Journal of Experimental and Clinical Medicine
https://dergipark.org.tr/omujecm

Research Article

J Exp Clin Med
2023; 40(3): 562-567
doi: 10.52142/omujecm.40.3.23

Evaluation of type differences of arteria vertebralis with C2 vertebral artery groove variation origin

Dilek ARSLAN

Department of Neurosurgery, Healty Sciences University, İzmir Tepecik Training and Research Hospital, İzmir, Türkiye

Received: 16.06.2023 • **Accepted/Published Online:** 23.09.2023 • **Final Version:** 30.09.2023

Abstract

Vertebral artery Groove (VAG) variations at the C2 vertebral level are one of the most important factors determining the risks of C2 pedicle screw surgery. However, there are no accepted guidelines for radiographic parameters that can predict C2 screw placement and probabilty of fracture risk. In our study, we evaluated the type differences in the C2 pedicle caused by the C2 VAG variation of the arteria vertebralis, which is specific to our population, with three-dimensional computed tomography angiography (3D-CTA). Therefore, we aimed to easily estimate the risks of C2 pedicle screw placement by type in patients scheduled for surgery. Measurements were made on a total of 200 patients in 100 female and 100 male patients who underwent cervical 3D-CTA. C2 level VAG variations were categorized into four groups as Type I, Type II, Type III and Type IV. Female, male, right pedicle and left pedicle type comparisons were statistically analysed. It was predicted that screw placement was possible with low risk in Type I, with high risk in Type III and Type IV, and impossible in Type II. Type I pedicle was the most common variation with a rate of 66.5% in men and 48 iin women. There was no significant difference between men and women in the distribution of Type I C2 pedicles in our population ($p=0.067$, $p=0.138$). There were statistically significant differences between men and women in the distribution of Type II, Type III and Type IV variations ($p=0.008$, $p=0.037$, $p=0.0069$). Type II pedicle variation was 5% in men and 15% in women. We think that the evaluation of the type differences of the C2 VAG variation origin of the arteria vertebralis in our population will be a guide for surgical interventions in this region.

Keywords: C2 pedicle screw, C2vertebral artery Groove, HRVA, narrow pedicle

1. Introduction

Variations in the anatomical C2 vertebral artery groove (C2 VAG), observed in preoperative imaging, have been reported to influence the surgical plan for C2 pedicular. No guidelines have been established as to which radiographic parameters can be used as predictors of the risk of pedicle fracture with C2 pedicle insertion. The diameters of the C2 pedicles vary according to various researchers, often due to the use of alternative methods and images from different slices of a computed tomography (CT) scan. Hassan et al. reported in 2010 that a thin-section CT scan before surgery can predict the risk of C2 pedicle screw placement and that the risk of cortical fracture is two times higher in pedicles with a C2 pedicle diameter of less than 6 mm[1). According to Wang et al. describes as the greater the vertical distance from the VAG apex to the upper facet joint surface and the horizontal distance from the VAG entrance to the vertebral canal, the safer pedicle screw implantation will be. If any of these distances is less than 4.5mm, there is a high risk of inserting a screw with a maximum diameter of 3.5mm[2).

Preoperative thin-section three-dimensional computed tomography angiography (3D- CTA) to measure pedicle diameter can be a sensitive parameter for assessing screw placement risks. As a result, we used 3D-CTA to assess the type differences of Arteria vertebralis originating from C2 VAG variation unique to the Turkish society in the C2 pedicle. Thus, we aimed to easily predict the risks of C2 pedicle screw application due to type differences in patients who are planned to undergo for a C2 instrumentation.

2. Material and Method

For this study, permission was obtained from the ethics committee University of Health Sciences İzmir Tepecik Training and Research Hospital, with Decision No: 2023/05-18. Cervical 3D-CTA images of 200 patients obtained in our institution between January 2017 and January 2023 were evaluated retrospectively.

3D-CTA application technique: All patients' neck regions and craniocervical regions were scanned with 64-channel dual-source computed tomography (GE company, USA). A 20- 22 G intravenous cannula was used to administer contrast agent injection from the right upper extremity. An iodized contrast agent (Iohexol) was administered at a rate of 5 ml/sec using a 60 ml 350 mg/ml auto-injector. The scan lasted for

*Correspondence: dilekozenc@gmail.com

approximately 6-10 seconds. Following extraction, a 20 ml saline infusion was administered intravenously to the patients. The area between the arcus aorta and the vertex was examined. Curved reformat reconstruction, color coding, maximum intensity projection (MIP), and 3D volume rendering algorithms were applied to 0.5 mm thick images in all three planes. Digitally generated 3D-CTA images were used for measurements.

