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DEFORMITY

Instrumentation Failure After Posterior Vertebral Column Resection in Adult Spinal Deformity

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Study Design. Retrospective study of instrumentation failure after posterior vertebral column resection (pVCR) in adult spinal deformity (ASD) patients.

Objective. The morbidity and related risk factors of the instrumentation failure.

Summary of Background Data. Instrumentation failure is another common complication after pVCR. But no report about it has been published before. The safety of titanium mesh cages (TMCs) for this failure is still unknown so far.

Methods. A total of 35 consecutive ASD patients (18 females and 17 males), who underwent pVCR between May 2005 and December 2014 in our hospital, were retrospectively reviewed. The mean age and follow-up period were 37.8 ± 12.8 years and 45.5 ± 27.3 months. Proportion was used to describe the morbidity of instrumentation failure. Potential risk factors were compared between patients with and without instrumentation failures by using Student *t* test or χ^2 tests (Fisher exact tests). Risk factors related to TMCs were analyzed in TMC group.

Results. There were 70 vertebra resected in total, with the mean of 10.3 segments instrumented. The mean correction rates of main curve (n = 25) and segmental kyphosis (n = 35) were 68.8% and 67.9%, respectively. Five patients (14.3%) suffered rod breakage. The failure was noted an average of 6.8 months after surgery. The risk factors included BMI (>27, $P = 0.026$), comorbidity (Achondroplasia, $P = 0.047$), and anterior column defect (ACD>20 mm, $P = 0.045$). TMC subsidence of ≥ 5 mm was the risk factor related to TMC in TMC group ($P = 0.041$).

Conclusion. It is safe to reconstruct with a TMC after pVCR in ASD, but the height should be as low as possible to reduce ACD. For those patients with risk factors, autologous bone graft and a satellite rod should be considered. If TMC subsidence ≥ 5 mm, a frequent follow-up should be performed.

Key words: adult, complication, instrumentation failure, posterior vertebral column resection (pVCR), retrospective study, risk factors, rod breakage, spinal deformity, subsidence, titanium mesh cage (TMC).

Level of Evidence: 4

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Vertebral column resection (VCR) is the most powerful operative technique and reserved for severe spinal deformity. It was first illustrated by MacLennan for the treatment of severe scoliosis in 1922.[1] Then, it was performed by Bradford through a combined anterior and posterior approach in 1987.[2] To mitigate complications of anterior and posterior vertebral column resection (apVCR), the posterior vertebral column resection (pVCR) was introduced in 2002.[3]

VCR, as strictly defined by Lenke *et al*,[4] is a three-column circumferential vertebral osteotomy creating a segmental defect with sufficient instability to require provisional instrumentation. Although pVCR offers the advantages of reduced operation time and bleeding, more reliable reconstruction of the vertebral column, and abolishing the complications related to the anterior approach, it still has the high risk of complications with 32%.[3,5] Except for the neurologic complication, instrumentation failure was another common complication. But, no article predominantly concerning on this complication has been published yet.

The surgical technique of thoracolumbar spinal reconstruction is a difficult challenge for surgeons.[6] The anterior column is suggested to reconstruct with a titanium mesh cage (TMC) to avoid excessive shortening of the spinal cord when anterior gaps were more than 5 mm by Suk *et al*.[3] But TMCs cannot still represent ideal vertebra shapes for the reconstructions, there is a lack of intrinsic

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stability.[7] The addition of supplemental instrumentation may improve the stability. However, there are persistent problems of mechanical instability and instrumentation failure.

The purpose of this retrospective study is to answer the following problems: (A) what is the incidence of the instrumentation failure after pVCR in adult spinal deformity (ASD); (B) what are the related risk factors; and whether (C) is it safe to reconstruct with TMCs.

MATERIALS AND METHODS

Patients

A total of 35 consecutive ASD patients (18 females and 17 males), who had a spinal deformity in the coronal plane and/or the sagittal plane after skeletal maturation, were retrospectively reviewed. According to the types of the deformities, they were separated into two groups: kyphoscoliosis (in both coronal and sagittal planes) and kyphosis (only in the sagittal plane). All of them underwent pVCR between May 2005 and December 2014 in our hospital with at least 1-year follow-up. According to the definition of VCR,[4] the patients who only underwent hemivertebra resection were excluded. The major comorbidities included Pott disease ($n = 9$), Achondroplasia (ACH, $n = 3$), and Scheuermann disease ($n = 1$). The mean age was 37.8 ± 12.8 years (range 18–64 yr) and the mean follow-up period was 45.5 ± 27.3 months (range 14–127 months).

