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ORIGINAL ARTICLE

A late neurological complication following posterior correction surgery of severe cervical kyphosis

Yoshihiro Hojo · Manabu Ito · Kuniyoshi Abumi · Yoshihisa Kotani · Hideki Sudo · Masahiko Takahata · Akio Minami

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Abstract Though a possible cause of late neurological deficits after posterior cervical reconstruction surgery was reported to be an iatrogenic foraminal stenosis caused not by implant malposition but probably by posterior shift of the lateral mass induced by tightening screws and plates, its clinical features and pathomechanisms remain unclear. The aim of this retrospective clinical review was to investigate the clinical features of these neurological complications and to analyze the pathomechanisms by reviewing pre- and post-operative imaging studies. Among 227 patients who underwent cervical stabilization using cervical pedicle screws (CPSs), six patients who underwent correction of cervical kyphosis showed postoperative late neurological complications without any malposition of CPS (ND group). The clinical courses of the patients with deficits were reviewed from the medical records. Radiographic assessment of the sagittal alignment was conducted using lateral radiographs. The diameter of the neural foramen was measured on preoperative CT images. These results were compared with the other 14 patients who underwent correction of cervical kyphosis without late postoperative neurological complications (non-ND group). The six patients in the ND group showed no deficits in the immediate postoperative periods, but unilateral muscle weakness of the deltoid and biceps brachii occurred at 2.8 days postoperatively on average. Preoperative sagittal alignment of fusion area showed significant kyphosis in the ND group. The average of kyphosis correction in the ND was 17.6° per fused segment (range 9.7°–35.0°), and 4.5° (range 1.3°–10.0°) in the non-ND group. A statistically significant difference was observed in the degree of preoperative kyphosis and the correction angles at C4–5 between the two groups. The diameter of the C4–5 foramen on the side of deficits was significantly smaller than that of the opposite side in the ND group. Late postoperative neurological complications after correction of cervical kyphosis were highly associated with a large amount of kyphosis correction, which may lead foraminal stenosis and enhance posterior drift of the spinal cord. These factors may lead to both compression and traction of the nerves, which eventually cause late neurological deficits. To avoid such complications, excessive kyphosis correction should not be performed during posterior surgery to avoid significant posterior shift of the spinal cord and prophylactic foraminotomies are recommended if narrow neuroforamina were evident on preoperative CT images. Regardless of revision decompression or observation, the majority of this late neurological complication showed complete recovery over time.

Keywords Cervical kyphosis · Spinal reconstruction · Pedicle screw fixation · Neurological complication · Foraminal stenosis

Introduction

Posterior reconstruction has become popular in treatment of various cervical disorders caused by trauma, deformity, rheumatoid arthritis, metastatic tumors and other unstable conditions. There are many spinal fixation techniques in posterior cervical reconstruction surgery, such as interspinous process wiring [1], laminar hooks [2], lateral mass

Y. Hojo · M. Ito (✉) · K. Abumi · Y. Kotani · H. Sudo · M. Takahata · A. Minami
Department of Orthopaedic Surgery, Hokkaido University Graduate School of Medicine, Kita-15, Nishi-7, Kita-ku, Sapporo 060-8638, Japan
e-mail: maito@med.hokudai.ac.jp

screws [3], pedicle screws [4] and lamina screws [5]. Among these posterior fixation techniques, cervical pedicle screw (CPS) fixation has been reported as the most rigid fixation method by previous studies of biomechanics [6, 7]. Despite its biomechanical superiority, there are potential complications related to CPS of the cervical spine including perforation into the transverse foramen and injury to the vertebral artery. Another possible complication of CPS is a direct injury either to the nerve roots or to the spinal cord. Because of these potential complications, CPS is still considered the most risky spinal instrumentation and many surgeons refrain from using this technique regardless of its biomechanical benefits.

Besides the risks of screw malposition stated above, a different type of complication related to cervical reconstruction surgery was reported by Heller et al. [8] who utilized lateral mass screws. They used the term "iatrogenic foraminal stenosis" to describe this complication and pointed out the possibility of nerve root compression due to narrowing of the neural foramen after posterior reconstruction surgery of the cervical spine. They speculated that this complication was related to a posterior shift of the lateral mass induced by a lag screw effect. Since this complication is relatively new to spine surgeons and its clinical features as well as pathomechanisms remain unclear, it is of clinical importance to discover the causes and find ways to reduce the risk of this unique complication. The purposes of this study were the following: (1) to investigate the incidence and clinical features of neurological complications not associated with screw malposition after cervical posterior reconstruction surgery using CPS, and (2) to analyze possible pathomechanisms of late neurological complications using pre- and post-operative imaging studies.