We used 0.5 mm 3D-CTA slices obtained at the C2 pedicle direction in cervical region to perform a type of CT scan spectrum generation method of C2 VAG used by Wang et al. in 2013(2). Wang et al (2013)'s study is the result of a series of 45 patients they operated on, and the current study is a retrospective study of 200 patients in whom patients under the age of 18, those who had upper cervical surgery, those who had trauma or tumors in the upper cervical vertebrae, and those who had congenital anomalies were all excluded from the study. Whereas vertical height from the apex of the C2 VAG to the upper facet joint surface was referred to as the 'e' parameter, a horizontal distance from the entrance of the C2 VAG to the vertebral canal was referred to as the 'a' parameter. Three-dimensional CT reconstruction was performed based on the defined 'e' and 'a' parameters. A C2 VAG model figure was used to create a safe zone area for pedicle screw placement.

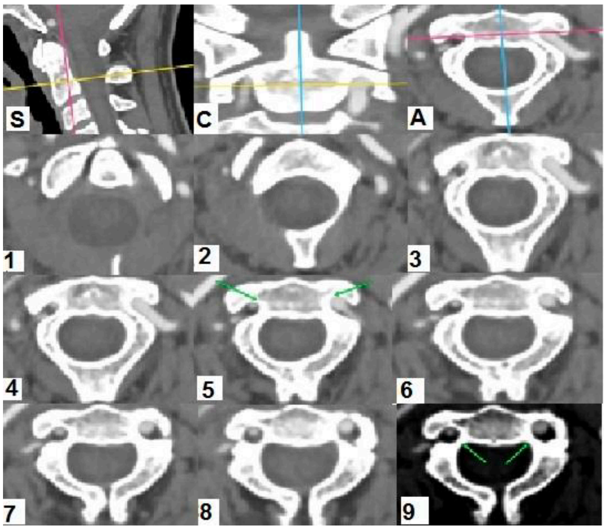

Fig. 1. 0.5mm 3D-CTA sections taken along the axis pedicle direction. S: Sagittal image, C: Coronal image, A: Axial image. Numbered photographs are 0.5mm axial sections parallel to the pedicle. The arrows in image 5 indicate the peak of VAG and then the parameter 'e' is calculated according to the number of slices. The parameter 'a' can be measured in slice 9 ofm Fig.1, where the markings indicate the distance from the entrance of the VAG to the vertebral canal.

Curved reformat reconstruction images were obtained from 0.5 mm sequential cervical 3D-CTA images along the C2 pedicle direction. The arrows in Fig. 1, Slice 5 indicate the peak of the VAG, and the parameter 'e' is calculated based on the number of slices. The 'a' parameter can be measured in the slice where the marks in the 9th slice of Fig. 1 demonstrate the distance from the VAG entry to the spinal canal. In Fig. 2, the 'e' and 'a' parameters are shown in the photograph coded 'C'. Four anatomical typings in terms of C2 pedicle screw insertion specific to the Turkish population were made by measuring "e and 'a' parameters in the coronal and axial sections of the pedicle. These typings were described as follows: TYPE I: wide and low (a > 4.5mm, e ≥ 4.5mm), TYPE II: narrow and high (a ≤ 4.5mm, e<4.5mm), TYPE III: narrow and low (a < 4.5mm, e ≥ 4.5mm), TYPE IV: wide and high (a ≥ 4.5mm, e < 4.5mm). Measurements were grouped according to sex (female or male) and based on the measurement direction (right or left). Type I was estimated to have the lowest risk of C2 screwing complications. For Type II, it was estimated that a C2 pedicular screw could not be applied safely. The complication risk of C2 pedicular screw application was predicted to increase in Type III and Type IV.

