VERTEBRAL ARTERY GROOVE ANATOMY

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ABSTRACT

Introduction: Several surgical techniques have been carried through in the skull-cervical region due to various pathologies. During the surgical access to this region, a potential risk of iatrogenic injury of the vertebral artery exists, related to extended lateral access and the inadequate evaluation of the local anatomy. Variations in the groove of the vertebral artery lead to a greater risk of vascular injury during surgery. Preoperative image study of the vertebral artery anatomy and its groove has been realized to enhance surgical safety. Objective: to study the morphometry of atlas vertebral artery on computed tomography scan images of the vertebral artery groove (VAG) in 30 dry atlas. Methods: VAG and its relationship with the midline were evaluated through eight linear and two angular measures, bilaterally. The average, maximum and minimum values, and standard deviation were calculated for each parameter. Results: VAG has shown to be wider and thicker on the left side ($p<0,05$). Conclusion: our data suggest that the posterior and superior dissection of the posterior arch must be made at lateral distance of 11,2mm and 7,4mm to the midline in order to provide safety during the procedure.

Keywords: *Spine. Atlas. Vertebral artery. Spinal fusion.*

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INTRODUCTION

After emerging from axis transverse process, the vertebral artery flexes posterior and laterally towards atlas costotransverse foramen, forming the sub-occipital segment, outlining atlas posterior arch.[1] Vertebral artery's sub-occipital segment, after a short slope posterior to atlas lateral mass, forms an impression over the upper surface of atlas arch, named as vertebral artery groove (VAG). VAG is extended horizontally from the medial edge of transverse foramen to the medial edge of posterior arch. This groove can be easily visualized in isolated cadaver vertebrae as a depression area on atlas posterior arch, posterior to the lateral mass. VAG accurately marks, on isolated vertebrae, the site where vertebral artery pulses. Sometimes, the distal portion of VAG forms a full bone bridge to the posterior edge of atlas' upper joint facet, forming a foramen. This anatomical structure is called ponticulus posticus (PP), Kimmerle´s variant, upper retroarticular foramen, vertebral canal, retroarticular canal, or retrocondylar vertebral artery arch.[2-7]
The presence of PP, either partially or totally, found in literature ranges from 5.14%[8] to 51%.[9]
The number of procedures on atlantoaxial joint has been increasingly performed because of the development of diagnostic instruments, a better understanding about this transition area's biomechanics and of the development of fixation methods.[10,11] Fixation methods include wiring, transarticular screws fixation, the use of hooks, screws insertion into joint or translaminar atlas joint. The iatrogenic injury of vertebral artery is the most frequently mentioned peroperative complication.[12-16] Injuries most commonly occur during fixation with transarticular screws or on lateral mass, and seldom during surgical access on craniocervical joint.[17]
The objective of this study is to describe VAG in dried atlas by studying anatomic and X-ray characteristics using helical computed tomography.

MATERIALS AND METHODS

Thirty cervical vertebrae (C1 or atlas) of adult non-identified cadavers were donated by Aracaju Urban Services Company (EMURB - Sergipe, Brazil – protocol number 047/2005). Vertebrae were removed from local individuals, buried as indigents, not making any distinction regarding gender, age or ethnicity. After dissecting, cleaning and fixation, the vertebrae were numbered for future analysis by means of manual anatomical measures with a 4-D digital pachymeter (Starret SR44, 0.01mm precision) and radiological assessments by helical computed tomography (Toshiba Asteion TSX – 021A/1A, 1mm-thick slides).
The anatomical parameters measured with the tomography and the anatomical study were the following: Inner groove length (Il), Outer groove length (Ol), groove width (W), groove thickness (T), proximal medial projection (D1), proximal lateral projection (D2), distal medial projection (D3), distal lateral projection (D4). Angular measures for angle $\beta1$, formed by the line crossing the inner edge of the arch at the initial portion of the groove and crossing the posterior tubercle to the mid line, and for angle $\beta2$, formed by the line crossing the outer portion of the posterior arch and crossing the posterior tubercle to the mid line, were assessed only with computed tomography. (Figure 1)