Materials and methods

Patients' demographics

From June 2002 through January 2007, 227 patients underwent posterior cervical reconstruction surgery which conducted spinal fusion more than 1 level from C2–3 to C6–7 with CPS at the authors' institution. Patients who underwent posterior fusion from the occiput to C2 and from C1 to C2 were excluded. Among the 227 patients, six patients (male, 5; female, 1) (ND group) showed postoperative neurological complications without any evidence of screw mal-positioning or surgical site hematoma (Table 1). Their ages ranged from 15 to 58 years with an average of 56.1. Their cervical disorders were postlaminectomy kyphosis in 2 patients (cases 1, 4), cervical spondylotic myelopathy with kyphosis caused by athetoid cerebral palsy in 1 (case 2), cervical spondylotic myelopathy with kyphosis in 1 (case 3) and cervical kyphosis without an identifiable cause in 2 (cases 5, 6). All six patients whose Japanese Orthopedic Association (JOA) scores [9] for cervical myelopathy were 10 points on average (full mark 17) had preoperative cervical myelopathy.

All the six patients had preoperative severe cervical kyphosis (31.2° kyphosis at C2–7 on average) and underwent correction of kyphotic deformity. Since late neurological complications occurred only in the patients who underwent correction of cervical kyphosis, the other 14 patients who underwent correction of cervical kyphosis without such late neurological complications were also included in this study as the control group (non-ND group) (Tables 1, 2). Their ages ranged from 15 to 77 years (average 51.4), and the follow-up period ranged from 2 to 7 years (average 4.9 years). There were no statistically significant differences between the ND group and the non-ND group in age, gender, or number of fused segments. All of the surgeries were performed by the senior surgeon (K.A.). All patients were evaluated with computed tomography (CT) to exclude the mal-positioning of CPS.

Surgical procedures of kyphosis correction

General concepts of kyphosis correction and reconstruction in the cervical spine were as follows: (1) when the cervical spine is still flexible without solid bony union, a single posterior surgery using CPS is indicated. For correction of kyphosis, two pre-contoured rods are connected to CPSs by applying a distraction force between neighboring screw heads to minimize shortening of the posterior column of the spine. This surgery was performed in cases 1–4 and those in the non-ND group except case 13 with metastatic spinal tumor. (2) When the cervical spine is rigid due to bony union of several spinal segments, a combined anterior and posterior procedure consisting of anterior diskectomy, bilateral uncinectomy, and posterior facetectomies with posterior instrumentation is indicated. An anterior bone graft is performed at the final stage of the surgery. This type of surgery was performed in cases 5 and 6. In case 6, corpectomy of C4 and circumferential resection of bony elements were performed due to a severe ankylosing condition and a tricortical iliac bone graft was inserted at C4 after application of posterior instrumentation. In case 13 with metastatic spinal tumor, posterior instrumentation using CPSs from C6 to T1, corpectomy of C7 and anterior iliac bone graft were performed.

As to decompression procedures, laminectomy was performed for neural decompression in combination with spinal reconstruction in all the patients except cases 5 and 15. Spinal levels for posterior decompression in the majority of patients were C3–C6, which was determined by

Table 1 Demographics and surgeries of six patients in the ND group

Case	Age	Sex	Cervical disorder	FA	NFS	App	Laminectomy	Foraminotomy	C2–7 angle (°)			FAA (°)			
									Pre	Post	Corr	Pre	Post	Corr	Corr/Seg
1	15	M	Kyphosis after laminectomy	C2–5	3	P	C1–4	None	+30	+5	−25	+34	0	−34	−11.3
2	42	M	CSM associated with athetoid CP	C4–6	2	P	C3–7	None	+31	+12	−19	+35	+4	−31	−15.5
3	41	M	CSM with kyphosis	C3–5	2	P	C4–7	Uni. C5–C6	+10	−10	−20	+12	−17	−29	−14.5
4	45	M	Kyphosis after laminectomy	C3–6	3	P	C3–6	Bil. C4–C5	+27	−1	−28	+26	−3	−29	−9.7
5	58	F	Unknown etiology of kyphosis	C4–5	1	A/P	None	Bil. C4–C5	+29	−2	−31	+30	−5	−35	−35.0
6	48	M	Unknown etiology of kyphosis	C3-6	3	A/P/A	C3-6	Bil. C4–C5	+60	+4	−56	+60	+1	−59	−19.7
Avg	41.5				2.3				+31.2	+1.3	−29.8	+32.8	−3.3	−36.2	−17.6
SD	5.9				0.8				16.1	7.5	13.6	15.7	7.4	11.5	8.4

In fused area angles, kyphotic and lordotic angles are indicated by positive and negative values, respectively