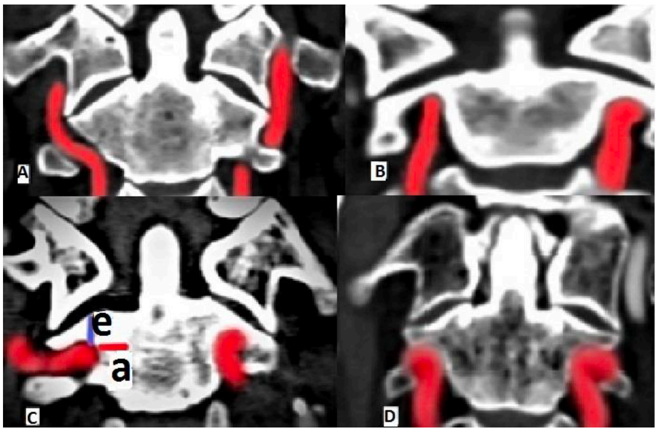

Fig. 2. Arteria vertebralis are coloured in 3D-CTA coronal section images. A) Bilateral Type I pedicle, male case. Right pedicle; e:8.32mm, a:8.15mm. Left pedicle e:8.51mm, a: 6.59mm B) Bilateral Type II pedicle, female patient. Right pedicle; e: 1.91mm, a: 0mm. Left pedicle e: 3.43mm, a: 3.92mm C) Bilateral Type III pedicle male case. Representative e and a parameters are shown. Right pedicle; e:5.86mm, a:3.7mm. Left pedicle e:5.55mm, a: 3.1mm D) Bilateral Type IV pedicle male case. Right pedicle; e:3.8mm, a: 6.11mm. Left pedicle e: 3.8mm, a:4.79mm.

2.1. Statistical Method

Data were evaluated using the IBM SPSS Statistics Standard Concurrent User V 26 statistical package program (IBM Corp., Armonk, New York, USA). Number of units (*n*), percent (%), mean ($\bar{x}$), standard deviation (*sd*), and standard error (*se*) were used to demonstrate descriptive statistics. The Shapiro-Wilk normality test was used to evaluate the normal distribution of numerical variable data. Levene's test was used to evaluate the homogeneity of the variances. For independent samples, the 'a' and 'e' values of male and female patients were compared using the *t*-test. Since male and female patients' ages differed statistically, age-adjusted 'a' and 'e' values were also compared using one-way covariance analysis. The Pearson chi-square test was used to compare the type distributions of males and females based on the measurement sides (right or left). In Pearson chi-square analyses, the Bonferroni (correction) two-ratio z-test was used to compare subgroups. A paired t-test was used to compare the a and e values obtained from both male and female patients' measurements from the right and left sides. The McNemar Bowker test was used for type comparisons for both left and right. A *p*-value of <0.05 was considered statistically significant.

3. Results

According to the incidence rates, 62 (62 %) Type I, 9 (9%) Type II, 6 (6%) Type III, 23 (23%) Type IV pedicle variations were found on the right side in 100 male patients, respectively. On the left side, 71 (71%) Type I, 1 (1%) Type II, 19 (19%) Type III, and 9 (9%) Type IV pedicle variations were found in 100 male patients. According to the incidence rates, 39 (39 %) Type I, 14 (14%) Type II, 6 (6%) Type III, 41(41%) Type IV pedicle variations were found on the right side in 100 female patients, respectively. On the left side, 57 (57%) Type I, 16 (16%) Type II, 10 (10%) Type III, and 17 (17%) Type IV pedicle variations were found in 100 female patients.

Type I was the most common variation in both males and females. While Type II was the least common variation in males, Type III was the least observed variation in females.

Table 1. Comparisons by male and female

Unadjusted values by age					Age adjusted values			
	Gender		**Test Statistics**		**Gender**		**Test Statistics**	
	Male (n:100) $\bar{x}$±*ss*	**Female (n:100)** $\bar{x}$±*ss*	*Test value*	*p*	**Male** $\bar{x}$±*sh*	**Female** $\bar{x}$±*sh*	*Test value*	*P value*
Age, (*yıl*)	59.8±15.8	53.6±15.2	**2.824**	**0.005**†	-	-	-	-
a Right	6.11±2.07	6.34±2.13	0.774	0.440†	6.12±0.21	6.31±0.21	0.388	0.534‡
e Right	5.11±1.33	4.34±1.30	**4.126**	**<0.001**†	5.12±0.13	4.31±0.13	**18.333**	**<0.001**‡
Type of pedicle on the right side *n* (%)								
I	62 (62.0)^{a}	39 (39.0)^{b}						
			11.387	**0.010**$^{\&}$				
II	9 (9.0)^{a}	14 (14.0)^{a}						
III	6 (6.0)^{a}	6 (6.0)^{a}						
IV	23 (23.0)^{a}	41 (41.0)^{b}						
a Left	6.16±2.10	5.73±2.22	1.409	0.161†	6.14±0.22	5.76±0.22	1.506	0.221‡
e Left	6.33±1.71	5.02±1.61	**5.571**	**<0.001**†	6.36±0.16	4.97±0.16	**33.390**	**<0.001**‡
Type of pedicle on the left side, *n* (%)								
I	71 (71.0)^{a}	57 (57.0)^{b}						
			20. 021	**<0.001**$^{\&}$				
II	1 (1.0)^{a}	16 (16.0)^{b}						
III	19 (19.0)^{a}	10 (10.0)^{a}						
IV	9 (9.0)^{a}	17 (17.0)^{a}						