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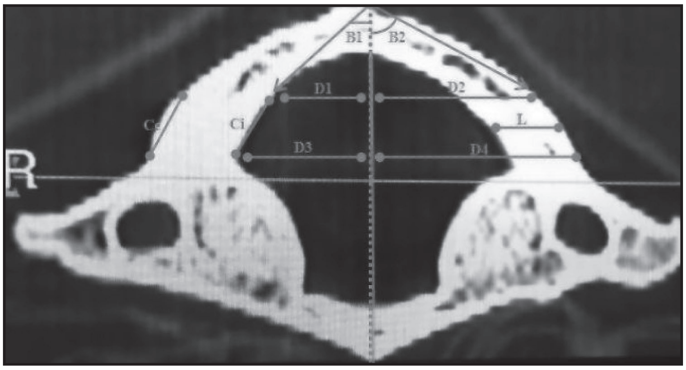

Figure 1 – *VAG tomography study:* **(Ci):** *VAG anteroposterior distance,* **(Ce):** *anteroposterior distance ,* **(L):** *distance between inner and outer edge ,* **(E):** *distance between upper and bottom surface ,* **(D1):** *distance between the inner arch edge on the initial portion of the groove and the longitudinal mid line,* **(D2):** *distance between the outer arch edge on the initial portion of the groove and the mid line,* **(D3):** *distance between the inner arch edge on the final portion of the groove and mid line,* **(D4):** *distance between the outer arch edge on the final portion of the groove and mid line,* **(β1):** *angle formed by the line crossing the inner arch edge at the initial VAG portion and crossing the posterior tubercle to the mid line,* **(β2):** *angle formed by the line crossing the outermost arch edge at the initial VAG portion and crossing the posterior tubercle to the mid line.*

For assessing measurements reproducibility, the anatomical measurements were made by two different investigators, with first results blinded to the second investigator. A subgroup of five vertebrae was randomly selected, which were submitted to a new tomography test in which the measurements were performed again by the same investigator, blinded to the results of the first measurement. For assessing inter-investigator and intra-investigator variations and with the radiologic study, the intra-class correlation coefficient (ICC) was calculated.[18,19]
Consistency between measurements performed by both investigators and by radiology was assessed by ICC[18,19] and by the relevant confidence interval (95% confidence). For comparing variables assessed on right and left sides, a linear regression model was adopted. In the cases where more than one measurement was provided in a same vertebra by different methods (or researchers) (investigators 1 and 2, and radiology), the model enabled the adjustment of one line for each method. Sides similarity was assessed by the hypothesis test, in which the line intercept was equal to zero and the angular coefficient was equal to one.

RESULTS

Based on the findings of the measurements on the thirty atlas, median, mean, maximum value, minimum value, standard deviation and intra-class correlation coefficient were calculated. Both linear and angular measurements do not show statistical differences inter-, intra-investigator, and radiological. The reliability of these measurements is significantly higher than zero. All intra-class correlation coefficient values were close to 1, evidencing measurement reliability, both inter- an intra-investigators.
The measurements for inner and outer VAG length did not show significant differences between right and left sides both in the anatomical and in the radiological study. The mean value found for inner length was 7.58 ± 1.50 mm to the right of investigators' mean values, and 7.80 ± 1.48 mm on radiology. The mean values on the left were 7.29 ± 1.20 mm of investigators' mean values, and 7.53 ± 1.24 mm on radiology. For outer VAG length, the mean values found to the right of investigators' mean values were 9.68± 2.18 mm and 9.93 ± 2.09 on radiology, and the mean values found to the left were 9.54 ± 1.77 mm of investigators' mean values, and 9.85 ± 1.70 mm on radiology. (Table 1)
Measurements obtained both from VAG width and thickness showed a significant difference between right and left sides both on the findings of the two investigators and in the radiologic study. The mean value found for width was 8.49 ± 1.43 mm to the right of investigators' mean values, and 7.73 ± 1.54 mm on radiology. The mean values found on the left were 8.78 ± 1.49 mm of the investigators' mean values, and 7.96 ± 1.57 mm on radiology. The mean value found for thickness at the right of investigators' mean values was 3.87 ± 0.83 mm and 3.82 ± 0.82 mm on radiology and the mean values found to the left were 3.92 ± 1.10 mm of investigators' mean values, and 3.81 ± 1.06 mm on radiology. (Table 2)
β1 angle measurements showed a mean value of 47.45° ± 6.24° to the right and 47.31° ± 6.06° to the left. A significant difference was found between right and left sides ($p = 0.1826$). β2 angle measurements showed a mean value of 63.51° ± 5.22° to the right, and 62.95° ± 3.85° to the left ($p = 0.0001$). (Table 3)
Concerning D1 projection, we found varying results between right and left sides both on the findings of the two investigators and in