All the patients were followed up separately after 3, 6, and12 months of the surgery and each year afterward in the follow-up. The symptoms, signs, and X-rays were routinely collected every time. Computed tomography (CT) scans were only performed after 12 months of the surgery to evaluate the bone fusion at the locations of the osteotomy.

The Cobb angles of the main coronal curve and the segmental kyphosis were separately measured as Ruf description[8] before surgery, after surgery and at last follow-up based on X-rays. The heights of TMCs' subsidence were recorded by comparing the immediate postoperative and the last follow-up X-rays. The segmental angles of kyphosis were separately calculated with the corresponding standard values.[9] The instrumentation failures, including rod breakage, screws out, and cage dislodgment, were collected during the follow-up.

Surgical Procedures

The surgical plans were decided by all spine experts in the Department of Orthopaedics based on their X-rays, CT images, and MRI images. The location and the number of vertebrae removed were determined by the type of the deformity and the desired correction to restore the trunk balance. In the kyphoscoliosis group, the fusion level was from one level above the upper end vertebra of index curve to one level caudal to the lower end vertebra of the index curve. In the kyphosis group, three vertebrae above the resection to two vertebrae below the resection were fused in most of the patients.

The patients were placed in the prone position on a radiolucent operating table after general anesthesia. The spinous process, lamina, transverse processes, and facet joints of the vertebra in the fusion range were subperiosteal exposed by a standard midline incision. All pedicle screws were implanted by free hand, and confirmed by a fluoroscopy in these patients. A standard 2-rod construct was applied in all those patients.

The procedure of VCR was performed by a single-stage posterior approach as Suk description in 2002 by a senior spine surgeon.[3] The posterior elements, including the lamina with the transverse process, the facet joint, and the posterior parts of the pedicle, were first removed. In the thoracic spine, the rib heads were also resected. Then, the remnants of the pedicle, the vertebral body, and the adjacent discs were removed. If the osteotomy gap were too large (>5 mm), a TMC with autologous bone, combining allogenic bone if insufficient, would be applied to reconstruct the anterior column of the spine. Posterolateral spinal fusion was performed with the combination of autologous and allogenic bone graft.

An intraoperative monitoring with the combination of sensory evoked potential and motor evoked potential was performed during the operation. The number and the location of the resected vertebra, the diameter of the rod, the height of the cage, the diameters of the cage and the endplates, and the fusion levels were all recorded after surgery. Plastic brace was suggested to wear for at least 3 months after operation.

Statistic Analysis

Means and proportions were used to describe the overall sample as well as the groups identified by the presence or absence of instrumentation failures. All potential risk factors, including sex, age, body-weight index (BMI, ≤ 27 or >27), type of deformity (Kyphosis or Kyphoscoliosis), comorbidity (Achondroplasia, Scheuermann disease, and Pott disease), preoperative Cobb angle of main curve and Segmental Kyphosis, correction of segmental kyphosis, number of resected vertebra, fusion levels, location of resected vertebra (Thoracolumbal (TL) or Thoracic (T)/ Lumbral (L)), insert of TMC (yes or no), anterior column defect (ACD, ≤ 20 mm or >20 mm), rod diameter (≤ 5.5 or >5.5 mm), and crosslink (yes or no), were compared between patients with and without instrumentation failures by using Student *t* test or Chi-square tests (Fisher exact tests where appropriate). ACD was defined as the residual gap of anterior column after correction (see Figure 1). If there was no TMC, ACD was 0; if there was TMC, ACD was similar to the height of the TMC. Risk factors related to TMCs: subsidence of TMC (<5 or ≥ 5 mm), ratio of diameters for cage/endplate (≤ 0.5 or >0.5), and position of TMC (upright or oblique), were also analyzed by using Chi-square tests (Fisher exact tests where appropriate) in the TMC group ($n = 28$). The statistic analysis was performed with SPSS 19.0 (IBM Company, Armonk, New York, USA). *P* values of <0.05 were considered significant. The study design was

