Computed tomography morphometric analysis for C-1 posterior arch crossing screw placement in the pediatric cervical spine

Guang-Heng Xiang, MD, Chong Wang, MD, Chao Lou, MD, Ming-Qiao Fang, MD, Nai-Feng Tian, MD, and Hua-Zi Xu, MD

Zhejiang Spine Research Center, Department of Orthopaedic Surgery, Second Affiliated Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

OBJECT The goal of this study was to evaluate the feasibility of the C-1 posterior arch crossing screw fixation technique in the pediatric age group.

METHODS One hundred twenty-three pediatric patients were divided into 6 age groups. Computed tomography morphometric analysis of the C-1 posterior arch was performed. Measurements included height, width, and length. Statistical analysis was performed using the Student t-test and linear regression analysis.

RESULTS The mean measurement of the posterior arch was height (6.35 ± 1.80 mm), width (Width 1: 4.48 ± 1.25 mm; Width 2: 4.42 ± 0.68 mm; Width 3: 4.42 ± 0.50 mm), and length (14.48 ± 1.67 mm). Seven (6.93%) of the 101 children in Groups 1–4 and 13 (59.1%) of the 22 children in Groups 5 and 6 could safely accommodate placement of C-1 posterior arch crossing screws.

CONCLUSIONS This investigation found that a C-1 posterior arch crossing screw was feasible in this group of Chinese pediatric patients, particularly in those 13 years and older. Preoperative thin-cut CT is essential for identifying children in whom this technique is applicable and for planning screw placement.

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KEY WORDS computed tomography; morphometric analysis; C-1 posterior arch; crossing screws; pediatric patients; spine

PEDIATRIC upper cervical instability may occur due to several congenital and acquired disorders, such as traumatic injuries, rheumatism and connective tissue disorders, Down syndrome, and os odontoideum.^{9,10,17,19} Surgical intervention is usually necessary to produce a stable construction. Conventional methods included posterior wiring (Brooks and Gallie techniques), Halifax clamps, C1–2 transarticular screws (Magerl technique), C-1 lateral mass screws, C-2 pedicle screws, and C-2 translaminar screws (Wright technique).^{3,5,6,11,12,20} These methods are associated with a high risk of pseudarthrosis, recurrent atlantoaxial instability, and vertebral artery (VA) injury.

The C-1 posterior arch crossing screw fixation tech-

nique was studied using anatomical and biomechanical evaluation. Its superiority was that it entailed little risk of injury to the neural and vascular structures as long as the implants remained intraosseous.¹⁴ Our study was designed to evaluate the dimensions of the C-1 posterior arch in a group of Chinese children to determine the feasibility of inserting screws using the C-1 posterior arch crossing screw fixation technique (Fig. 1). Assuming a 3.5-mm tolerance for each screw and allowing for a margin of error (minimum 0.5 mm) for screw placement under direct vision, the minimum height, width, and length for screw placement would be 8 mm, 4 mm, and 15 mm, respectively.¹⁴

ABBREVIATION VA = vertebral artery.

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FIG. 1. Schematic drawing showing the C-1 posterior arch crossing screw fixation technique. For posterior arch screw placement, after exposing the dorsal part of the posterior arch, the entry points were identified approximately 2 mm from the posterior tubercle on the opposite side; the lower point was 1 mm below the middle part of the posterior tubercle and parallel to the inferior rim of the C-1 arch, and the upper point was 2 mm higher on the other side to avoid screw interference.

Methods

The research was approved by the institutional review board of our hospital. A morphometric analysis of the C-1 posterior arch was performed in 123 pediatric patients treated at our hospital between January 2006 and December 2013. All CT scans were obtained as a result of trauma, neck pain, or any other complaint requiring cranial investigation. Exclusion criteria included congenital deformity, fracture, tumors, inflammatory disease, and previous surgery. The patients were grouped according to age (Table 1) as follows: Group 1 (1–3 years, 9 cases); Group 2 (4–6 years, 42 patients); Group 3 (7–9 years, 30 patients); Group 4 (10–12 years, 20 patients); Group 5 (13–15 years, 15 patients); and Group 6 (16–18 years, 7 patients).