Table 1 – *Vertebral artery groove length – inner and outer*

	Inner length								Outer length							
	R				L				R				L			
	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad
Minimum	4.19	4.12	4.16	4.60	5,27	5,24	5,53	5,60	6,36	5,74	6,35	6,70	7,23	7,18	7,25	7,50
Maximum	10.83	10.43	10.63	11.10	10,81	10,28	10,55	10,90	16,24	16,51	16,38	16,50	13,42	13,15	13,29	13,60
Median	7.39	7.67	7.60	7.70	7,45	7,52	7,52	7,65	9,47	9,57	9,56	9,70	9,16	9,36	9,27	9,40
Mean	7.54	7.61	7.58	7.80	7,28	7,30	7,29	7,53	9,69	9,67	9,68	9,93	9,51	9,56	9,54	9,85
SD	1.47	1.56	1.50	1.48	1,26	1,18	1,20	1,24	2,11	2,32	2,18	2,09	1,79	1,75	1,77	1,70
ICC	0.99				0.99				0.99				0.99			
$CI_{95\%}$	[0.98;1]				[0.98;0.99]				[0.97;0.99]				[0.99;1]			
P	<0.0001				<0.0001				<0.0001				<0.0001			

Table 2 – Vertebral artery groove – width and thickness

	Width								Thickness							
	R				L				R				L			
	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad
Minimum	4.61	4.73	4.67	3.30	5,15	5,17	5,32	4,40	2,49	2,16	2,42	2,40	2,26	2,27	2,39	2,40
Maximum	11.28	11.45	11.37	9.90	11,36	11,74	11,55	10,30	6,48	6,13	6,31	6,10	8,02	8,25	8,14	7,70
Median	8.56	8.55	8.52	7.80	9,22	9,15	9,23	8,30	3,84	3,86	3,79	3,75	3,65	3,81	3,62	3,55
Mean	8.47	8.51	8.49	7.73	8,73	8,82	8,78	7,96	3,83	3,91	3,87	3,82	3,86	3,98	3,92	3,81
SD	1.43	1.44	1.43	1.54	1,44	1,55	1,49	1,57	0,86	0,83	0,83	0,82	1,09	1,14	1,10	1,06
ICC	0.90				0.95				0.98				0.99			
$CI_{95\%}$	[0.81;0.95]				[0.91;0.97]				[0.96;0.99]				[0.98;0.99]			
P	<0.0001				<0.0001				<0.0001				<0.0001			

Table 3 - Atlas overall angles

	Angle B1		Angle B2	
	R	L	R	L
Minimum	33.90	31.10	52.10	54.20
Maximum	57.90	56.70	79.80	69.70
Median	49.35	48.35	64.00	63.45
Mean	47.45	47.31	63.51	62.95
SD	6.24	6.06	5.22	3.85

the radiologic study (p= 0.1428). The mean values for D1 projection found at the right on the anatomical study were 10.96 ± 2.03 mm and 11.20 ± 2.07 mm on radiology; and, at the left, 11.27 ± 2.18 mm and 11.50 ± 2.14 mm on radiology. (Table 4)