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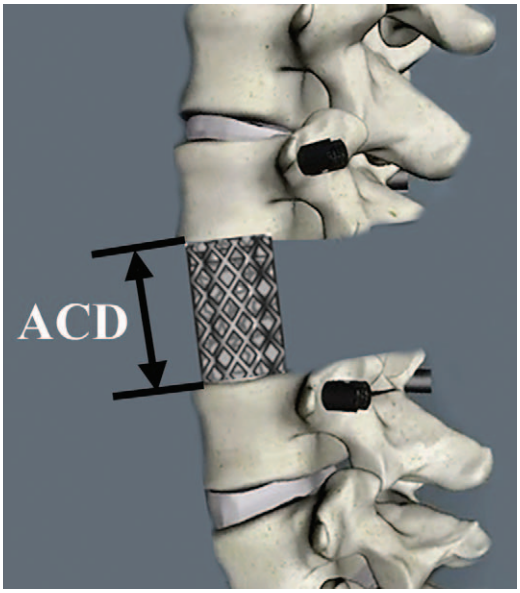

Figure 1. Definition of anterior column defect (ACD): the residual gap of anterior column after correction. If there is no TMC, ACD = 0; if there is a TMC, ACD = the height of the TMC. TMC indicates titanium mesh cage.

reviewed and approved by the Ethics Committee of authors' hospital.

RESULTS

General Characteristics

There were 10 patients with kyphosis and 25 patients with kyphoscoliosis included in this study. A total of 70 vertebrae were resected (range: 1–5) with the mean of 10.3 fusion levels (range: 2–14 levels). In the kyphoscoliosis group (n = 25), the main cure was corrected from preoperative 38.4° (range: 14–132°) to postoperative 14.3° (range: 0–78°) on average, and 16.6° (range: 2–83°) at the latest follow-up in the coronal planes. The mean correction rate was 68.8% (range: 31.3–100%). In both kyphosis (Figure 2) and kyphoscoliosis (Figure 3) groups (n = 35), the correction of the segmental kyphosis was from preoperative 94.3° (range: 31.5°–153°) to postoperative 31.2° (range: 2°–89°) on average, and 36.8° (range: 4°–90°) at the latest follow-up in the sagittal planes. The mean correction rate was 67.9% (range: 41.8–95.3%). There were four patients (11.4%) suffering from perioperative complications, including three neurologic complications