FA fused area, *FAA* fused area angle, *NFS* number of fused segments, *App* approach, *Pre* preoperative angle, *Post* postoperative angle, *Corr* correction angle, *Corr/Seg* correction angle per segment, ° degree, *CSM* cervical spondylotic myelopathy, *CP* cerebral palsy, *P* posterior, *A* anterior, *A/P* anterior–posterior, *A/P/A* anterior–posterior–anterior, *Avg* average, *SD* standard deviation

preoperative neurologic status and preoperative imaging studies. Though prophylactic foraminotomy was not performed during surgery in cases 1 and 2, prophylactic foraminotomy was added in cases 3–6 at the site of foraminal stenosis identified on preoperative CT images. The surgical technique of foraminotomy and facetectomy used was similar to "the Ponte procedure" [10]. The Ponte procedure is a surgical technique of wide posterior chevron osteotomies commonly used for Scheuermann's kyphosis in the thoracic spine. Prophylactic foraminotomy was not conducted in all the patients in the non-ND group.

The surgical technique of pedicle screw insertion was the method reported by Abumi et al. [4, 11]. In order to correct kyphotic deformity, rods or plates were bent to fit the anticipated cervical lordosis and connected to CPSs with connectors (Depuy Spine, Raynham, MA).

Pedicle screw stimulation by an electric cautery was conducted during surgery in all the patients to make sure that no muscle motions in the upper extremities were observed after insertion of each CPS. Since somatosensory (SEPs) and motor-evoked potentials (MEPs) of the spinal cord have been monitored during surgery since 2003, the spinal cord monitoring was used for cases 4–6.

Clinical signs of patients with postoperative neurological deficits

The clinical courses of the patients, before the onset of neurological deficits following initial reconstruction surgery, were thoroughly reviewed from the medical records. Initial symptoms, such as neck pain, radiating pain to the upper extremities, development of motor weakness, and sensory disturbances that occurred before motor deficits were investigated. Neurological recovery and residual symptoms after the salvage surgery were also examined at an outpatient clinic.

Radiographic assessment

Sagittal alignment of the cervical spine was evaluated with five parameters (C2–7 angle, angle of the fused area, segmental angle, slip of each vertebra, and posterior intervertebral disc height) on pre- and post-operative lateral radiographs in the neutral position. The C2–7 angle (angle A in Fig. 1a) was determined by tangential lines along the posterior edge of the C2 and C7 body. The angle of the fused area (angle B in Fig. 1b) was defined as the angle between the most superior and the most inferior vertebra within the range of stabilized segments using CPSs. The segmental angle (angle C in Fig. 1c) was defined as the angle between lines parallel to the posterior border of the neighboring vertebral bodies. Kyphosis was shown by positive values and lordosis was shown by negative values. The percentage of vertebral body slip was evaluated with the Meyerding classification system [12]. The anterior slip of the vertebral body was shown by positive values and the posterior slip was by negative values. Posterior height of the intervertebral disc was defined as the posterior interval between neighboring vertebrae.

Table 2 Summary of 14 patients in the non-ND group

Case	Age	Sex	Cervical disorder	FA	NFS	App	Laminectomy	Foraminotomy	C2–7 Angle (°)			FAA (°)			
									Pre	Post	Corr	Pre	Post	Corr	Corr/Seg
7	63	F	SAL	C2–6	4	P	C3–7	None	+18	−5	−23	+18	0	−18	−4.5
8	62	M	OAL, SAL	Oc–C6	6	P	C1, C3–5	None	+35	+30	−5	+35	+24	−11	−1.8
9	42	F	Dumbbell type spinal cord tumor; schwannoma	C6–T1	2	P	C7	None	−5	−17	−12	−5	−15	−10	−5.0
10	59	F	Kyphosis after laminoplasty	C2–5	3	P	C3–5	None	+22	−8	−30	+22	−5	−27	−9.0
11	35	M	Adjacent segmental lesion after anterior fusion	C3–7	4	P	C3–7	None	−13	−20	−7	−13	−23	−10	−2.5
12	63	F	SAL	C2–7	5	P	C3–6	None	−14	−16	−2	−11	−22	−11	−2.2
13	24	M	Metastatic vertebral tumor	C6–T1	2	A/P	C7	None	0	−10	−10	+2	−8	−10	−5.0
14	65	M	CSM with spondylolisthesis	C3–4	1	P	C3–4	None	+7	−11	−18	+1	−9	−10	−10.0
15	65	F	OAL	Oc–C4	4	P	None	None	−7	−10	−3	−7	−17	−10	−2.5
16	61	F	CSM with kyphosis and spondylolisthesis	C2–5	3	P	C3–6	None	−1	−5	−4	+3	−9	−12	−4.0
17	77	M	Spinal lesion of multiple myeloma	Oc–C4	4	P	C2	None	−1	−10	−9	+7	−17	−24	−6.0
18	52	F	Metastatic vertebral tumor	C4–T6	9	P	C5–T4	None	−8	−9	−1	−7	−19	−12	−1.3
19	61	F	OAL	C1–4	3	P	C3–4	None	−2	−15	−13	−1	−23	−22	−7.3
20	54	F	SAL	C2–T1	6	P	C6	None	−1	−9	−8	−4	−15	−13	−2.2
Avg	55.9				4.0				+2.1	−9.7	−6.3	+2.9	−11.3	−14.3	−4.5
SD	3.7				2.0				13.9	11.8	8.4	13.6	12.3	5.9	2.7

