PVCR. Two hemothorax occurred during releasing the pleurae from the lateral wall of vertebrae and the other during the resection of ribs. We found that the thickness of the tissues in different areas around the angular kyphotic segment had severely changed therefore easily injuring the pleurae. In such cases, we should be more careful and more gentle during releasing the pleurae from the ribs and vertebral walls.

We used titanium mesh cage in 16 cases. Titanium mesh cage usually is preferred to fill the gap of corpectomy area due to varieties of size; but we can see titanium mesh cage subsidence or migration. Severe subsidence can lead to neurologic deficit.[35] Yu Fan et al[30] analyzed the complications of PVCR in 40 patients with spinal tumors. They used titanium mesh cage. Subsidence occurred in six patients but they did not need to revise their cases. In our study, two patients (12.5%) had shifted cage in our study. Revision was not necessary for these patients during follow-up period.

In this study, dural laceration occurred in the two patients. One dural laceration was repaired intraoperatively, while the other healed spontaneously.

Limitations of our study were; having patients with various etiologies, limited number of patients, no control group for alternative surgical procedures, lack of intra- and inter-observer reliability measurement of the radiographic parameters and performance of the PVCR surgical procedure by two different surgical teams.

While performing PVCR for SAK more than 100° is more dangerous and involves more risk of neurological deficit, this procedure allows excellent correction of severe spinal deformity. We had MEP changes in five patients with spinal cord problems. Although spinal cord function impairment occurred during the PVCR procedure in one patient (lost neurogenic motor evoked potentials (NMEPs), intraoperatively), we continued to PVCR. This patient ended up with paraplegia postoperatively. Four patient's procedures were postponed until neurological deficit was healed. In such severe and complicated cases, we can initially plan a two stage procedure and therefore, the spinal cord can rest. In the surgery, the goal of the correction amount of kyphotic deformity must be enough to prevent neurological complications and organ dysfunction which may develop in the future. All spine surgeons must speak with the patients and their families about the risks of surgery. We can look over the PVCR procedure performed in SAK and we can search for alternative surgical procedures.

In conclusion, when comparing the preoperative, the early postoperative and the last follow-up parameters statistically, significant improvement was found in the local angular kyphosis angle ($p < 0.05$). We think that PVCR technique allows a great amount of correction of the large and stiff SAK deformities. Unfortunately, PVCR procedure for SAK more than 100° includes a lot of challenges and serious complications.

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