Pedicle versus laminar screws: what provides more suitable C2 fixation in congenital C2–3 fusion patients?

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Abstract Patients with Klippel–Feil syndrome (KFS) have congenital fusions of at least 1 cervical motion segment, and often present with compensatory hypermobility or symptomatic stenosis of the cranio-vertebral junction which requires occipitocervical reconstruction and fusion. One subgroup of KFS patients in which this is particularly common is those with isolated C2–3 congenital fusion (C2–3 CF). The anatomic suitability for C2 pedicle and laminar screw placement had been analyzed in the general adult population, and guidelines for their techniques had been established. However, the feasibility and safety of the two techniques in KFS patients with congenital C2–3 fusion has not been reported. This radiographic study was performed to evaluate the feasibility of these two widely used methods in such patients. We recruited 108 patients with atlantoaxial dislocation and reconstructed CTs were performed. Among them, 53 had C2–C3 congenital fusion diagnosed as KFS and 55 had normal cervical segmentation (NCS). The maximum possible diameters and length were measured along the ideal screw trajectories. Both of mean diameters and lengths of the C2 laminar screw trajectory in the C2–3 CF group were significantly larger than that in NCS. Mean diameters of the C2 pedicle screw trajectory in this group were significantly smaller than that in NCS group, however, C2–3 CF patients had longer

pedicle paths than NCS. In the C2–3 CF group, all 53 cases had suitable trajectory for C2 laminar screw, while 21 (39.6%) had a pedicle diameter less than 4.5 mm. In the NCS group, 5 cases (9.1%) had a pedicle diameter less than 4.5 mm. All 108 cases had sufficient diameters for C2 laminar screw placement. Klippel–Feil patients with C2–3 CF are good candidates for the technique of C2 laminar screw. Preoperative radiography should be carefully evaluated and the option of C2 fixation be determined with a thorough consideration in these patients.

Keywords Klippel–Feil · Congenital C2–3 fusion · Occipitocervical fixation · Pedicle screw · Laminar screw

Introduction

Klippel–Feil syndrome (KFS) was described as a syndrome including short neck, low posterior hairline, and a limited range of motion of the neck. Patients with KFS have congenital fusion of at least one cervical motion segment [15]. These patients often present with compensatory hypermobility or symptomatic stenosis of the cranio-vertebral junction (CVJ) secondary to occipitalization of the atlas and fusion of C2–C3 segment [16]. The C2–C3 segment is the most commonly fused region (Fig. 1a, b), with Shen et al. [16] reporting its occurrence in 72.7% of KFS patients. This places KFS patients at increased risk of neurological injury, and patients often present with cervical myelopathy during their second or third decade [17]. In these patients, occipitocervical reconstruction and fusion is required.

Several methods for C2 fixation have been previously described. Among them, pedicle screw instrumentation of C2 is widely used and has proved to be effective both

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Fig. 1 **a** A 52-year lady with Klippel–Feil syndrome had C2–C3 congenital fusion (*arrow*), occipitalization of the atlas, and atlantoaxial dislocation. **b** Parasagittal section for the C2 pedicle (fused with the C3, *white arrow*). **c** Bilateral laminar screws placement. **d** C2 pedicle screw placement in another KFS patient

biomechanically and clinically [1, 8, 11, 14]. However, previous cadaveric and radiographic studies have shown a high rate of pedicle wall violation associated with C2 screw placement [5, 20]. In addition, pedicle screws for C2 fixation also carry the risk of damaging the vertebral arteries. In 2004, Wright et al. [19] reported a new technique involving bilateral C2 laminar screws, which reduces the threat to the vertebral artery. Biomechanically, the intra-laminar screw constructs were shown to provide equivalent stability to the pedicle screw constructs [7]. Similarly, Lapsiwala et al. [10] also found that C2 translaminar screws provide equal structural stiffness as compared with transarticular screws and C2 pedicle screws.