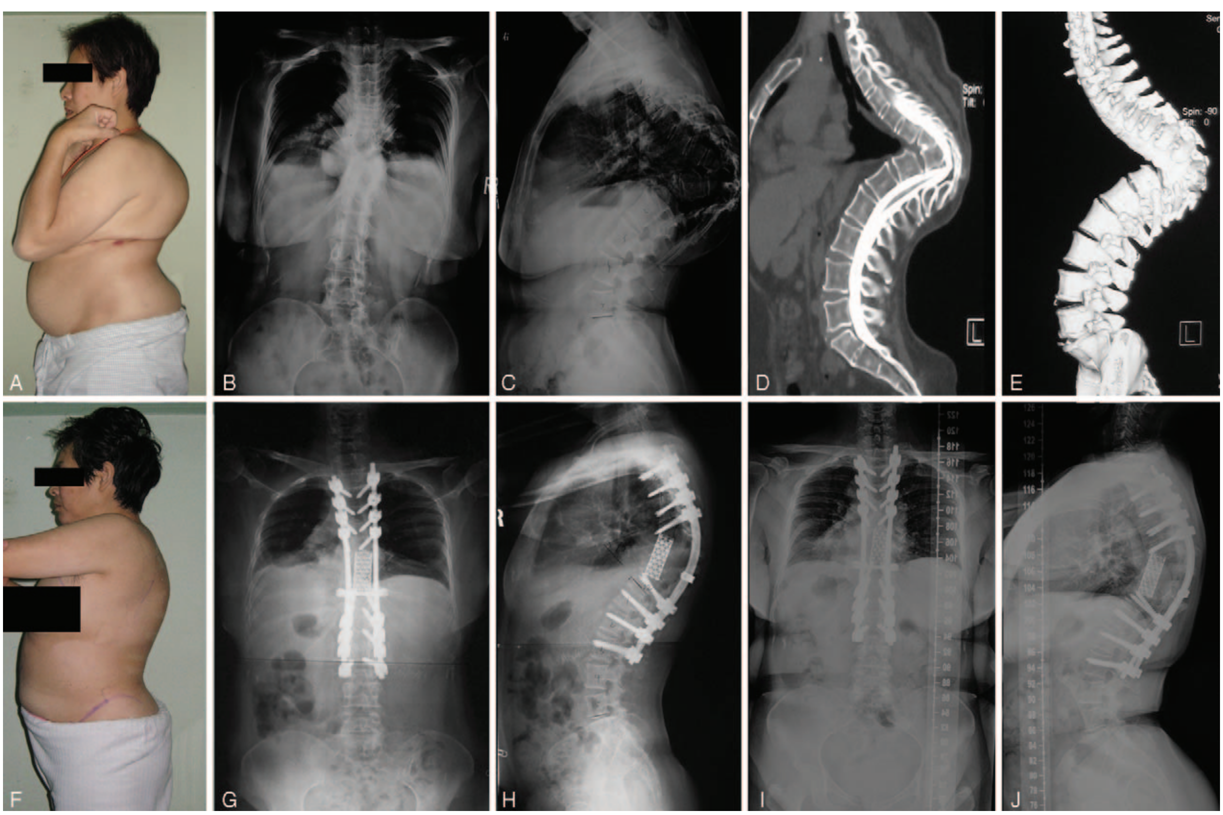

Figure 2. Images of a 52-year-old female patient with a kyphosis for Pott disease. She underwent a pVCR procedure at T7-11 with the fusion level of T3-L3. (**A**) Preoperative gross photo. (**B, C**) Preoperative standing coronal and sagittal long-cassette radiographs with the local kyphosis angle of 127°. (**D, E**) Preoperative sagittal CT myelography (CTM) and 3D CT reconstruction images, that shows the spinal cord compression. (**F**) Postoperative gross photo. (**G, H**) Postoperative standing coronal and sagittal long-cassette radiographs with the local kyphosis angle of 60° and the correction rate of 64.1%. (**I, J**) The standing coronal and sagittal long-cassette radiographs at last follow-up. 3D CT indicates three-dimensional computed tomography.

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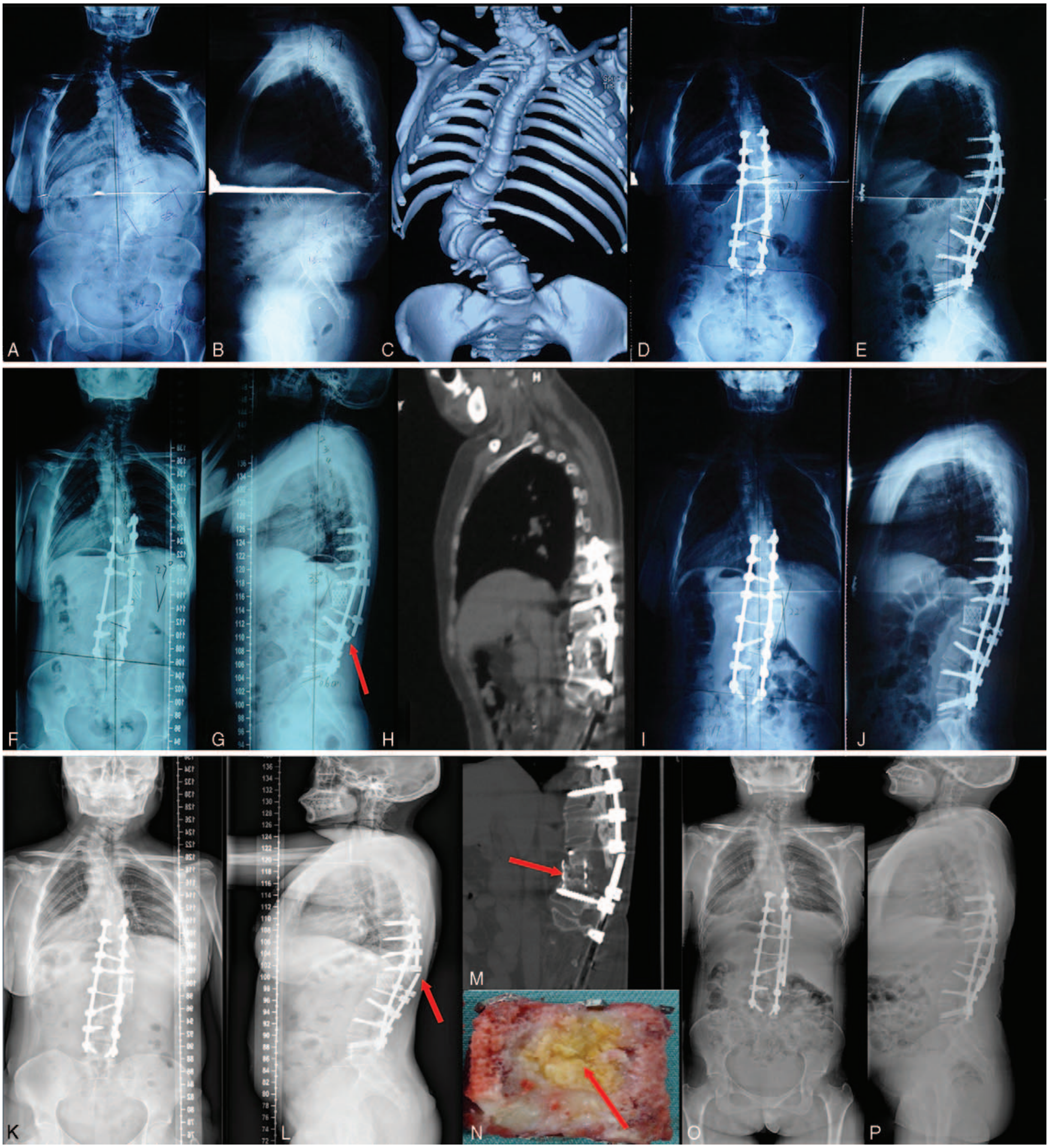