All CT images of patients were taken using a 16-T CT scanner (Philips Medical Systems). The scan parameters were 120 kV, 180 MA, 512 × 512 matrix, and slice thickness 2 mm. The height of the posterior tubercle was measured through the middle plane of the posterior tubercle on the sagittal plane. The width of the posterior arch was measured bilaterally in 3 parts on the axial plane (the posterior tubercle; the medial side of the VA groove, where the arch transforms into the VA groove; and the middle part between the posterior tubercle and the medial side of the VA groove). The length of the posterior arch was measured bilaterally from the entry point to the interior VA groove.¹⁴ Representative dimensions were defined as shown in Fig. 2, and measurements were analyzed for placement of crossing screws in the C-1 posterior arch. All measurements were obtained with a picture archiving and communication system (PACS) and were rounded to the nearest 0.01 mm.

TABLE 1. Summary of group design in 123 pediatric patients with screw fixation of the C-1 posterior arch

Group	Age (yrs)	Male	Female	All
1	1–3	5	4	9
2	4–6	26	16	42
3	7–9	22	8	30
4	10–12	14	6	20
5	13–15	13	2	15
6	16–18	7	0	7

FIG. 2. Measurement of the C-1 posterior tubercle by using CT analysis. **Left:** The width (W) of the posterior tubercle was measured bilaterally in 3 parts on the axial plane (W1, the posterior tubercle; W2, the middle part between the posterior tubercle and the medial side of the VA groove; W3, the medial side of the VA groove, where the arch transforms into the VA groove). The length (L) of the posterior arch was measured bilaterally from the entry point to the interior VA groove. **Right:** The height (H) of the posterior tubercle was measured through the middle plane of the posterior tubercle on the sagittal plane. Figure is available in color online only.

Graphic representations of our data were created using an Excel spreadsheet (Microsoft Corp.), and statistical analysis was performed with SPSS (SPSS, Inc.). The mean ± SD values were calculated for all parameters. An independent t-test was used to test the difference between boys and girls in the different age groups. Linear regression analysis was used to estimate the growth rate of the C-1 posterior arch. A p value < 0.05 was considered statistically significant.

Results

There were 87 boys and 36 girls featured in our study. The median patient age at the time of CT scanning was 8.14 years (range 8 months–17 years). The measurements of mean posterior arch height, width, and length are shown in Table 2 and described below.

Height of the Posterior Tubercle

The mean values and SDs for the posterior tubercle height of each group are presented in Table 2. The mean height of the posterior tubercle was 6.35 ± 1.80 mm (range 2.65–11.32 mm). A total of 41.5% (51/123) of the posterior tubercles had a height ≥ 7 mm, and 16.3% (20/123) had a height ≥ 8 mm. Insignificant differences were noted with respect to patient sex in any age group (p > 0.05). The posterior tubercle height appeared to correlate well with age (R 0.799, p < 0.001).

Width of the Posterior Arch

The mean values and SDs for the posterior arch width of each group are presented in Table 2. The mean width of the 3 parts of the posterior arch was as follows: Width 1 (4.48 ± 1.25 mm, range 2.04–8.22 mm); Width 2 (4.42 ± 0.68 mm, range 2.55–6.12 mm); and Width 3 (4.42 ± 0.50 mm, range 3.09–5.90 mm). A total of 74.8% (92/123) of the posterior arches had a width ≥ 3.5 mm, and 58.5% (72/123) of the widths were ≥ 4 mm. Except in Groups 3 and 5, there were no significant differences between boys and girls in the other age groups. The posterior arch width appeared to correlate well with age (Width 1: R 0.733, p

TABLE 2. Height, length, and width of C-1 in 123 pediatric patients with screw fixation of the C-1 posterior arch*