Previously, Resnick et al. [13] and Cassinelli et al. [2] studied the anatomic suitability for C2 pedicle and laminar screw placement in the general adult population, and established guidelines for these techniques. However, the feasibility of such techniques in KFS patients with C2–3 CF has not yet been reported. In the setting of C2–C3 congenital fusion, questions arise during the procedure of occipito-vertebral fixation; namely, do these patients have special anatomic considerations for C2 pedicle screw and laminar screw placement that need to be considered (Fig. 1c, d)? The purpose of this study is to evaluate and compare, from the anatomic point of view, the feasibility of the C2 pedicle and laminar screw placement in KFS patients with C2–3 CF by measuring the diameters and lengths of both screw trajectories in a large cohort of affected patients and compare them with those of normal subjects.

Materials and methods

Following approval by the institutional review board at our institution, a total of 108 patients with atlantoaxial dislocation (AAD) were recruited from the practice of our senior author (C.W.). These were selected out of a total of 510 cases of AAD that were diagnosed at our institution from the period extending from January 2003 to September 2008. Among these 510 patients, 53 had C2–C3 congenital fusion (C2–3 CF) and were diagnosed with Klippel–Feil syndrome (KFS). Among them 19 were male and 34 were female, with an age ranging from 18 to 63 years. From the remaining cases, we randomly selected 55 patients who had normal cervical segmentation (NCS); which included 44 cases with a diagnosis of os odontoideum and 11 with a documented fracture of the odontoid. In NCS group, 37 were male and 18 were female, with an age ranging from 18 to 63 years. Exclusion criteria included the presence of other associated spinal pathology or cervical osseous anomalies other than those described.

All 108 patients underwent reconstructive computed tomography (CT). Three-dimensional (3-D) CT was performed using a 64-slice scanner (lightspeed VCT, GE) with the following parameters: 120 kV, 500 mA, 0.6 s/rotation, table speed with 0.5 mm/rotation and 0.625 mm slice thickness. The measurements were made in the reconstructed sagittal and axial sections of the C2–C3 segment. The sagittal planes were reconstructed in parallel with the C2 pedicle, while the axial planes were vertical to the C2

laminar. The maximum possible diameters and length were measured along the ideal screw trajectory in the para-sagittal and axial planes (Figs. 2, 3). Each value was measured by two senior spine surgeons separately in a blind fashion and then averaged. Pedicle screw ideal trajectories were based on the recommendations of Harms and Melcher [8]. We considered it suitable to place a pedicle or laminar screw in an osseous canal that is at least 4.5 mm wide, assuming 0.5 mm tolerance on either side of a 3.5-mm diameter screw. The statistical analysis was performed using SAS (version 9.1, NC, Inc.).

Results

1. Age of the patients had no significant difference between the two groups. Both the mean diameters and lengths of the C2 laminar screw trajectory in C2–3 CF group were significantly larger than those in the NCS group. Mean diameters of the C2 pedicle screw trajectory in C2–3 CF group were significantly smaller than that in NCS group, however, C2–3 CF patients had longer pedicle path than NCS. (Table 1).
2. In the C2–3 CF group, all 53 cases were found to have a suitable trajectory for C2 laminar screw placement, while 21 cases (39.6%) had a pedicle diameter measuring less than 4.5 mm. In the NCS group, 5 cases (9.1%) had a pedicle diameter that measured less than 4.5 mm. All 108 cases had sufficient diameters for C2 laminar screw placement. (Tables 2, 3).

Discussion

Klippel–Feil syndrome (KFS) may result from mutations or disruptions in genes regulating segmentation and re-segmentation [17]. This is supported by Clarke et al. [3], who found that chromosomal inversion could disrupt the function of a certain gene, resulting in KFS. Fusions of C2 and C3, which is the most commonly fused extend [16], represent failed segmentation between the corresponding cervical somites during the third to the eighth week of fetal life [9]. During the procedure of posterior C2 fixation in the setting of C2–3 CF, we found that the size of some of the C2 pedicles were insufficient for screw placement. Nevertheless, patients with C2–3 CF tended to have thicker laminar and larger spinous process than the patients without KFS.