Figure 3. Images of a 43-year-old female congenital kyphoscoliosis patient (Case No. 1 in Table 1). She underwent a primary surgery of pVCR at T12/L1 with the fusion level of T8-L5. (**A, B**) Preoperative coronal and sagittal radiographs. (**C**) A 3D CT reconstruction image. (**D, E**) Postoperative coronal and sagittal radiographs. After 6 months, she underwent the first revision surgery of rod replacement and crosslink implant because of the right rod breakage. (**F, G**) Preoperative corona and sagittal radiographs. (**H**) A preoperative sagittal CT reconstruction image with bony fusion in the cage. (**I, J**) Postoperative coronal and sagittal radiographs. After 24 months, she underwent a second revision surgery of Rod replacement, satellite rod implant, cage removal, and autologous rib graft for the second right rod breakage. (**K, L**) Preoperative coronal and sagittal radiographs. (**M, N**) No clear bony fusion in the center of the cage (arrow) in the preoperative sagittal CT reconstruction image with iterative metal artifact reduction and the sagittal photo of the cage sample (arrow). (**O, P**) Postoperative coronal and sagittal radiographs. 3D CT indicates three-dimensional computed tomography; pVCR, posterior vertebral column resection.

(8.6%), and one pneumonia (2.9%). All neural sings and symptoms were improved in both of two patients 3 months after operation, who suffered from incomplete paraplegia of the lower extremities before surgery.

Instrumentation Failure

A total of five patients with instrumentation failure were identified (Table 1). In this study, the incidence after pVCR in ASD was 14.3%. The failure was noted in the mean of

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TABLE 1. Instrumentation Failures After pVCR in Five ASD Patients

Case No.	Age (y/o)	Sex	Comorbidity	Location of pVCR	Fusion Levels	TMC Height (mm)	TMC Subsidence (mm)	Failure	Duration (Months)	Revision Operation
1	43	F	—	T12-L1	T9-L5	25	6	① Rod breakage ② Rod breakage	① 6 ② 24	① Rod replacement, and crosslink implant ② Rod replacement, satellite rod implant, cage removal, and autologous rib graft
2	28	M	ACH	T11-T12	T5-L4	55	8	Rod breakage	12	Rod replacement
3	44	M	Scheuermann disease	T11	T6-L3	30	5	Rod breakage	5	Rod replacement
4	25	F	—	T11-T12	T7-L4	25	8	Rod breakage	5	Rod replacement
5	47	M	ACH	T11	T8-S1	25	5	Rod breakage	6	Rod replacement

ACH indicates achondroplasia; ASD, adult spinal deformity; F, female; M, male; pVCR, posterior vertebral column resection.