D2, D3, and D4 projections did not show significant differences between right and left sides, both in the anatomical study and in the radiologic study (p< 0.001). D2 projection measurements showed a mean value to the right of 18.83 ± 3.03 mm on investigators' mean values, and 19.06 ± 3.04 mm on radiology; at left, we found a mean value of 18.87 ±2.43 mm and 19.07 ± 2.43 mm on radiology. On D3 projection, we found a mean value at the right of 14.18 ± 2.36 mm on investigators' mean values, and 14.46 ± 2.37 mm on radiology; at the left, we found a mean value of 14.26 ± 1.71 mm on investigators' mean values, and 14.54 ± 1.70 mm on radiology. On D4 projection, we found a mean value at right of 23.01 ± 2.79 mm on investigators' mean values, and 23.19 ± 2.88 mm on radiology; at the left, we found a mean value of 23.85 ±2.17 mm and 24.07 ± 2.20 mm on radiology. (Tables 4 and 5)

PP presence was found in 12 studied atlas (n=30). Vertebrae were classified into 5 types (Table 6): Type I (n=3), when PP was fully present on both sides forming an arch outlining a second foramen with VAG; Type II (n=2), when PP was fully present on only one side; Type III (n=4) when PP was partially present on both sides forming a semi-arch or bone spicule, and Type V (n= 0) when full PP was present on one side and partially on the contralateral side. (Figure 2)

In the five cases in which the structure was classified as unilateral, in the two type-II, and three type-IV, the anatomical accident was seen on the right. Table 6 describes the incidence of the different types found in the present study. In the studied series, no case was found with the presence of full PP on one side, and partially on the contralateral side.

Table 4 – Proximal and Distal Medial Projections of the vertebral artery groove

	D1								D3							
	R				L				R				L			
	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad
Minimum	7.32	7.49	7.47	7.40	7,63	7,68	7,66	7,90	10,53	10,82	10,68	10,90	11,46	11,19	11,33	11,70
Maximum	14.73	14.91	14.73	15.00	15,16	15,76	15,46	15,90	23,46	23,82	23,64	24,00	19,34	19,31	19,33	19,50
Median	10.41	10.81	10.52	10.75	11,26	11,13	11,33	11,50	13,94	14,04	13,98	14,20	14,07	14,16	14,12	14,45
Mean	10.90	11.01	10.96	11.20	11,23	11,30	11,27	11,50	14,15	14,21	14,18	14,46	14,24	14,28	14,26	14,54
SD	2.06	2.01	2.03	2.07	2,13	2,24	2,18	2,14	2,33	2,40	2,36	2,37	1,72	1,70	1,71	1,70
ICC	0.99				1.00				1.00				1.00			
$CI_{95\%}$	[0.99;1]				[0.99;1]				[0.99;1]				[0.99;1]			
P	<0.0001				<0.0001				<0.0001				<0.0001			

Table 5 – *Proximal and Distal Lateral Projections of the Vertebral Artery Groove*

	D2								D4							
	R				L				R				L			
	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad	Inv1	Inv2	Mean	Rad
Minimum	11.14	11.18	11.16	11.30	14,08	14,13	14,11	14,40	13,29	13,94	13,62	13,50	19,95	19,37	19,66	19,70
Maximum	23.64	23.94	23.79	24.10	23,91	23,36	23,64	24,10	26,38	26,74	26,56	26,20	27,43	27,58	27,43	27,60
Median	18.16	18.60	18.38	18.40	18,39	18,57	18,43	18,95	23,91	23,95	23,99	24,30	23,81	23,88	23,79	24,10
Mean	18.78	18.88	18.83	19.06	18,81	18,91	18,87	19,07	22,93	23,09	23,01	23,19	23,81	23,88	23,85	24,07
SD	3.05	3.02	3.03	3.04	2,47	2,40	2,43	2,43	2,83	2,75	2,79	2,88	2,14	2,23	2,17	2,20
ICC	1.00				1.00				1.00				1.00			
$CI_{95\%}$	[1;1]				[0.99;1]				[1;1]				[0.99;1]			
P	<0.0001				<0.0001				<0.0001				<0.0001			