n: Number of patients, %: Percentage of column, x̄:, ss: standard deviation, sh: standard error, †: Independent samples t test, ‡: One-way analysis of covariance, &: Pearson chi-square analysis$^{\&}$:, Superscripts a and b show the difference between genders in the same row. There is no statistical difference between genders with the same superscripts.

According to Table 1, male patients are statistically older than females (p=0.005). 'a' values obtained from the right side do not differ according to sex (p=0.440). Even when right side 'a' values were adjusted for age (p=0.534), no statistical difference was found between male and female patients. Right side 'e' values of male patients were statistically higher than females (p<0.001). When adjusted for age, the right side 'e' values of male patients were found to be statistically higher than female patients. The right-sided type variations differ statistically by sex (p=0.010). The number of Type I pedicles on the right side was 62 (62.0%) in males and 39 (39.0%) in females, which was showing that males having statistically more Type I pedicles than females. For the right side, there is no statistical difference between the distribution of males and females with a Type II pedicle. Female patients with Type IV pedicles on the right side out number males statistically.

Male and female patients' left side 'a' values were not statistically different (p=0.161). Even when left side 'a' values were adjusted for age (p=0.221), no statistical difference was found between male and female patients. Left side 'e' values of male patients were statistically higher than females (p<0.001). When adjusted for age, the left side 'e' values of male patients were found to be statistically higher than female patients (p<0.001). For the left side, the type distributions in males and females were statistically different (p<0.001). Males were statistically more than females in Type I for the left side, whereas females were statistically more than males in Type II.

No statistical difference was found in terms of the distribution of males and females for Type III and Type IV.

Table 2. Right and left side e-a comparisons in all patient group, male and female patients

Test Statistics				
	Right side $\bar{x}$±*ss*	**Left side** $\bar{x}$±*ss*	Test value	*P* value
All patients, *n*=200				
a	6.23±2.10	5.94±2.17	1.895	0.060$^{\gamma}$
e	4.72±1.37	5.68±1.78	**8.044**	**<0.001**$^{\gamma}$
Male patients *n*=100				
a	6.11±2.07	6.16±2.10	0.206	0.837$^{\gamma}$
e	5.11±1.33	6.33±1.71	**6.873**	**<0.001**$^{\gamma}$
Female patients, *n*=100				
a	6.34±2.12	5.73±2.22	**3.098**	**.003**$^{\gamma}$
e	4.34±1.30	5.02±1.61	**4.476**	**0.001**$^{\gamma}$

$\bar{x}$: mean, *ss*: standard deviation, $^{\gamma}$: Paired samples t-test, n:number of patients

The differences in right and left 'a' values in all patients were not statistically significant (*p*=0.060), according to Table 2. In all patients, left side 'e' values were found to be statistically higher than right side 'e' values (*p*<0.001). No statistically significant difference was found between right and left 'a' values in males (*p*=0.837). In males, left side 'e' values were found to be statistically higher than right side 'e' values (*p*<0.001). In females, left side 'e' values were found to be statistically higher than right side 'e' values (*p*<0.001).

According to Table 3, the type distribution for the right and left pedicles was statistically different in all patients (*p*<0.001). Eighty-four (42.0%) of the patients had bilateral Type I pedicles, 6 (3.0%) had bilateral Type II pedicles, 9 (4.5%) had bilateral Type III pedicles, and 15 (7.5%) had bilateral Type IV pedicles. Thirty-four (17.0%) of the patients had a Type I pedicle on the left side and a Type IV pedicle on the right side.