In fused area angles, kyphotic and lordotic angles are indicated by positive and negative values respectively

FA fused area, *FAA* fused area angle, *NFS* number of fused segments, *App* approach, *Pre* preoperative angle, *Post* postoperative angle, *Corr* correction angle, *Corr/Seg* correction angle per segment, ° degree, *SAL* subaxial lesion due to rheumatoid arthritis, *OAL* occipito-atlantoaxial lesion due to rheumatoid arthritis, *CSM* cervical spondylotic myelopathy, *Oc* occiput, *P* posterior, *A* anterior, *A/P* anterior–posterior, *Avg* average, *SD* standard deviation

Diameter of the neural foramen (distance D in Fig. 1d) at each spinal level was measured on preoperative CT images. The difference in diameter between the right and left foramen was calculated at every segment.

Statistical analysis

Statistical analyses were performed using a two-tailed independent *t* test. A difference of $p < 0.05$ was considered to be statistically significant.

Results

Clinical signs of postoperative neurological deficits

Intraoperative spinal cord monitoring using SEPs or MEPs did not show any abnormal findings during surgery in cases 4–6. Intraoperative pedicle screw stimulation by an electric cautery did not show any signs of irritation to the nerves. Immediately after surgery, cervical myelopathy of the six patients in the ND group showed remarkable recovery in motor functions of the upper and lower extremities. Their JOA score improved from 10 to 15 points on average.

Four patients (cases 2–5) first complained of moderate or severe pain of the unilateral lower neck and scapular arch on the postoperative first day. Within several days after the occurrence of pain, muscle weakness of the deltoid and biceps brachii became clear (Table 3). In the other two patients (cases 1, 6), muscle weakness of the deltoid and biceps brachii became clear without preceding pain of the neck and scapular arch. The muscle weakness in the six patients became clear at 2.8 days of average postoperatively (range 1–7 days). Muscle weakness of the deltoid muscle was more severe than that of the biceps brachii muscle. Sensory disturbance in the unilateral upper

