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Incidence of the Arcuate Foramen of Atlas Vertebra and its Morphometric Differences with the Ipsilateral Transverse Foramen in the Egyptian Population

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Abstract

Background: The first cervical (atlas) vertebra has no vertebral body and consists only of 2 lateral masses (right and left) interconnected by the anterior and posterior arches.

The third part of the vertebral artery (VA) passes inthe retroarticular groove on the upper surface of the posterior arch of atlas just behind the lateral mass. A bony bridge called ponticulus posticus (Posterior ponticle) may form over the retroarticular groove transforming it into a retroarticular canal (Arcuate foramen) that occasionally compresses the vertebral artery leading to disturbed blood supply of the posterior part of the brain.

Aim of Study: This study was performed for assessment of the incidence of the arcuate foramen (AF) of the atlas vertebra in the Egyptian population and to compare its dimensions with the ipsilateral transverse foramen of atlas to evaluate the role of the arcuate foramen as an occasional cause of the VA compression.

Material and Methods: The atlas vertebrae in the Anatomy departments, Faculties of Medicine of Cairo, Ain Shams, Al-Azhar, Helwan, Benha, Suez Canal, Zagazig, Tanta, Kafr El-Sheikh, Mansoura, Beni Suef, Minia, Fayoum, Assiut, Sohag and South Valley Universities were demonstrated for the presence of the AF. The dimensions of the arcuate foramina were measured by the Bacolis digital caliper and compared to the dimensions of the ipsilateral transverse foramina of atlas.

Results: About 12.6% of the atlas vertebrae have AF. All arcuate foramina were narrower than the ipsilateral transverse foramina.

Conclusion: About 12.6% of the Egyptian population have AF on the first cervical vertebrae. These foramina are narrower than the ipsilateral transverse foramina, so the presence of the AF represents a possible cause for compression of the VA.

Key Words: *Arcuate foramen – First cervical vertebra – Atlas – Transverse foramen – Incidence – Dimensions – Morphometric differences – Vertebral artery – Egyptian population.*

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Introduction

ATLAS (First cervical) vertebra is the only vertebrae that has no vertebral body and consists only of two (Right and left) lateral masses interconnected by two arches; shorter anterior and longer posterior arches. The most anterior part of the upper surface of the posterior arch (Just behind the lateral mass) shows the retroarticular groove produced by the third part of the VA **[1]**.

During the development of the vertebral column, the atlas develops from the first cervical sclerotome that is formed by the fusion of the caudal part of the fifth and the cranial part of the sixth mesodermal somites. In some people, the retroarticular groove for the third part of the VA is transformed into the AF by the formation of a bony bridge (Ponticulus posticus of atlas) above the third part of the VA. This bony bridge represents ossification of the posterior atlanto-occipital membrane **[2]** and it is more common on the left side than on the right side **[3,4,5]**.

The AF is elliptical in shape with its anteroposterior diameter longer than its vertical (Superoinferior) diameter. The incidence and sizeof the AF varyin the different regions of the world according to regional and ethnic factors **[6]**.

The transverse foraminaare special foramina located through the left and right transverse processes of all cervical vertebrae and transmit the second part of the VA, vertebral venous plexus and sympathetic nerve plexus around the VA through the upper six transverse foramina **[7]**. The transverse foramenof atlas is elliptical in shape with itsanteroposterior diameter is longer than its mediolateral diameter **[8]**.

The VA begins in the root of the neck as a branch from the first part of the subclavian artery and divides along its course into 4 parts; the first part extends from the beginning till the transverse foramen of the sixth cervical vertebra passing in front of the seventh cervical transverse process, the second part ascends through the transverse foramina of the upper six cervical vertebrae, the third part extends from the transverse foramen of atlas till the foramen magnum curving over the posterior arch of atlas passing through the retroarticular groove or canal and the fourth part enters the cranial cavity and ascends on the anterolateral aspect of medulla oblongata till the lower border of pons where the right and left vertebral arteries end by uniting together forming the basilar artery. The basilar artery ascends in the basilar groove in the midline on the anterior surface of pons and ends at the upper border of pons by dividing into the right and left posterior cerebral arteries **[9-12].**

The intracranial part of the VA and the basilar artery give numerous branches that supply the upper part of the spinal cord, medulla oblongata, pons, midbrain, cerebellum, inner ear and the posterior part of the cerebral hemisphere that includes the occipital lobe and the lower part of the temporal lobe **[9-12].**