6.8 months (range 5–12 months) after surgery. All of them were rod breakages, occurring at the level of the osteotomy, and suffered from different degrees of back pain. But no one experienced neurological deterioration at the time of instrumentation failure. They all underwent selective revision surgeries of rod replacement. Only one patient meanwhile accepted the replacement of a dislodged cage by an autologous rib for the second rod breakage after 18 months (Case No. 1 in Table 1).

Risk Factors Analysis

Among these risk factors, BMI (>27, $P = 0.026$), comorbidity (Achondroplasia, $P = 0.047$), and ACD (>20 mm, $P = 0.045$) were significantly related to the instrumentation failure (Table 2). None of other factors, including sex, age, type of deformity, preoperative Cobb angle of main curve and Segmental Kyphosis, correction of segmental Kyphosis, number of resected vertebra, fusion levels, insert of TMC, location of osteotomy, rod diameter, and crosslink, was significantly related to instrumentation failures. Patients with BMI >27 exhibited higher morbidities of the instrumentation failure (36.4% *vs.* 4.2%). Two of three patients (66.7%) with ACH experienced instrumentation failures, whereas only three of 32 patients (9.4%) without ACH experienced. Although there were 17.9% of patients with reconstruction of TMCs who had instrumentation failures, it was no significant difference from those patients without TMCs ($P = 0.559$). For those patients who had ACD >20 mm because the TMC was too high, they suffered more instrumentation failures than others (27.8% *vs.* 0%, $P = 0.045$).

Risk factors related to TMCs were further analyzed in patients with TMCs. Patients with TMC subsidence of ≥5 mm exhibited higher morbidities of instrumentation failures (35.7% *vs.* 0%, $P = 0.041$). Neither of the ratio of diameters for TMC/endplate and the position of TMC was associated with the instrumentation failure in TMC group.

ILLUSTRATIVE CASES

Case 1

A 52-year-old female patient suffered from sever back pain because of the kyphosis (Figure 2A–C) secondary to spinal tuberculosis in her adolescence (Pott disease). Although her spinal cord was compressed as shown in the CT myelography (CTM, Figure 2D, E), there were no neurological symptoms and signs. She underwent a pVCR procedure at T7-11 with the fusion level of T3-L3. The cobb's angle of the local kyphosis was remarkably corrected from 127° to 60° (Figure 2A, C, F–H). The correction rate was 64.1%. Her back pain was relieved after surgery. There was no instrumentation failure observed in the follow-up of 5years (Figure 2I, J).

Case 2

A 43-years/old female congenital kyphoscoliosis patient (Case No. 1 in Table 1) with a hemivertebra at T2 and a

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TABLE 2. Risk Factors Associated With the Instrumentation Failure After pVCR in ASD

	Instrumentation Failure		
	Yes (n = 5)	No (n = 30)	*P*
Sex Female	2 (11.1%)	16 (88.9%)	0.658*
Male	3 (17.6%)	14 (82.4%)	
Age (yr/old)	37.4 ± 10.1	37.8 ± 13.3	0.945
BMI ≤27	1 (4.2%)	23 (95.8%)	0.026*
>27	4 (36.4%)	7 (63.6%)	
Type of deformity Kyphosis	1 (10.0%)	9 (90.0%)	1.000
Kyphoscoliosis	4 (16.0%)	21 (84.0%)	
Comorbidity Achondroplasia	2 (66.7%)	1 (33.3%)	0.047*
Others	3 (9.4%)	29 (90.6%)	
Preoperative Cobb angle of main curve	40.2 ± 29.4	38.9 ± 41.7	0.946
Preoperative Cobb angle of segmental kyphosis	103.3 ± 24.1	92.8 ± 28.8	0.447
Correction of segmental kyphosis	75.8 ± 30.0	61.0 ± 17.8	0.128
Number of resected vertebra	1.6 ± 0.5	2.1 ± 1.2	0.414
Fusion levels	10.4 ± 0.9	10.2 ± 2.7	0.797
Location of osteotomy Thoracolumbar	4 (22.2%)	14 (77.8%)	0.338*
Thoracic/lumbar	1 (5.9%)	16 (94.1%)	
Insert of TMC Yes	5 (17.9%)	23 (82.1%)	0.559*
No	0 (0%)	7 (100%)	
Anterior column defect ≤20 mm	0 (0%)	17 (100%)	0.045*
>20 mm	5 (27.8%)	13 (72.2%)	
Crosslink Yes	3 (12.0%)	22 (88.0%)	0.610*
No	2 (20.0%)	8 (80.0%)	
Diameter of rod ≤5.5 mm	4 (26.7%)	11 (73.3%)	0.141*
>5.5 mm	1 (5.0%)	19 (95.0%)	