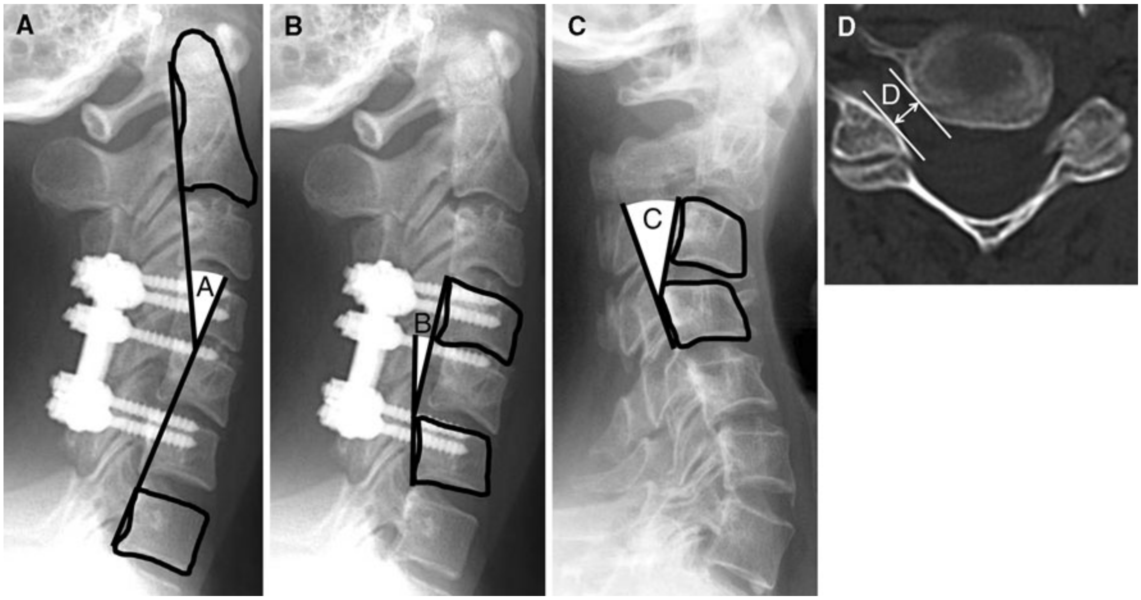

Fig. 1 Parameters of radiologic measurements. **a** The C2–7 angle determined by tangential lines along the posterior edge of the C2 and C7 body. **b** The fused area angle was defined as the angle between the most superior and most inferior vertebra within the range of stabilized segments using a cervical pedicle screw system. Angle *B* indicates the postoperative angle of C4–6 as an example. **c** The cervical segmental angle was defined as the angle between lines parallel to the posterior aspect of the adjacent vertebral bodies. Angle *C* indicates the preoperative angle of C3–4 as an example. *D* Anteroposterior diameters of all cervical neural foramina were measured on preoperative axial CT images

extremity C5 dermatome occurred on the same side of the motor weakness in cases 1 and 3.

Intraoperative findings at salvage surgery

Salvage surgeries were performed in four patients (cases 1–4).

In cases 1–3, salvage surgery was conducted after the onset of neurological deficits (Table 3). Intraoperative findings of the salvage surgery at C4–5 in the three patients without previous foraminotomy showed that the C5 nerve root on the side of neurological deficits was impinged by the superior articular process of C5 at the C4–5 foramen. Decompression of the C5 nerve root was achieved by resection of the superior articular process of C5 and C4–5 foraminotomy [10]. Distraction force was also applied to CPSs at C4 and C5 to enlarge the C4–5 neural foramen.

In case 4, since prophylactic C4–5 foraminotomy had already been performed in the first operation, there was no obvious finding of C4–5 foraminal stenosis at the salvage surgery. Though there was no obvious foraminal stenosis, posterior shift of the dural sac was noted and some bony edges of the remaining laminae disturbed the posterior expansion of the dural sac, so a resection of the bony edges and a distraction force was applied to the CPSs at C4 and C5 to enlarge the neural foramen.

Two patients (cases 5, 6) did not undergo additional surgeries because bilateral prophylactic foraminotomy had been performed at the initial surgery and their motor weakness showed gradual recovery.

Clinical course after salvage surgery

In cases 1–3, improvement of the muscle weakness of the deltoid and biceps brachii muscle was observed within a week after the salvage surgery. The motor deficits of the deltoid and biceps brachii muscles returned to normal in a few months (Table 3). In case 4, the muscle weakness of the deltoid progressed even after the salvage surgery. Improvement of the motor deficits in case 4 was observed at 2 months after the salvage surgery, and continued during follow-up. His muscle weakness of the upper extremities returned to normal by 8 months after the salvage surgery (Fig. 2).

Radiographic assessment

Cervical alignment in the sagittal plane

C2–7 angle The average preoperative C2–7 kyphosis angles in the ND group and the non-ND group were 31.2° (range 10°–60°) and 2.1° (range −14° to 35°), respectively (Tables 1, 2). This difference was statistically significant ($p < 0.01$). After kyphosis correction using CPS, the average angles were 1.3° of kyphosis in the ND group and

Table 3 Status of postoperative neurological deficit

Case	Initial sign	From surgery to deficit (days)	MMT (D/B)	Sensory disturbance	Salvage surgery		Period for recovery (months)
					From deficit to surgery (days)	Methods	
1	Muscle weakness	2	2/4	Unilateral brachial paresthesia	4	Bil. C4–5 foraminotomies	1
2	Neck and scapular arch pain	1	2/2	None	1	Bil. C4–5 foraminotomies	4
3	Neck and scapular arch pain	7	2/3	Unilateral brachial paresthesia	1	Bil. C4–5 foraminotomies	3
4	Neck and scapular arch pain	2	2/2	None	12	Appling distraction between C4 and C5	8
5	Neck and scapular arch pain	1	3/4	None	No salvage surgery		1
6	Muscle weakness	4	2/4	None	No salvage surgery		4