Type distributions for the right and left sides in males were statistically different (*p*=0.003). Among male patients, 50 (50.0%) of them had bilateral Type I pedicles, 4 (4.0%) had bilateral Type III pedicles, and 4 (4.0%) had bilateral Type IV pedicles. No male patient had a bilateral Type II pedicle. Within the group of the males, 15 (15%) of them had Type I pedicle on the left side and Type IV pedicle on the right side.

Table 3. Right and left type comparisons in all patient group, male and female patients

	Type of pedicle on the left side				Test Statistics	
	I	II	III	IV	Test value	*p* value
Type of pedicle on the right side						
All Patients n:200 *n* (%)						
I	84 (42.0)	3 (1.5)	8 (4.0)	6 (3.0)	**35.606**	**<0.001**$^{¥}$
II	8 (4.0)	6 (3.0)	4 (2.0)	5 (2.5)		
III	2 (1.0)	1 (0.5)	9 (4.5)	0 (0.0)		
IV	34 (17.0)	7 (3.5)	8 (4.0)	15 (7.5)		
Male patients n:100 *n* (%)						
I	50 (50.0)	1 (1.0)	7 (7.0)	4 (4.0)	**19.946**	**0.003**$^{¥}$
II	4 (4.0)	0 (0.0)	4 (4.0)	1 (1.0)		
III	2 (2.0)	0 (0.0)	4 (4.0)	0 (0.0)		
IV	15 (15.0)	0 (0.0)	4 (4.0)	4 (4.0)		
Female patients n:100 *n* (%)						
I	34 (34.0)	2 (2.0)	1 (1.0)	2 (2.0)	**21.002**	**0.002**$^{¥}$
II	4 (4.0)	6 (6.0)	0 (0.0)	4 (4.0)		
III	0 (0.0)	1 (1.0)	5 (5.0)	0 (0.0)		
IV	19 (19.0)	7 (7.0)	4 (4.0)	11 (11.0)		

n: Number of patients, %: Percentage of the total number,$^{¥}$: McNemar Bowker test

Type distributions for the right and left sides for females were statistically different (*p*=0.002). Within the females, 34 (34.0%) of them had bilateral Type I pedicles, 6 (6.0%) had bilateral Type II pedicles, 5 (5.0%) had bilateral Type III pedicles, and 11 (11.0%) had bilateral Type IV pedicles. Of the females, 19 (19.0%) of them had Type I pedicle on the left side and Type IV pedicle on the right side.

4. Discussion

The reason for the differences in cervical pedicle anatomical measurement may be because of sex or geographical race difference (3). In general, females have smaller pedicle diameters and heights than males in many races. According to cervical anatomical measurements, Asians have smaller pedicles than Europeans and Americans (4). Anatomical measurements obtained with sensitive imaging devices such as thin-section CTA will now more clearly reveal anatomical differences in different populations (5).

Upper cervical vertebral fractures, dislocations, transverse ligament damage, congenital anomalies, rheumatic diseases, and upper cervical tumors may necessitate craniocervical stabilization. Çokluk and Aydın (6) reported that 17% of C2 fractures are upper cervical spine fractures.

The C2 pedicle is strong and has a well-vascularized structure (7,8). Therefore, pure C2 fractures are rare (7, 9). Biomechanical studies on cadavers show that C2 pedicle screws are quite stable (10). C2 pedicular screwing is easier to apply than transarticular screwing and the risk of complications is less (11,12). Although Yoshida et al. reported that both applications had the same surgical risk, Klepinowski et al. stated that C1 lateral mass and C2 screwing were the gold standards for craniocervical junction stabilization (13-14). Bicortical polyaxial screws are biomechanically strong and easier to apply in this narrow area. The facets are preserved, and when the fracture heals, motion can be preserved when the instrument is removed. Alternative surgical options can be preferred if a C2 pedicle screw is risky or impossible.

If the pedicle is narrow, pedicular screw insertion is commonly avoided. Maki et al. reported that a safe C2 screw can be applied when the C2 VAG is oriented towards the cranial, but if the C2 VAG is both cranial and medial, the C2 pedicular screw cannot be applied (15).

Lee et al. classified the intra-axial vertebral artery based on two anatomical parameters, namely in the coronal and lateral plane, and divided them into 9 types (16). They discovered an increase in intra-axial vertebral artery tortuosity in female and elderly patients.