*Fisher exact test.

TMC indicates titanium mesh cage.

bar at T12/L1 (Figure 3C) underwent the primary surgery of pVCR at T12/L1 for severe back pain. The fusion levels were from T9 to L5. Before surgery, the Cobb angles of the upper thoracic curve and the main thoracolumbar curve were respectively 56° and 86°, and the Cobb angle of the segmental kyphosis was 135° (Figure 3A, B). After surgery, the Cobb angles of the main thoracolumbar curve and segmental kyphosis were 27° and 19° (Figure 3D, E). The correction rates of the curve and the kyphosis were 68.6% and 85.9%, respectively.

After 6 months, she suffered from back pain again for the right rod breakage (Figure 3F, G). Because the sagittal reconstruction image of CT scans showed that there was apparent bone fusion (Figure 3H), she underwent the first revision surgery of rod replacement and strengthening with a crosslink by the posterior approach (Figure 3I, J).

Unfortunately, she got back pain again for the right rod breakage 24 months later (Figure 3K, L). Different from before, the sagittal reconstruction image of CT scans with iterative metal artifact reduction found that there was no

TABLE 3. Risk Factors Associated With the Instrumentation Failure in TMC Group

	Instrumentation Failure		
	Yes (n = 5)	No (n = 23)	*P*
Subsidence of TMC <5 mm	0 (0%)	14 (100.0%)	0.041*
≥5 mm	5 (35.7%)	9 (64.3%)	
Ratio of diameters for TMC/endplate ≤0.5	3 (37.5%)	5 (62.5%)	0.123*
>0.5	2 (10.0%)	18 (90.0%)	
Position of TMC oblique	1 (10.0%)	9 (90.0%)	0.626*
Upright	4 (22.2%)	14 (77.8%)	

*Fisher exact test.

TMC indicates titanium mesh cage.

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clear bony fusion in the central of the cage, which was confirmed during the second revision surgery (Figure 3M, N). Thus, we performed a revision surgery of rod replacement, satellite rod implant, cage removal, and autologous rib graft by the combination of the anterior and posterior approaches (Figure 3O, P).

DISCUSSION

In this study, the high incidence of instrumentation failure (14.3%) after pVCR in ASD was observed, and even a little higher than that of the neurologic complication (8.6%). It was higher than 2% reported in all deformities,[5] and was similar to that of pedicle subtraction osteotomy in ASD (16.2%–22.0%).[10,11] It might be associated with ASD for its higher morbidity. VCR, which completely separates the spinal column into two limbs, is the most powerful mobilization strategy.[4] It provided the correction rates of 68.8% and 67.9% for the curve and the kyphosis respectively. It is only reserved for severe spinal deformity for its high risk of complications.[5] Its neurologic complications have drawn a lot of attentions,[12,13] but rare study about its instrumentation failures is performed. The high incidence of instrumentation failure was associated with sufficient spinal instability after VCR, so it is necessary to pay more attention for instrumentation failure and analyze the risk factors.

Currently, polymethyl methacrylate, structural autologous or allogenic bone grafts, and TMCs are available for the anterior spinal column reconstruction.[7] TMCs with the combination of autologous local bone and/or allogenic bone have been widely used without unexpected complications of harvesting bone. They can provide structural support, promote solid osseous union, and achieve a high fusion rate.[14] The shortening of the spinal cord should not be more than 10 mm or two-thirds of the normal vertebral segment to avoid neurologic complications according to the result in dogs.[15] In humans, if anterior gaps more than 5 mm, TMC was suggested to be used to provide reliable anterior column reconstruction.[3] The application of TMCs would not significantly increase the instrumentation failure in ASD ($P = 0.559$). It was also confirmed in ASD by a previous study.[16] Thus, it is safe and recommended to reconstruct anterior column with TMC after pVCR in ASD.