Table 6 – *Incidence of Ponticulus posticus*

Ponticulus presence/ Type		R	L	Bilateral
Full	Type I	-	-	3
	Type II	2	0	-
Partial	Type III	-	-	4
	Type IV	3	0	-

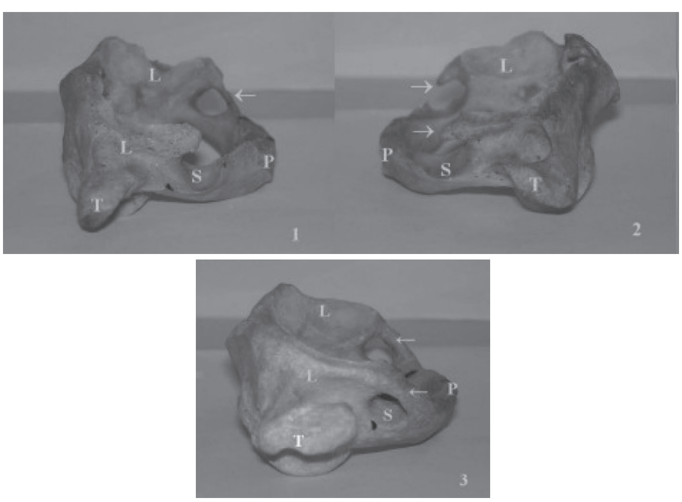

Figure 2 – *Dried human atlas presenting with ponticulus posticus.* **2.1:** *PP type II, where PP is totally present on one side,* **2.2:** *PP type III, where PP is incomplete, forming a semi-arch or bone spicule outlining a second foramen with a port,* **2.3:** *PP type I, where PP is completely present on both sides, forming an arch outlining a foramen with VAG.* **(®):** *Ponticulus,* **(P):** *Posterior Arch*, **(S):** *Vertebral artery groove,* **(L):** *Lateral Mass,* **(T):** *Transverse apophysis.*

DISCUSSION

The high values for intra-class correlation coefficient between radiologic and anatomical studies performed with a pachymeter allow us to infer that VAG evaluation by radiology is a reliable and accurate method for studying VAG and assuring that surgical procedures do not cross the line for established safety boundaries.

On VAG morphology, we found the presence of a bone bridge with the posterior edge of atlas' upper joint facet, forming a foramen in 40% of the cases, called ponticulus posticus. In our study, PP was found either totally or partially, having a full arch in 42% (n=5) of the cases. Hasan et al.[3], when reviewing literature, found an incidence of 5.84% - 51% in the studied population.

In 58% (n=7) of the cases, the ponticulus was found bilaterally. In cases where the presence of PP was unilateral, this structure was exclusively located on the right. Although in the series of dissections by Hasan et al.[3] and Dhall et al.[9], PP was more often found on the left side. Dhall et al.[9] believe that the higher incidence would be on the left side, since the majority of people are right-handed, thus the right sternocleidomastoid muscle would be stronger, and likely to bend head to the opposite side.

VAG is located at the anterior portion of atlas posterior arch. In an upper view, this presents a curved course from lateral to medial, posterior to atlantoccipital facet base.[20,21] In our study, we found that the outer length was significantly longer than the inner length ($p<0.05$). The mean vale found for inner length was 7.58 mm to the right of investigators' mean values, and 7.80 mm on radiology. The mean values found for the left side were 7.29 mm of investigators' mean values, and 7.53 mm on radiology. For outer VAG length, the mean values found to the right of investigators' mean values were 9.68 mm and 9.93 on radiology, and the mean values found for the left side were 9.54 mm of investigators' mean values, and 9.85 mm on radiology.