Wang et al. used 74 transpedicular screws and 16 translaminar screws on the C2 pedicles, which they classified into four types. They reported that transpedicular screwing cannot be used if there is a Type II C2 pedicle. Pedicle screw placement is impossible in Type II because the "safe zone" of "*e* and a" is less than 4.5 x 4.5 mm (2). The C2 translaminar screw method may be recommended in such cases. The elimination of the potential risk of arterial injury is the most significant advantage of the C2 translaminar screw (17). Wang et al. observed vertebral canal breach in 2 pedicles with a rate of 2.7% in patients who underwent transpedicular screw application in their series (2). No complications were observed with translaminar screws. However, the outcomes of C2 translaminar screw surgery were often unsatisfactory, with significant rates of screw dislocation and reoperation (18).

Yeom et al. reported that a breach was observed in 8 of 39 C2 pedicle screws (21%) to the vertebral artery groove but none of them caused arterial injury (19). However, no breaches were detected on intraoperative and postoperative radiographs. They may have detected VAG violations at a high rate because they used 3D-CTA in both preoperative and postoperative measurements. Angiography is generally not preferred for routine postoperative contralateral angiography, even though 3D-CTA is sometimes used in preoperative preparations.

In our study, 57.2% Type I pedicles were observed in 200 patients. This rate is similar to the rate of 58.9% Type I C2 pedicles in the series of Wang et al. (2). In our study, Type I pedicle was observed in 66.5% of 100 male patients and 48% of 100 female patients.

In our study, 10% Type II pedicles were detected in 200 patients. Wang et al. reported a higher rate 17.8% of Type II pedicles in their series (2). Yusof et al. found that 3.5 mm diameter screws could not be used in 54.2% of males with only pedicle diameter measurement in their study on different levels of cervical vertebral pedicles in 40 Malaysian participants (5). Patwardhan et al. reported that 3.5 mm diameter screws could not penetrate approximately 30% of C2 pedicles, their study involved 27 participants from the Indian population (20).

However, in both studies, pedicle widths of less than 5 mm were taken into account. The prevalence of Type II pedicles in our study in males and females was 5% and 15%, respectively. It can be said that it is impossible to apply C2 pedicular screws to these pedicles. The rate of C2 pedicle Type II in females was found to be 3 times higher than that of males.

Wang et al. reported that of the C2 pedicles in their series, 14.4% of them were Type III and 8.9% were Type IV (2). In our study, of the 200 patients, 10.25% were Type III and 22.5% Type IV. Type III pedicle was observed more frequently in males (12.5%) than in females (8%). Type IV was more common in females (29%) than males (16%). The risk of C2 screw insertion in Type III and Type IV pedicles is higher than in Type I pedicles.

The limitations of this study include the fact that it was not based on clinical outcomes and was conducted retrospectively. Since it is a cross-sectional imaging study, it cannot reveal the frequency of vertebral artery injury. However, if surgery is required, preoperative pedicle classification based on C2 vertebral artery groove type may help with surgical planning. By avoiding potential complications, the risk of surgical morbidity and mortality can be reduced.

The classification of the type differences of the arteria vertebralis originating from the C2 vertebral artery groove variation can guide the surgeon in a practical manner in patients who are scheduled to undergo a C2 pedicular screw insertion. In order to prevent possible complications in C2 pedicle screw placement, it is necessary to determine the safe zone preoperatively. For this purpose, preoperative thin section 3D-CTA imaging of the upper cervical region is routinely recommended.

Conflict of interest
The authors declared no conflict of interest.

Funding
No funding was used for the study.

Acknowledgments
The author would like to thank Dr. Yeliz Pekçevik for her

technical support.

Authors' contributions

Concept: D.A., Design: D.A., Data Collection or Processing: D.A., Analysis or Interpretation: D.A., Literature Search: D.A., Writing: D.A.

Ethical Statement

For this study, permission was obtained from the ethics committee University of Health Sciences İzmir Tepecik Training and Research Hospital, with Decision No: 2023/05-18.