ACD >20 mm is one of risk factors for the instrumentation failure after pVCR in ASD ($P = 0.045$). It is mainly caused by the application of TMCs. If the height of the TMC is higher, there will be more segmental defect in anterior column that needs osseous fusion. In addition, the laminectomy length should be longer than that of the resected vertebra to avoid excessive kinking of the spinal cord when shortening it.[7] There is more posterior lamina defect than ACD. So as little vertebra as possible should be resected to reduce ACD.

An instrumentation failure can be caused by the lack of biological osseous fusion.[17] Togawa *et al*[18] found that there was a relatively high prevalence of hyaline and fibrocartilage in the failed interbody cages. A similar result was also found in Case No. 1. ACH slows growth plate activity and consequently linear bone growth,[19] so there might be impaired bone formation in those patients. That is why the patients with ACH suffered more instrumentation failures ($P = 0.047$). The importance of bone graft in the TMC should be stressed, and sometimes bone morphogenetic protein should be considered, especially for those patients with impaired bone formation.

The instrumentations provided major stability after pVCR before bony fusion. The failures might relate to excessive biomechanic stress at the pVCR site, if there was no osseous fusion. In this study, all instrumentation failures manifested as rod breakage at the level of osteotomy in 12 months. It suggested that the rod failure had more incidence compared to the other instrumentation failures, such as screw out and cage dislodgment. A similar finding was also described by Smith *et al*.[20] Thence, a multirod construct might contribute to reduce the instrumentation failure, because it is a safe, simple, and effective method to provide increased stability across 3-column osteotomy sites to significantly prevent implant failure *versus* a standard two-rod construct.[21] BMI >27 was another significant risk factor. In those obese patients, the added stress from greater body mass might contribute to the failures. It was also described by Smith *et al*[20] before. A satellite rod at the osteotomy site should be considered for those patients with the risk factors of the instrumentation failure, such as greater BMI (>27) and so on.

Server TMC subsidence ($\geq$5 mm) was another important risk factor related to the instrumentation failure in TMC group ($P = 0.041$). The load imposed on the posterior instrumentation would increase when the load failed to share in the anterior column for cage subsidence.[17] It might develop because of the fragility of the interface or the failure of osseous fusion between the cage and the graft site.[18,22] Lim *et al* found that the load that produced failure in specimens with an intact endplate was significantly greater than that producing failure in specimens with no endplate. So graft site preparation is a critical factor for preventing cage subsidence and instrumentation failures, and the excision line should be extended to the disc space to expose the bony endplates with better mechanical strength.[17]

The major limitation of this study was the small sample size (n = 35) from one medical center. According to Peduzzi suggestion,[23] a logistic regression analysis cannot be conducted to eliminate influences of farraginous factors for lack of failure samples. Meanwhile, no later instrumentation failure could be observed in these cases because there were only seven patients with the follow-up of more than 5 years. Thus, it is necessary to perform a multicenter cohort study to address the limitations on sample size and lack of instrumentation failures observed in the future. The other limitation was that sagittal imbalance could not be evaluated in all patients, for lack of long-cassette radiographs in some cases.

In conclusion, the high incidence of instrumentation failure (14.3%) should draw more attention after pVCR

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in ASD. It is safe to reconstruct anterior spinal column with a TMC, but the height of the TMC should be as low as possible to reduce ACD. For those patients with risk factors (BMI >27, ACH, ACD >20 mm), autologous bone graft and a satellite rod should be considered. If TMC subsidence ≥5 mm, a frequent follow-up should be performed to prevent a neurologic complication secondary to instrumentation failure (Table 3).

➢ Key Points

- The instrumentation failure (14.3%) is another common complication except the neurologic complication after pVCR in ASD.
- It is safe to reconstruct anterior spinal column with a TMC, but the height of the TMC should be as low as possible to reduce ACD.
- The risk factors included BMI >27, ACH, ACD >20 mm, and TMC subsidence ≥5 mm.
- For those patients with risk factors, autologous bone graft and a satellite rod should be considered.

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