Age (yrs)	Sex	Height (mm)	Length (mm)		Width 1 (mm)	Width 2 (mm)		Width 3 (mm)	
			Rt	Lt		Rt	Lt	Rt	Lt
1–3	F	4.08 ± 0.99	11.87 ± 1.16	11.90 ± 1.17	2.82 ± 0.44	3.44 ± 0.75	3.36 ± 0.73	3.77 ± 0.69	3.85 ± 0.57
	M	4.11 ± 1.77	11.44 ± 4.74	11.36 ± 4.70	2.72 ± 1.21	3.38 ± 1.41	3.41 ± 1.44	3.76 ± 1.56	3.88 ± 1.62
	All	4.10 ± 0.75	11.63 ± 1.00	11.60 ± 0.96	2.77 ± 0.47	3.41 ± 0.51	3.39 ± 0.52	3.77 ± 0.47	3.87 ± 0.43
4–6	F	5.10 ± 0.96	12.98 ± 0.83	12.86 ± 0.86	3.54 ± 0.76	3.94 ± 0.68	3.96 ± 0.67	4.19 ± 0.42	4.21 ± 0.35
	M	5.15 ± 0.92	13.57 ± 0.96	13.56 ± 0.94	3.74 ± 0.68	4.16 ± 0.49	4.12 ± 0.51	4.36 ± 0.61	4.32 ± 0.58
	All	5.13 ± 0.92	13.34 ± 0.95	13.29 ± 0.96	3.66 ± 0.71	4.07 ± 0.57	4.06 ± 0.58	4.30 ± 0.55	4.28 ± 0.50
7–9	F	6.15 ± 1.24	14.06 ± 0.71†	14.24 ± 0.73†	4.62 ± 0.69	4.37 ± 0.29	4.39 ± 0.29	4.21 ± 0.37†	4.18 ± 0.35†
	M	6.40 ± 1.46	15.02 ± 0.84†	15.04 ± 0.85†	4.83 ± 1.02	4.74 ± 0.51	4.74 ± 0.66	4.61 ± 0.41†	4.63 ± 0.36†
	All	6.34 ± 1.39	14.76 ± 0.90	14.83 ± 0.89	4.77 ± 0.93	4.64 ± 0.49	4.64 ± 0.60	4.51 ± 0.43	4.51 ± 0.41
10–12	F	7.95 ± 0.67	15.72 ± 0.60	15.63 ± 0.55	5.71 ± 0.45	4.99 ± 0.29	4.87 ± 0.40	4.59 ± 0.45	4.55 ± 0.35
	M	7.31 ± 0.65	15.49 ± 0.50	15.40 ± 0.47	4.78 ± 1.00	4.65 ± 0.40	4.61 ± 0.43	4.54 ± 0.23	4.53 ± 0.28
	All	7.50 ± 0.70	15.56 ± 0.52	15.47 ± 0.49	5.06 ± 0.97	4.75 ± 0.40	4.69 ± 0.43	4.55 ± 0.30	4.53 ± 0.29
13–15	F	9.13 ± 2.68	15.84 ± 0.85	15.99 ± 0.18	4.70 ± 0.03†	4.86 ± 0.66	4.85 ± 0.73	4.76 ± 1.68	4.66 ± 1.47
	M	8.42 ± 1.26	16.55 ± 1.13	16.47 ± 0.91	6.22 ± 1.23†	5.04 ± 0.60	5.13 ± 0.61	4.65 ± 0.40	4.75 ± 0.34
	All	8.52 ± 1.39	16.45 ± 1.10	16.41 ± 0.87	6.02 ± 1.25	5.02 ± 0.58	5.09 ± 0.60	4.66 ± 0.59	4.74 ± 0.51
16–18	F	—	—	—	—	—	—	—	—
	M	8.78 ± 1.76	16.66 ± 1.11	16.59 ± 1.16	5.66 ± 0.65	4.82 ± 0.32	4.63 ± 0.51	4.69 ± 0.25	4.71 ± 0.34
	All	8.78 ± 1.76	16.66 ± 1.11	16.59 ± 1.16	5.66 ± 0.65	4.82 ± 0.32	4.63 ± 0.51	4.69 ± 0.25	4.71 ± 0.34

— = none.

* Values are expressed as the mean ± SD.

† Significant at $p < 0.05$.

< 0.001 ; Width 2: $R\ 0.602$, $p < 0.005$; Width 3: $R\ 0.415$, $p < 0.005$).

Length of the Posterior Arch

The mean values and SDs for the posterior arch length of each group are presented in Table 2. The mean length of the posterior arch was 14.48 ± 1.67 mm (range 10.25–19.06 mm). A total of 45.9% (113/246) of the posterior tubercles had a length ≥ 15 mm, and 17.5% (43/246) had a length ≥ 16 mm. Except in Group 3, there were no significant differences between boys and girls in the other age groups. The posterior tubercle height appeared to correlate well with age ($R\ 0.854$, $p < 0.001$).

Estimated Growth Rates

The growth rates of the posterior arch (height, width, and length) were estimated using linear regression models. The growth rate of height was estimated to be 0.366 mm/year, and the growth rate of length was 0.361 mm/year. With respect to width, the rates were 0.237 mm/year at Width 1, 0.105 mm/year at Width 2, and 0.053 mm/year at Width 3 (Fig. 3).