MMT indicates manual muscle test, *D* deltoid, *B* biceps brachii

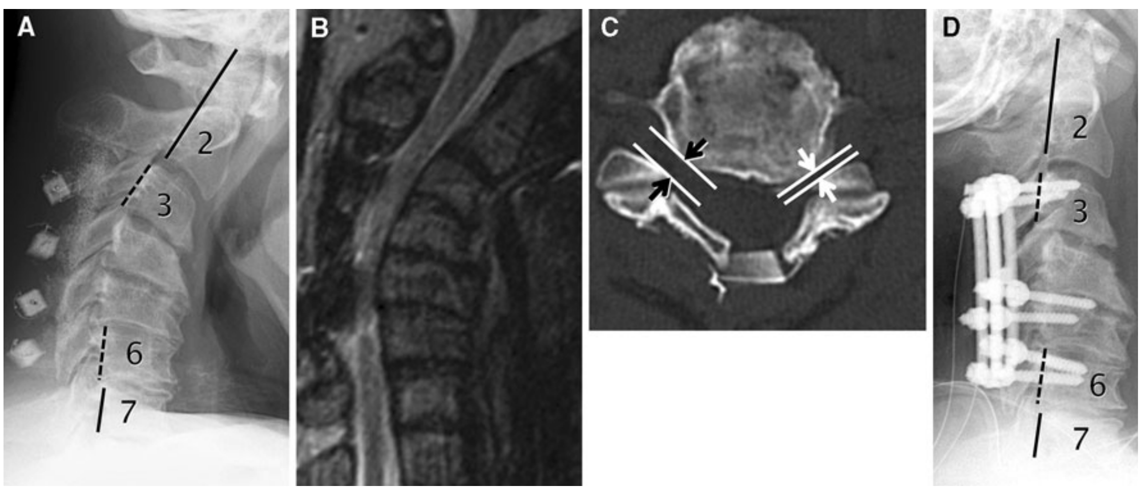

Fig. 2 Case presentation. **a**, **b** This 45-year-old man (case #4 in Table 1) had undergone laminoplasty with ceramic spacers for cervical spondylotic myelopathy. At 2 years postoperatively, kyphotic deformity gradually increased and cervical myelopathy recurred. His C2–7 kyphosis was 27° and kyphosis at the fused area was 26°. **c** The right–left difference of the anteroposterior diameter of the C4–5 foramen detected in the preoperative CT image. The anteroposterior diameter of the right C4/5 foramen was 4 mm (*black arrows*) and that of the left C4–5 foramen was 2 mm (*white arrows*). **d** Single posterior surgery consisting of laminectomy from C3 to C6, prophylactic C4–C5 foraminotomy on the both sides and correction of kyphosis using pedicle screw system were conducted. C3–6 kyphosis changed from 26° to 3° in lordosis. Muscle weakness of left deltoid and biceps brachii started 2 days after the operation and worsened to grade 1 in MMT. In the salvage surgery, there was no obvious finding of C4-5 foraminal stenosis. The only obvious finding was significant posterior shift of the dural sac which was obstructed by some bony edges of the remaining laminae. Resection of these bony edges and distraction between the CPS at C4 and C5 to enlarge the neural foramen was conducted. His muscle weakness returned to normal in 8 months

9.7° of lordosis in the non-ND group. The average angle changes of C2–7 in the ND group and the non-ND group were 29.8° and 6.3°. This difference was statistically significant ($p < 0.01$).

Fused area angle The average angles of kyphosis correction at the level of the fusion performed with spinal instrumentation in the ND group and the non-ND group were 36.2° (range 29°–59°) and 14.3° (range 10°–27°) (Tables 1, 2). This difference was statistically significant ($p < 0.01$).

The average correction angle per segment was 17.6° (range 9.7°–35.0°) in the ND group and 4.5° (range 1.3°–10.0°) in the non-ND group. This difference was statistically significant ($p < 0.01$).

Angle change at each segment In the ND group, the average angle of kyphosis correction at C4–5 was the

Table 4 Comparison between the ND group and the non-ND group (mean ± standard deviation)

	ND	Non-ND	p
Change of segmental angle (°) (+, kyphosis; −, lordosis)			
C2–3	+3.3 ± 4.7	−1.6 ± 6.3	0.16
C3–4	−10.3 ± 14.2	−1.3 ± 9.9	0.13
C4–5	−24.3 ± 11.3	−1.0 ± 5.2	<0.01[a]
C5–6	−1.0 ± 5.6	+2.4 ± 7.0	0.37
C6–7	+4.3 ± 3.9	+1.1 ± 6.2	0.35
Change of VB slip (%) (+, anterior; −, posterior)			
C2	−1.3 ± 02.5	−3.6 ± 1.2	0.74
C3	−6.3 ± 6.3	−2.4 ± 6.2	0.27
C4	−22.0 ± 32.1	−2.5 ± 22.0	<0.05[a]
C5	+1.8 ± 3.5	−1.4 ± 1.7	0.51
C6	+0.8 ± 4.3	−0.7 ± 0.7	0.58
C7	+1.3 ± 2.2	+0.6 ± 1.2	0.62
Change of disc height (mm)			
C2–3	−0.7 ± 1.5	−0.2 ± 1.6	0.50
C3–4	−1.2 ± 2.6	+0.1 ± 1.1	0.11
C4–5	−1.8 ± 1.8	+0.3 ± 1.1	<0.01[a]
C5–6	−0.2 ± 2.0	+0.2 ± 0.6	0.40
C6–7	−0.5 ± 0.5	+0.1 ± 0.7	0.13
Preoperative foraminal diameter (mm)			
C2–3	0.5 ± 1.0	0.5 ± 0.6	0.86
C3–4	1.0 ± 2.0	0.6 ± 0.7	0.44
C4–5	2.8 ± 0.9	0.8 ± 1.2	<0.01[a]
C5–6	1.0 ± 0.0	0.6 ± 0.8	0.31
C6–7	1.0 ± 0.8	0.7 ± 1.1	0.64