The AF containing the third part of the VA is narrowerthan the ipsilateral transverse foramen (TF) of atlas that transmits the second part of the VA, so the AFrepresents a site for occasional narrowing of the VA due tocompression and kinking ofthe artery **[5]** specially during extreme head and neck rotation and extension leading to vertebrobasilar insufficiency (Disturbed arterial supply of the areas supplied by the vertebral and basilar arteries) **[13].**

Clinically, the vertebrobasilar insufficiency produced by the compression of the VA at the AF is manifested mainly during extreme head and neck extension and rotation by headache, vertigo, dizziness, spontaneous loss of consciousness, recurrent disturbance of vision, hearing loss **[14,15],** Barre-Lieou syndrome **[16]** and Bow hunters syndrome **[17,18].** In rare severe cases of AF, there are torticollis, facial asymmetry and local pain **[16].**

Arcuate foramen causes compression and disturbance of the sympathetic nerve plexus around the VA producing the symptoms of Barre-Lieou syndrome such as ipsilateral facial pain, neck pain and ear pain in addition to dizziness and vertigo **[16,19].**

Bow hunter's syndrome (BHS) is a symptomatic vertebrobasilar insufficien cycondition manifested by vertigo, dizziness, headache and rarely nystagmus due to stenosis or occlusion of the vertebral artery (VA) with extreme head and neck extension and rotation **[17,18].**

The presence of AF is confirmed radiologically by computed tomography (CT) while the diagnosis of vertebrobasilar insufficiency is confirmed by dynamic CT angiography and dynamic catheter angiography. In the cases of very narrow AF leading to severe vertebrobasilar insufficiency, the treatment is only surgical by VA decompression through resection of the posterior ponticle (Ponticulus posticus) of atlas because the conservative methods are ineffectivein these cases **[20,21].**

Aim of the work: The aim of this study is to determine the incidence of the AF of the atlas vertebra and to assess its dimensions in comparison with the ipsilateral transverse foramen of atlasin the Egyptian population becauseit represents a possible cause for compression of the VA leading to neurological manifestations due to disturbance of the arterial supply of the posterior part of the brain, upper part of the spinal cord and the inner ear.

Material and Methods

Site of the study: The atlas vertebrae were examined for the presence of the AF in the Anatomy Departments, Faculties of Medicine of Cairo, Ain Shams, Al-Azhar, Helwan, Benha, Suez Canal, Zagazig, Tanta, Kafr El-Sheikh, Mansoura, Beni Suef, Minia, Fayoum, Assiut, Sohag and South Valley Universities.

Time of the study: This study was done from April to August 2022.

Material: Dry atlas vertebrae of adults.

Methods: 864dry atlas vertebrae were examined for the presence of the AF. The superoinferior and anteroposterior diameters of the AF were measured by the Bacolis digital caliper and compared to the mediolateral and anteroposterior diameters of the ipsilateral transverse foramina of atlas. The superoinferior diameter of the AF was measured from the floor of the retroarticular groove to the inner aspect of the overlying bony bridge, while the anteroposterior diameter was measured from the posterior end of theretroarticular groove to the posterior end of the superiorarticulating facet of atlas (Fig. 1).

The cross sectional area of the foramina was calculated using the formula for an ellipse:

Area = pi (D1/2 x D2/2)

Where D 1 and D2 are the diameters of the foramen and Pi = 3.14 **[22]**.

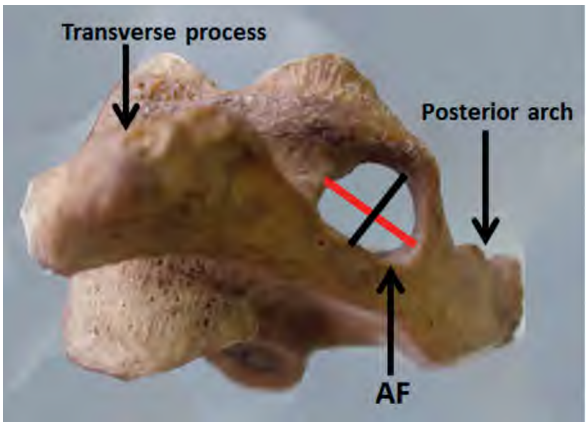

Fig. (1): The lateral aspect of an arcuate foramen (AF) on the left side of the first cervical vertebra showing the direction of the anteroposterior diameter (Red line) and the superoinferior diameter (Black line).