Discussion

Surgical treatment of atlantoaxial instability can be challenging in pediatric patients. There were various fixation options discussed for C1–2. Wiring fixation was the first technique described to treat pediatric patients with Down syndrome.^{8,18} However, it was difficult to obtain solid fusion, and the procedure would increase the risk of spinal cord injury. Then the use of C1–2 transarticular

screws had been reported in pediatric patients with atlantoaxial instability.^{1,2} However, it did not provide good stability during extension and flexion because of 2-point fixation. Leonard and Wright¹⁶ reported that C-2 trans-laminar crossing screws could be used successfully in children. This technique has gained popularity due to the rigid fixation obtained and the low risk of injury to the VA. In 2008, Donnellan et al.⁷ presented a novel technique of atlantoaxial fixation in which multiaxial C-1 posterior arch screws were used. Its superiority was that it entailed little risk of injury to the neural and vascular structures as long as the implants remained intraosseous. As far as we know, though, there is no clinical evidence about this technique in the general pediatric population. Our study evaluated the dimensions of the C-1 posterior arch in 123 Chinese children in 6 different age groups to determine the feasibility of inserting screws using the C-1 posterior arch crossing screw fixation technique.

In this study, the mean measurement of posterior arch was height (6.35 ± 1.80 mm), width (Width 1: 4.48 ± 1.25 mm, Width 2: 4.42 ± 0.68 mm, Width 3: 4.42 ± 0.50 mm), and length (14.48 ± 1.67 mm). Except in Groups 3 and 5, there were no significant differences between boys and girls in other age groups. Width changed little with age, but statistically significant age-related differences were noted in height and length (Fig. 3). Christensen et al.⁴ found that the mean thickness of the median of the arch was 7.82 ± 2.64 mm and the average height was 9.58 ± 2.26 mm in 120 atlas vertebrae. Hong et al.¹³ showed that the average width of the lateral arch in 30 cases was 4.7 ± 1 mm. Kaplan¹⁵ found that the anterior medial side of the VA groove to the posterior tubercle was 12–16 mm and the outer side

FIG. 3. Graphs demonstrating width, length, and height of the C-1 posterior tubercle. Linear regression analysis was used to determine an annual growth rate. Figure is available in color online only.

half-distance of the arch was 22–28 mm (left, 20.7 mm; right, 20.2 mm). These results were the same as ours.

Assuming a 3.5-mm tolerance for each screw and allowing for a margin of error (minimum 0.5 mm) for screw placement under direct vision, the minimum height, width, and length for screw placement would be 8 mm, 4 mm, and 15 mm, respectively.¹⁴ Our data also showed that a total of 16.3% (20/123) of the posterior tubercles had a height ≥ 8 mm; 58.5% (72/123) had a Width 1 ≥ 4 mm; 72.8% (179/246) had a Width 2 ≥ 4 mm; 82.5% (203/246) had a Width 3 ≥ 4 mm; and 45.9% (113/246) of the posterior tubercles had a length ≥ 15 mm. The data imply that the height of the posterior tubercle is the main restrictive factor for inserting crossing screws into C-1 in pediatric patients. We found that 6.93% (7/101) of the children in Groups 1–4 and 59.1% (13/22) of the children in Groups 5 and 6 could safely accommodate placement of C-1 posterior arch crossing screws (Fig. 4). These findings suggest that this technique may be safer and technically easier in older children.

However, there are a number of limitations with our study. First, the measurement error is inevitable. Next, our

FIG. 4. Graph showing the distribution of patients whose anatomy was able to accept C-1 posterior arch crossing screws. Twenty (16.3%) of the 123 posterior arches could accept inserted screws, and the majority of children in Groups 5 and 6 could safely accommodate placement of C-1 posterior arch crossing screws. No = C-1 posterior arch crossing screws could not be accommodated; yes = C-1 posterior arch crossing screws could be accommodated.

study gave less consideration to the surrounding anatomy such as the VA and others. Last, this study was merely a CT morphometric analysis, and clinical practice is essential to test the safety and effectiveness of C-1 posterior arch crossing screws.

Conclusions

Our investigation found that use of a C-1 posterior arch crossing screw was feasible in Chinese pediatric patients, particularly in those 13 years and older. Preoperative thin-cut CT is essential for identifying children in whom this technique is applicable and for planning screw placement.

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Author Contributions

Conception and design: Xiang. Acquisition of data: Xiang, Lou. Analysis and interpretation of data: Xiang, Wang, Fang, Tian. Reviewed submitted version of manuscript: Xu. Approved the final version of the manuscript on behalf of all authors: Xu.

Correspondence

Hua-Zi Xu, Zhejiang Spine Research Center, Department of Orthopaedic Surgery, Second Affiliated Hospital of Wenzhou Medical University, 109 Xueyuanxi Rd., Wenzhou 325000, China. email: spinexu@163.com.