References

1. Alosh H, Parker SL, McGirt MJ, Gokaslan ZL, Witham TF, Bydon A, et al. Preoperative radiographic factors and surgeon experience are associated with cortical breach of C2 pedicle screws. J Spinal Disord Tech. 2010; 23(1):9-14.
2. Wang J, Xia H, Ying Q, Lu Y, Wu Z, Ai F, et al. An anatomic consideration of C2 vertebrae artery groove variation for individual screw implantation in axis. Eur Spine J. 2013;22(7):1547-52.
3. Pruthi N, Dawn R, Ravindranath Y, Maiti TK, Ravindranath R, Philip M. Computed tomography-based classification of axis vertebra: choice of screw placement. Eur Spine J. 2014; 23(5):1084-91.
4. Liu J, Napolitano JT, Ebraheim NA. Systematic review of cervical pedicle dimensions and projections. Spine (Phila Pa 1976). 2010;35(24):E1373-80.
5. Yusof MI, Ming LK, Abdullah MS, Yusof AH. Computerized tomographic measurement of the cervical pedicles diameter in a Malaysian population and the feasibility for transpedicular fixation. Spine (Phila Pa 1976). 2006;31(8):E221-4.
6. Çokluk C, Aydın K. The Use Of Postnatal Developmental Cartilaginous Lines In The Classification Of C2 Fractures. Journal of Experimental and Clinical Medicine.2010;27(1):E13-5.
7. Park JB, Kim SK, Seo HY, Ko JH, Hong TM. Proposal of Treatment Strategy for Pedicle Fractures of the C2: An Analysis of 49 Cases. J Clin Med. 2021;10(17):3987.
8. German JW, Hart BL, Benzel EC. Nonoperative management of vertical C2 body fractures. Neurosurgery. 2005;56(3):516-21; discussion 516-21.
9. Cokluk C, Takayasu M, Yoshida J. Pedicle fracture of the axis: report of two cases and a review of literature. Clin Neurol Neurosurg. 2005;107(2):136-9.
10. Sim HB, Lee JW, Park JT, Mindea SA, Lim J, Park J. Biomechanical evaluations of various c1-c2 posterior fixation techniques. Spine (Phila Pa 1976). 2011;36(6):E401-7. 11) Chen JF, Wu CT, Lee SC, Lee ST. Posterior atlantoaxial transpedicular screw and plate fixation. Technical note. J Neurosurg Spine. 2005;2(3):386-92.
11. Shen FH, Samartzis D, Jenis LG, An HS. Rheumatoid arthritis: evaluation and surgical management of the cervical spine. Spine J. 2004;4(6):689-700.
12. Yoshida M, Neo M, Fujibayashi S, Nakamura T. Comparison of the anatomical risk for vertebral artery injury associated with the C2-pedicle screw and atlantoaxial transarticular screw. Spine (Phila Pa 1976). 2006;31(15):E513-7.
13. Klepinowski T, Limanówka B, Sagan L. Management of post-traumatic craniovertebral junction dislocation: A PRISMA-compliant systematic review and meta-analysis of casereports. Neurosurg Rev. 2021;44(3):1391-1400.
14. Maki S, Koda M, Iijima Y, Furuya T, Inada T, Kamiya K, et al. Medially-shifted rather than high-riding vertebral arteries preclude safe pedicle screw insertion. J Clin Neurosci. 2016;29:169-72.
15. Lee SH, Park DH, Kim SD, Huh DS, Kim KT. Analysis of 3-dimensional course of the intra-axial vertebral artery for C2 pedicle screw trajectory: a computed tomographic study. Spine (Phila Pa 1976). 2014;39(17):E1010-4.
16. Sciubba DM, Noggle JC, Vellimana AK, Conway JE, Kretzer RM, Long DM, Garonzik IM. Laminar screw fixation of the axis. J Neurosurg Spine. 2008; 8(4):327-34.
17. Wang Y, Wang C, Yan M. Clinical Outcomes of Atlantoaxial Dislocation Combined with High-Riding Vertebral Artery Using C2 Translaminar Screws. World Neurosurg. 2019;122:e1511-18.
18. Yeom JS, Buchowski JM, Park KW, Chang BS, Lee CK, Riew KD. Undetected vertebral artery groove and foramen violations during C1 lateral mass and C2 pedicle screw placement. Spine (Phila Pa 1976). 2008;33(25):E942-9.
19. Patwardhan AR, Nemade PS, Bhosale SK, Srivastava SK. Computed tomography-based morphometric analysis of cervical pedicles in Indian population: a pilot study to assess feasibility of transpedicular screw fixation. J Postgrad Med. 2012;58(2):119-22.