ND neurological deficit, *non-ND* no neurological deficit, ° degree, *VB* vertebral body, *%* percentage, *mm* millimeter

[a] Significant difference between the ND group and the non-ND group

largest of all the segments. The average angles of kyphosis correction at C4–5 in the ND group and the non-ND group were 24.3° and 1.0°. This difference was statistically significant ($p < 0.01$). There were no significant differences at the other segments (Table 4).

Slip at each segment in A–P direction Preoperative slip of each cervical segment in the ND group was not significantly different from the non-ND group. In the ND group, the average percentage of preoperative C4 anterior slip was 15% (range −10 to 40%). The average correction rate of vertebral slip of C4 after surgery was 22% in the posterior direction. The preoperative slip and correction of C4 slip were the largest among the cervical vertebrae (Table 4). The average correction of C4 showed a significant difference in comparison with that of the non-ND group ($p < 0.05$). The other vertebrae did not show a statistically significant difference.

Posterior height of intervertebral disc The average posterior disc height in the ND group decreased with surgical intervention at all the segments from C2–3 to C6–7. Among these segments, the disc height at C4–5 showed the largest amount of decrease (Table 4). A statistically significant difference in the change of disc height was observed at C4–5 between the ND group and the non-ND group ($p < 0.01$).

Morphology of foramen

The preoperative diameter of the neural foramen at C4–5 in the ND group, on the side of the neurological deficits was smaller than that of the opposite side in all the six patients. The right–left difference at C4/5 in the ND group was significantly larger than the non-ND group ($p < 0.01$). There was no statistical difference at the other segments (Table 4). The average preoperative diameter at C4/5 on the side of postoperative neurological problems in the ND group was 1.8 mm (range 1–4), which was significantly smaller than the average preoperative diameter of the neural foramen at C4/5 (4.4 mm, range 2–8) in the non-ND group ($p < 0.01$).

Discussion

There are several causes for severe cervical kyphosis, such as a subaxial lesion of rheumatoid arthritis, cerebral palsy, spinal tumor and postlaminectomy kyphosis. For kyphosis correction of the cervical spine, some surgeons select the anterior procedure [13, 14], whereas other surgeons choose the posterior [15, 16] or a combination of anterior and posterior approaches [17, 18].

In posterior cervical reconstruction surgery, postoperative neurological deficits unrelated to instrument mal-positioning or hematoma formation have been reported by some authors [8, 19–21] Heller et al. [8] reported 2 (2.7%) cases with this complication after posterior cervical reconstruction surgery using lateral mass screws and plates. They attributed this complication to a posterior shift of the lateral mass induced by a lag screw effect, which significantly narrowed the neuroforamina and caused radiculopathies. In the present study, six patients developed postoperative neurological deficits without mal-positioning of the pedicle screws. The incidence of this complication was only 2.6% among 227 patients who underwent posterior cervical reconstruction. However, when attempting to correct cervical kyphotic deformity, the incidence of this complication reached 30.0% (6/20 patients).

As Heller et al. [8] and Abumi et al. [19] pointed out in their reports, one possible cause of the neurological problem was iatrogenic foraminal stenosis caused by shortening the posterior elements of the spine to create cervical

lordosis. Another possible cause was tethering of the root after creating lordosis, which happened when the spinal cord of a patient who had posterior decompression and postoperative neurological complications shifted posteriorly by more than 5 mm during the first 24 h [22].

Takemitsu et al. [20] showed that postoperative neurological deficits were detected in 50% of patients who underwent cervical spinal reconstructions using lateral mass screws and pedicle screws. O'Shaughnessy et al. [21] reported three patients (19%) with transient C5 palsies in their series of surgical treatment for fixed cervical kyphosis. They performed correction surgeries via both anterior and posterior approaches. In these studies, however, detailed assessment of the stenotic condition of the neural foramen was not conducted. In the present study, radiographic assessments were performed by analyzing the morphological characteristics of the neural foramen. According to measurements of the anteroposterior slip of the vertebra, preoperative C4 vertebra was located anteriorly to C5 vertebra. After surgery, however, C4 vertebra showed significant posterior translation in the ND group. Additionally, average posterior C4–5 disc height was significantly reduced after surgery in the ND group even though the surgeon tried to minimize shortening of the posterior elements with applying distraction force between CPSs. These results indicated that kyphosis correction at C4–5, which was the largest among the other segments, was achieved by posterior shift of the C4 vertebra and shortening the disc height at C4–5, which eventually caused foraminal stenosis at C4–5. In addition, preoperative CT images showed that patients in the ND group had had stenotic conditions at C4–5 foramen on the side of the postoperative neurological deficits.