In the general population, the mean diameter and length of C2 pedicle were found to be 5.8–8 mm and 24–31 mm, respectively [5, 12, 13, 21], while C2 lamina were found to have an average diameter and length of 5.75–6.3 and 24.6–31.6 mm [2, 4, 18], respectively. In the present study, mean diameters and length of the C2 laminar screw trajectory in C2–3 CF patients were 8.6 and 31.6 mm; respectively, which were significantly larger than that in NCS patients. However, C2–3 CF patients had thinner pedicles than NCS patients, with the diameters of 5.7 in comparison with 8.5 mm. Although it was not the purpose of this study to determine why such differences occur, there are several possible explanations for this. In the general population, the vertebral artery makes an acute lateral bend under the

Fig. 2 Idealized screw trajectory in the pedicle plane. Measurement of C2 pedicle. Ideal diameter and length of the C2 pedicle were determined from the sagittal and the axial plane, using the minimum parameter

Fig. 3 Idealized screw trajectory in the axial plane. Measurement of C2 laminar

Table 1 Measurements of idealized trajectory for C2 pedicle and laminar screws

	KFS (<i>n</i> = 53)	NCS (<i>n</i> = 55)	<i>P</i> value
Age (year)	39.8 ± 11.5	41.9 ± 10.5	0.311
Pedicle trajectory (mm)			
Diameter	5.7 ± 1.5	8.5 ± 1.4	0.000
Length	26.6 ± 3.2	25.4 ± 2.2	0.02
Laminar trajectory (mm)			
Diameter	8.6 ± 1.3	6.3 ± 1.1	0.000
Length	31.6 ± 3.6	24.4 ± 2.4	0.000

There was no significant difference in any of the measurements made from either side of the patients. Independent *t* test (SAS, version 9.1, NC, Inc.)

C2 superior articular facet, and pedicle screw trajectory of C2 usually passes medial or supermedial to it [17]. Along with the embryonic failure of segmentation which results in

C2–3 congenital fusion, anomalies of the vertebral elements and vessels may also develop. We assumed that C2–3 CF patients would have wider and thicker posterior vertebral elements than normal population because of C2–C3 assimilation, while their C2 pedicles tend to be smaller. A possible explanation is that these findings are due to stress shielding in the pedicles of the fused segment. Further studies are required to determine the etiology of these anatomic differences.

In a cadaveric morphometric analysis, Wang [18] suggested that a diameter of the C2 lamina less than 5.5 mm was too small to accommodate a 3.5-mm screw, assuming a 1 mm tolerance on each side. Yoshida et al. [21] considered a trajectory of 4 mm as risky for laminar screws, while that of less than 3 mm was deemed unacceptable for C2 pedicle and transarticular screw placement. In the present study, a 4.5-mm diameter was determined to be

Table 2 Indications for pedicle and laminar screw placement (KFS group, *n* = 53)

		Diameter of the laminar (%)	
		<4.5 mm	≥4.5 mm
Diameter of the pedicle (%)			
<4.5 mm	Not suitable for any		Only suitable for laminar screw
	0		21 cases (39.6)
≥4.5 mm	Only suitable for pedicle screw		Suitable for both
	0		32 cases (60.4)

Table 3 Planning for pedicle and laminar screw placement (NCS group, *n* = 55)

		Diameter of the laminar (%)	
		<4.5 mm	≥4.5 mm
Diameter of the pedicle (%)			
<4.5 mm	Not suitable for any		Only suitable for laminar screw
	0		5 cases (9.1)
≥4.5 mm	Only suitable for pedicle screw		Suitable for both
	0		50 cases (90.9)

sufficient for a safe screw placement. In our experience, C2 pedicle and laminar can be directly visualized during the procedure. With at least 0.5 mm tolerance bilaterally, a pedicle or laminar screw of 3.5-mm diameter can be placed safely by experienced hands. Furthermore, a trajectory of laminar screw placement with slight penetration of the dorsal cortex had been recommended by several authors [2, 7]. For a patient with a relatively thin C2 lamina, this method has the benefit of placement with great ease, without the concern of penetration into the spinal canal.