Statistical analysis:

The collected data were coded, processed and analyzed using the SPSS (Statistical Package for Social sciences) version 22 for Windows ® (IBM SPSS Inc, Chicago, IL, USA). Data were tested for normal distribution by the Shapiro Walk test.The qualitative data were represented as frequencies and relative percentages. Chi square test was used to calculate the differences between two or more groups of qualitative variables. The quantitative data were expressed as mean ± SD (Standard deviation). The independent samples *t*-test was used to compare between two independent groups of normally distributed variables (parametric data). *p*-value <0.05 was considered significant.

Results

The total number of the first cervical vertebrae examined was 864 vertebrae, 755 of them were without arcuate foramina while 109 of them have arcuate foramina; 36 with right-sided AF, 51 with left-sided AF and 22 with bilateral AF (Fig. 2).

In all arcuate foramina, the anteroposterior and superoinferior diameters were shorter than the anteroposterior and mediolateral diameters of the ipsilateral transverse foramina respectively (Figs. 3,4,5).

Statistical analysis:

SPSS (Statistical Package for Social sciences) was used to detect the incidence of the arcuate foramina of the first cervical vertebrae and to compare their dimensions with those of the ipsilateral transverse foramina.

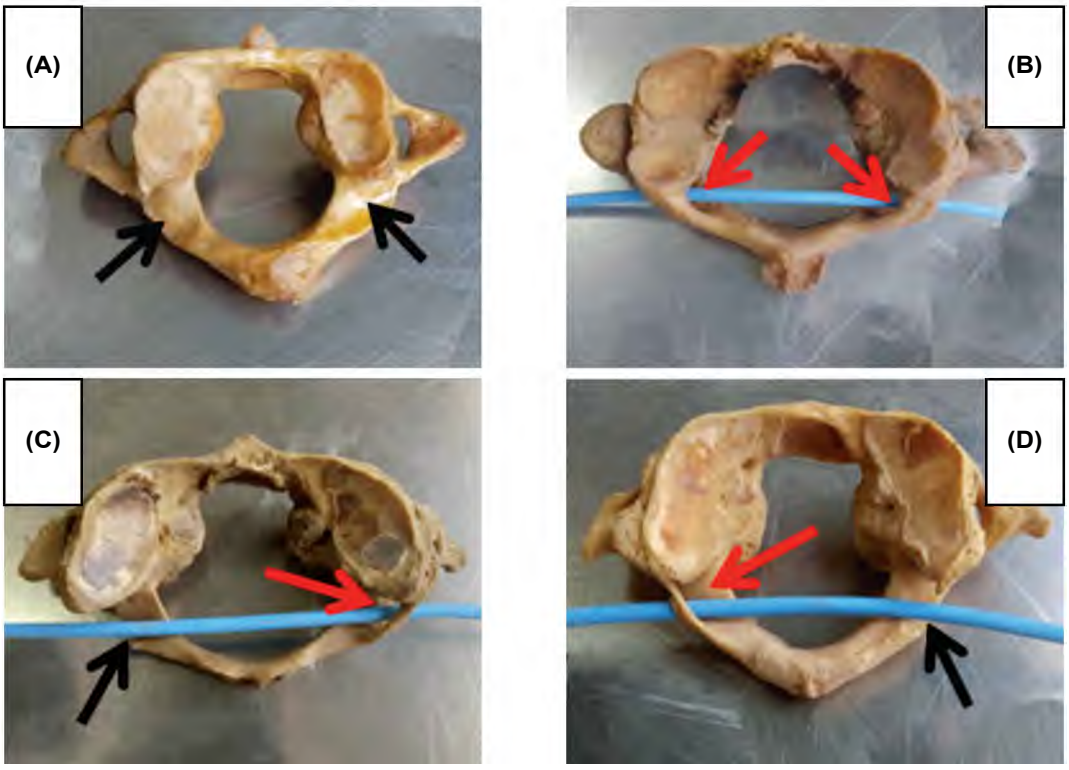

Fig. (2): Four atlas vertebrae; the first is without arcuate foramina (A), the second is with bilateral arcuate foramina (B), the third has a right-sided only AF (C) and the fourth has a left-sided only AF (D). The black arrows are pointing to the retroarticular grooves while the red arrows are pointing to the AF.

Fig. (3): Atlas vertebra with a right-sided AF measuring 6.9mm for its anteroposterior diameter (A) and 6.1mm for its superoinferior diameter (B) while the ipsilateral transverse foramen measures 8.5mm for its anteroposterior diameter (C) and 7.4mm for its mediolateral diameter (D).