Tethering of the nerve root is considered another possible reason for postoperative C5 palsy after cervical laminoplasty [23]. There are some common characteristics between the late postoperative neurological deficits in the present study and C5 palsy after cervical laminoplasty [24]. The common features were: (1) late onset after surgery, (2) unilateral weakness of the deltoid and biceps brachii muscles with or without sensory disturbance, and (3) preceding severe pain of the neck and scapular arch. Tethering of the nerve root is thought to be due to the posterior shift of the spinal cord [22]. When kyphosis of the cervical spine is corrected, the posterior shift of the spinal cord might be larger than that of cervical laminoplasty alone [25]. In the present study, the patients in the ND group had severe preoperative cervical kyphotic deformity (31.2° in C2–7 angle on average), and their minimum correction angle per segment was 9.7°. These results indicate that we should be aware of late postoperative neurological deficits when preoperative kyphosis is severe, and kyphosis correction of more than 9.7° per segment is performed through a posterior approach.

The anterior procedure has been one of the methods of choice for kyphosis correction. It permits decompression of anterior pathology as well as kyphosis correction with strut grafting [26]. There were some studies of anterior correction of cervical kyphosis via a single anterior approach, after which no postoperative neurological deficit occured [13, 26, 27]. With the anterior procedure, it is easy to apply a distraction force between vertebral bodies, which provides segmental widening of the disc space to create cervical lordosis. Thereby, the neural foramen is enlarged during kyphosis correction with the anterior procedure, which must be one reason for the reported lack of postoperative neurological deficits. As to correction angles of kyphotic deformity in the cervical spine treated by anterior procedures, Ferch et al. [27] reported the preoperative kyphosis was 10° and correction was 11° on average. Herman et al. [13] reported that their kyphosis correction was 21° on average. Both studies did not report any postoperative late neurological complications. The reasons for this are thought to be that the correction angle by the anterior surgery was smaller than our posterior surgery and intervertebral grafts could enlarge the neural foramens. When considering the fact that two patients developed postoperative neurological deficits in the present study even though they had undergone combined anterior and posterior procedures with intervertebral grafts, it is probable that the posterior shift of the spinal cord after surgery may play a major role in causing late neurological deficits after correction of severe cervical kyphosis.

To avoid late postoperative neurological complications in posterior reconstruction surgery for correcting cervical kyphosis, the present study recommends the following: (1) prophylactic foraminotomies at C4–5 [10] should be performed during surgery if there are findings of foraminal stenosis on preoperative CT images, (2) it is preferable to avoid excessive correction of cervical kyphosis exceeding 9.7° per segment, and (3) it is better to avoid conducting kyphosis correction mainly at C4–5, which may cause both foraminal stenosis at C4/5 foramen and the most dramatic posterior shift of the spinal cord at C4/5 segment. Despite using all the measures listed above, it may be said that such late neurological complications cannot be avoided perfectly.

The limitations of this study are: (1) since this study is retrospective, surgical strategies have not been uniform with several modifications as time proceeded. (2) This study used only axial CT images so that three dimensional morphological assessment of the foramen could not be performed. (3) Posterior shift of the spinal cord was not measured by using MR images in relation to the magnitude of kyphosis correction. (4) Postoperative EMG/NCS was not obtained prior to the salvage surgery in order to identify the location of neurological problems and assess their

severity. (5) The number of patients in this study was too small to draw conclusive statements. To compensate for these aforementioned limitations of this present study, further clinical investigation using more sophisticated imaging technologies with a higher number of patients is needed to further clarify the pathomechanism of the post-operative late neurological deficits and to make posterior correction surgery of cervical kyphosis safer.

Conclusions

Late neurological deficits after posterior correction surgery occurred in 2.6% of those who underwent cervical reconstruction surgery. This complication was associated with correction of cervical kyphosis by posterior instrumentation. The occurrence of this complication was 20% among those who underwent correction of cervical kyphosis. Postoperative severe unilateral neck pain or pain around the scapular region is predictive of impending neurological deficits. Possible causes of this complication are iatrogenic foraminal stenosis and/or tethering of the nerve root due to posterior shift of the spinal cord after kyphosis correction. As the correction angle increases, the incidence of this complication is becoming higher. Prophylactic foraminotomies at C4–5 are recommended when foraminal stenosis is present on preoperative CT images and excessive correction exceeding 9.7° per segment in the middle cervical spine should not be conducted to prevent this complication. When this complication occurs, regardless of revision decompression or observation, the majority will improve on their own over time.

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