Tan et al.[22] reported atlas fixation through posterior arch. The access port would be at 19.01 mm lateral to the posterior arch mid line and 2.03 mm above the bottom edge of the posterior arch. Vertebral groove thickness would be 9.51 ± 2.09 mm on the right, and 9.68 ± 2.40 mm on the left. In the 50 studied vertebrae, only in 4 cases (8%) posterior arch width was less than 4 mm. In these cases, fixation must be provided through lateral or transarticular mass. Ebraheim et al.[23] measured the dimensions of vertebral artery groove and found that vertebral artery groove thickness was 4.1 ± 1.2 mm. In our study, the mean thickness found by investigators was 3.87 ± 0.83 mm on the right, and 3.92 ± 1.10 mm on the left. These findings would make fixation through posterior arch, as suggested by Tan et al.[22] unfeasible.

Ebraheim et al.[23] studied dimensional VAG parameters in its atlas portion in 50 young adult cadavers. The authors studied the widths of VAG medial and lateral entries, and established a mean value of 9.2 mm for males, and 8.8 mm for females for the first measurement, and 6.8 mm for males and 5.6 mm for females for the second measurement.

In our study, we found that VAG was wider and thicker on the left side ($p<0.05$) both on anatomical measurements made by the investigators and on radiology, possibly because of the vertebral artery prevalence, which is dominant in 42% of the cases on the left, 32% on the right, and symmetrical in 26%.[24]

As a result of the ventral position of vertebral artery within bone groove on atlas upper posterior arch, vertebral artery is vulnerable during posterior surgical access to skull-brain transition, particularly during upper lateral extension of C1 arch. Concerning D1 projection, we found variable results between right and left sides both for investigators' findings and for radiologic study ($p= 0.1428$). The mean values for D1 projection found on the right in the anatomical study were 10.96 and 11.20 mm on radiology; and, on the left, 11.27 and 11.50 mm on radiology. D2 projection measurements showed a mean value on the right of 18.83 mm on investigators' mean values, and 19.06 mm on radiology; on the left, a mean value of 18.87 was found for investigators' mean values, and 19.07 mm on radiology. These data suggest that the posterior dissection of posterior arch should be kept at a lateral distance of 11.2 mm from the mid line, and that the upper dissection of the posterior arch should be kept within 7.4 mm from the mid line.

Stauffer et al.[25] recommended that the surgical manipulation on atlas posterior arch should be bilaterally made at approximately 10 mm from the posterior mid line in order to prevent against vertebral artery injuries during deeper dissections. Simpson et al.[26] reported that the surgical exposure of posterior atlas should not exceed 15 mm from the mid line in adults and 10 mm in children. Ebraheim et al.[23] showed that the distance between the posterior mid line to the VAG edge in the inner posterior arch cortex was 10 mm for males and 9 mm for females, with a minimum value of 8 mm for both genders, and that the distance of the posterior mid line to VAG edge in the outer posterior atlas arch cortex was 19 mm for males and 17 mm for females, with a minimum value of 12 mm for both genders.

$\beta1$ angles measurements showed a mean value of 47.45º on the right, and 47.31º on the left. A significant difference was found between right and left sides ($p>0.05$). $\beta2$ angle measurements showed a mean value of 63.51º on the right, and 62.95º on the left ($p < 0.01$). Ebraheim et al.[23] established the angle compared to the posterior mid line on sagittal plane, corresponding to $\beta2$, obtaining approximately 61° for males and 66° for females.

CONCLUSION

Based on the measurements of the 30 C1 cervical vertebrae, we presented a detailed set of data addressing vertebral artery groove and its correlation with the atlas mid posterior arch line. These data may be useful for avoiding vertebral artery injuries during posterior atlas instrumentation. Our study suggest that the ponticulus posticus is a usual abnormality, which can be easily confused with enlarged atlas posterior arch. We recommend that before inserting a screw into what apparently seems to be an enlarged posterior arch, surgeons should review cervical spine tomography images in order to check the presence of ponticulus posticus and to outline medial and lateral boundaries for surgical exposure to achieve safe procedures, preventing vertebral artery injuries.

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