Fig. (4): Atlas vertebra with a left-sided AF measuring 7.4mm for its anteroposterior diameter (A) and 5.8mm for its superoinferior diameter (B) while the ipsilateral transverse foramen measures 9.1mm for its anteroposterior diameter (C) and 7.3mm for its mediolateral diameter (D).

Fig. (5): Atlas vertebra with a left-sided arcuate foramen measuring 6.2mm for its anteroposterior diameter (A) and 5.4mm for its superoinferior diameter (B) while the ipsilateral transverse foramen measures 7.3mm for its anteroposterior diameter (C) and 6mm for its mediolateral diameter (D).

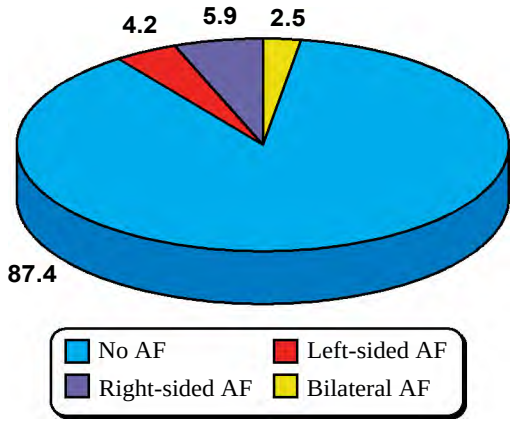

Fig. (6): A pie chart representing the Egyptian population showing the percentage of 87.4% having no AF, 4.2% have right-sided AF, 5.9% have left-sided AF and 2.5% have bilateral AF.

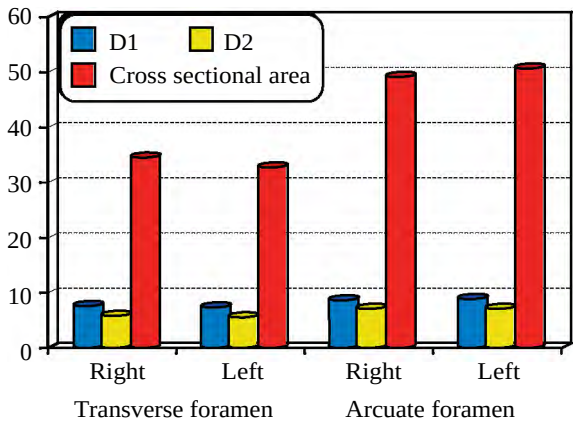

Fig. (7): The diameters and cross sectional area for the arcuate and transverse foramina on both sides.

Out of a total number of 864 atlas vertebrae examined, 755 (87.4%) of them were without AF and 109 (12.6%) have arcuate foramina; 36 (4.2%) on the right side, 51 (5.9%) on the left side and 22 (2.5 %) on both sides (Table 1 and Fig. 6).

The mean of the diameters and cross sectional area were calculated for the arcuate and transverse foramina. The mean of the anteroposterior and superoinferior diameters of the AF were significantly shorter than the anteroposterior and mediolateral diameters of the ipsilateral transverse foramina respectively where the mean anteroposterior diameter of the AF was 7.5mm and the superoinferior diameter was 5.7mm while for the transverse foramina, the mean anteroposterior diameter was 8.8mm and the mediolateral diameter was 7.1mm with insignificant difference between the right and left sides. The cross-sectional area of the AF was 34.6mm^2 on the right and 32.7mm^2 on the left side while the mean cross sectional area

of the transverse foramen was 49.1mm^2 on the right side and 50.8mm^2 on the left side (Tables 2,3,4 and Fig. 7).

Table (1): Demographic parameters of the studied atlas vertebrae. n=864.

	Without AF	With AF		
		On the right side	On the left side	Total sides
Count	755	36	51	22	109
Percentage %	87.4	4.2	5.9	2.5	12.6

AF: Arcuate foramen. N: Number.

Table (2): The mean diameters and cross sectional area for the arcuate and transverse foramina on both sides.

Mean ± SD in mm	Arcuate foramen		Transverse foramen	
	Right	Left	Right	Left
D 1	7.64±1.12	7.49±0.96	8.83±0.71	8.93±0.64
D 2	5.81±0.74	5.73±0.83	7.13±1.19	7.27±1.26
Cross sectional area	34.61±0.64	32.76±0.86	49.17±1.21	50.83±1.16

SD: Standard deviation. D: Diameter.
D1 = The anteroposterior diameter
D2 = Represents the superoinferior diameter for the AF and the mediolateral diameter for the transverse foramen

Table (3): The mean diameters and cross sectional area of the right and left arcuate foramina.