In the current study, guidelines for screw placement in C2 pedicle and laminar in C2–3 CF patients have been established. In C2–3 CF patients, the trajectory for laminar screws was larger and longer than that of pedicle screws (8.6 mm wide and 31.6 mm long in comparison with 5.7 mm wide and 26.6 mm long). Furthermore, 21 cases (39.6%) had C2 pedicles with diameter less than 4.5 mm. That means more than one-third of C2–3 CF patients do not have suitable pedicles that allow for the safe placement of a 3.5 mm screw. Interestingly, we found all C2–3 CF patients had a C2 lamina with a maximum diameter measuring no less than 4.5 mm. C2–3 CF patients had suitable C2 laminae for safe screw placement without the concern of vertebral artery injury. In the cases with normal cervical segmentation, the mean diameter of the C2 pedicle was 8.5 mm hence the choice of pedicle screw would be reasonable and safe.

Pedicle screw of C2 acts as a rigid and reliable anchor for occipitocervical reconstruction [1], but it is associated

with an increased risk for VA injury. Although the use of laminar screws at C2 can reduce the risk of VA injury, it has several drawbacks including the following: (1) instrumentation of the C2 lamina requires part of the C2 lamina to be occupied resulting in reduced surface area for the fusion bed [6]. (2) Although C2 laminar screw had been demonstrated to be equivalent to the transarticular and pedicle screws in atlantoaxial fixation, it has also been found to be significantly weaker than the two constructs in the occipitocervical fixation [6]. Finn et al. [6] explained that the biomechanical weakness was probably attributable to the acute bending of titanium rods in order to connect the laminar fixation points. (3) The anchor based on C2 is particularly important for the occipitocervical reconstruction in C2–3 CF patients because of the congenital osseous deformity present at the craniocervical junction. During the procedure of occipitocervical reconstruction, the polyaxial laminar screws and re-shaped rods with acute bend should be used to connect the unparallel fixation points, which will provide less force when acting as a posterior anchor than the pedicle screw constructs. Based on the points made above, preoperative radiography should be carefully evaluated. The options for C2 fixation should be determined with thorough consideration and great caution (Fig. 4).

This study can be criticized in that all the measurements were obtained from reconstructed CT scan hence the results could be different from the true measurements. However, it was not the goal of this study to carry out an anatomical study comparing measurement of cadavers with

Fig. 4 The options for C2 fixation in C2–3 CF patients: **a** A 28-year-old lady with KFS had a superior odontoid migration. **b** The diameter of her left C2 pedicle was only 3.3 mm, which was too thin for the pedicle screw placement. **c** The diameter of the right pedicle was 6.5 mm. **d** The superior migration of the odontoid was corrected after the occipitocervical reconstruction. **e** Because the left C2 pedicle was too thin for screw placement, a right side laminar screw was used for C2 fixation. **f** A 3.5 mm screw was inserted safely into the right pedicle

that of CT scan, because 3D CT scan has already been used to establish the guidelines for screw placement into C2 pedicle and lamina [13, 21]. More recently, Dean et al. [4] has also proved that CT scan measurement is significantly correlated with the true anatomic measurements of C2 lamina thickness. Another limitation of this study is that we neglected to take into account the relationship between the vertebral artery and the screw trajectory as this needs to be taken into consideration in choosing constructs for C2 fixation. Moreover, it is conceivable that defining the ideal trajectory for pedicle screws leaves more room for interpretation than for the lamina screws. Finally, in a clinical setting it may be possible to insert a screw even if the diameter is smaller than 4.5 mm, and all pedicle wall breaches may not be clinically relevant.

Despite these limitations, the results of this study can be used as operative parameters for the occipitocervical reconstruction in the population of patients with C2–3 CF.

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