Mean ± SD in mm	Right AF	Left AF	*p*-value	Significance
D 1	7.64±1.12	7.49±0.96	0.87	NS
D 2	5.81±0.74	5.73±0.83	0.54	NS
Cross sectional area	34.61±0.64	32.76±0.86	0.76	NS

SD: Standard deviation. D: Diameter. NS: Non-significant.
- *p*-value was calculated by Independent Sample *t*-Test.
- *p*-value >0.05 indicating non-significant difference between the right and left arcuate foramina in diameters and cross sectional area.

Table (4): The mean diameters and cross sectional area for the arcuate and transverse foramina.

Mean ± SD in mm	Arcuate foramen	Transverse foramen	*p*-value	Significance
D 1	7.58±1.65	8.87±0.35	<0.02	S
D 2	5.78±1.72	7.19±1.65	<0.02	S
Cross sectional area	33.47±0.82	49.84±0.81	<0.02	S

SD: Standard deviation. D: Diameter. S: Significant.
- *p*-value was calculated by Independent Sample *t*-Test.
- *p*-value < 0.05 indicating significant difference between the arcuate and transverse foramina in diameters and cross sectional area.

Discussion

The current study detected that, 12.6% of the Egyptian population have arcuate foramina on their atlas vertebrae either bilaterally or unilaterally and in all cases, the arcuate foramina aresignificantly narrower than the ipsilateral transverse foramina of atlas. This means that, 12.6% of the Egyptians are susceptible to the appearance of the manifestations of vertebrobasilar insufficiency produced by narrowing of the VA while passing through the AF specially during extreme head and neck rotation and extension.

The percentage of 12.6% of the Egyptian population having AF detected in the present study is near the percentages detected in numerous other countries where the AF is present in 7.3% of theItalian population **[6]**, 10.5% of the South Korean population **[23]**, 8.7% of the population in the American United States and Canada **[24]**, 8.6% of the Pakistani population **[25]**, 16.1% of the Caucasian and sub-Saharan African subjects **[26]** and 14.7% of the Japanese population **[27]**. Whereas, in some other countries, the percentage is much lower than in the current study where the AF is present in only 2-4% of the Indian population **[15,28]** and 3.8% of the Turkish population **[29]**.

In the present study, the AF was narrower than the ipsilateral transverse foramen in all atlas vertebrae having the arcuate foramina and these results werein agreement with the results of numerous previous studies **[6,30,31]** so, the foraminal diameter of the VA is narrower than its preforaminal and post-foraminal diameters where the foraminal diameter refers to the diameter of the VA at the AF of atlasas had been described by Nese et al., 2019 **[32]**.

In the current study, the mean diameters detected for the arcuate foramen were 7.6mm for the anteroposterior diameter and 5.8mm for thesuperoinferior diameter on the right side and 7.4mm for the anteroposterior diameter and 5.7mm for the superoinferior diameter on the left side without significant difference between the right and left sides, whereas the diameters of the transverse foramen were 8.8mm for the anteroposterior diameter and 7.1mm for the mediolateral diameter on the right side and 8.9mm for the anteroposterior diameter and 7.2mm for the mediolateral diameter on the left side without significant difference between the right and left sides and these results are in correlation with the results of numerous previous studies **[5,25,28,33]**.

The present study detected that, the arcuate foramina are more common on the left than on the right and bilateral sides where, out of a total number of 864 atlas vertebrae studied, 36 (4.2%) have right-sided AF, 51 (5.9%) have left-sided AF and 22 (2.5 %) have bilateral AF. These results are in correlation with numerous previous studies had detected the presence of the AF more on the left than on the right sides **[5,33,34].**

Conclusion: About 12.6% of the Egyptian population have AF on their atlas vertebrae and this foramen is narrower than the ipsilateral transverse foramen of atlas so it maycause compression of the vertebral artery while passing through it leading to vertebrobasilar insufficiency.

Recommendation: The clinicians should be aware of the possibility of the AF in patients complaining of the manifestations of vertebrobasilar insufficiency specially headache, migraine, vertigo, dizziness and spontaneous fainting specially when elicited by extreme head and neck rotation and extension because about 12.6% of the Egyptians have this foramen on their atlas vertebrae. This is important to be in mind because the early diagnosis and rapid treatment of these cases are important to improve the patient's quality of life and to avoid the appearance of potential deformities such as torticollis and facial asymmetry.

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نسبة حدوث الثقب المقوس للفقرة العنقية الأولى والاختلافات الشكلية بينه وبين الثقب المستعرض فى نفس الناحية فى الشعب المصرى

المقدمة : الفقرة العنقية الأولى تتكون من كتلة يمنى وكتلة يسرى يربطهما القوس الأمامى والقوس الخلفى ويحتوى النتوء المستعرض للفقرات العنقية كلها على ثقوب مستعرضة يمر بها الجزء الثانى من الشريان الفقرى. يوجد أخدود على القوس الخلفى للفقرة العنقية الأولى يسمى الأخدود خلف المفصل ويمر به الجزء الثالث من الشريان الفقرى وفى بعض الأشخاص يتحول هذا الأخدود إلى ثقب يسمى الثقب المقوس ليصبح الجزء الثالث من الشريان الفقرى يمر داخل هذا الثقب المقوس. الثقب المقوس يكون أقل اتساعاً من الثقب المستعرض مما قد يتسبب فى إختناق الشريان الفقرى أثناء مروره بالثقب المقوس مما يؤدى إلى قلة تدفق الدم الجزء الخلفى للمخ والذى قد تظهر أعراضه فى صورة صداع أو صداع نصفى أو دوار أو دوخة أو فقدان للوعى خصوصاً عند لف أو بسط الرأس والرقبة للدرجة القصوى.

الهدف من البحث : تحديد نسبة وجود الثقب المقوس للفقرة العنقية الأولى وأبعاده مقارنة بالثقب المستعرض فى نفس الناحية لنفس الفقرة فى المجتمع المصرى.

الأدوات وطرق الدراسة : تمت دراسة ٨٦٤ فقرة عنقية أولى فى أقسام التشريح الآدمى بكليات الطب البشرى بجامعات القاهرة وعين شمس وحلوان والأزهر والزقازيق وطنطا وكفر الشيخ والمنصورة وبنها وقناة السويس وبنى سويف والمنيا والفيوم وأسيوط وسوهاج وجنوب الوادى. تم تحديد عدد ونسبة الفقرات التى تحتوى على الثقب المقوس وتم قياس أبعاد الثقب المقوس ومقارنتها بأبعاد الثقب المستعرض لنفس الفقرة وفى نفس الناحية باستخدام معيار باكوليس الرقمى.

النتائج : من إجمالى عدد ٨٦٤ فقرة عنقية أولى تم فحصها وجد عدد ١٠٩ (١٢.٦٪) بهم الثقب المقوس منهم عدد ٣٦ فقرة (٤.٢٪) بهم الثقب المقوس على الناحية اليمنى فقط و ٥١ فقرة (٥.٩٪) بهم الثقب المقوس على الناحية اليسرى فقط وعدد ٢٢ فقرة (٢.٥٪) بهم الثقب المقوس على الناحيتين اليمنى واليسرى. وفى جميع الحالات كانت أبعاد الثقب المقوس أقل من أبعاد الثقب المستعرض لهذه الفقرة فى نفس الناحية.

الإستنتاج : حوالى ١٢.٦ بالمائة من المصريين لديهم الثقب المقوس على الفقرة العنقية الأولى بعضهم على الناحيتين وبعضهم على الناحية المينى أو اليسرى. وفى جميع الحالات تكون أبعاد الثقب المقوس أقل من أبعاد الثقب المستعرض لهذه الفقرة فى نفس الناحية مما قد يتسبب فى إختناق وضيق الشريان الفقرى الذى يمر بهما وذلك قد يؤدى إلى قلة تدفق الدم إلى الجزء الخلفى للمخ.

التوصية : يجب وضع وإحتمالية وجود الثقب المقوس للفقرة العنقية الأولى فى الإعتبار عند مصادفة المرضى الذين يعانون من أعراض مزمنة مثل الصداع النصفى والدوار والدوخة وفقدان الو عى المتكرر خاصة إذا كانت تحدث هذه الأعراض أثناء لف أو بسط الرأس والرقبة للدرجة القصوى حيث أن حوالى ١٢.٦ بالمائة من المصريين لديهم هذا الثقب المقوس على الفقرة العنقية الأولى.