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Original Article

Kinking, Coiling, and Diameters of Vertebral Artery First Segment and Their Relationships to Sex and Side

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Abstract

Introduction: Recent information on tortuosity in the prevertebral (V1) segment of the vertebral artery is based on case reports rather than systematic data on its presence, types, diameters, and sex- or left-right differences.

Aim: To estimate the frequencies of V1 tortuosity (kinking and coiling) and their relationship to sex and to the left or right side.

Materials and methods: This computed tomography angiographic (CTA) study included 100 adults without cerebrovascular and other related disorders (55 men and 45 women; age range 33–75 years). The presence or absence of kinking and coiling of V1 segment, as well as their sides and sex of subjects were registered and diameters were measured at the end of V1 part.

Results: We found tortuosity in 36% of subjects. Of these 36 cases, 19 were kinks and 17 coils. The kinks, with the exception of one on the right (in one man) were found either only unilateral on the left side (men 8; women 4) or bilateral (6 women only), while left-sided coiling was found both in men (9) and women (8). The finding of bilateral kinking only in women is a conspicuous sex difference.

Conclusions: This first detailed CTA study of kinking and coiling of V1 showed absolute left sided predominance of V1 tortuosity.

Keywords

left-right differences, sex differences, tortuosity, vertebral artery

INTRODUCTION

The vertebral artery (VA), which has extradural and intradural portions, originates from the first segment of the subclavian artery. Its extradural portion has a prevertebral (V1), cervical or transverse (V2), and atlantic (V3) segments.[1] The V1 segment extends from its origin to the entrance to the transverse foramen of the C6 vertebra. Both vertebral arteries constitute the best possible collateral flow for the vertebrobasilar territory, and the occlusion of one VA is almost invariably asymptomatic unless the other one is hypoplastic.[2]

Tortuous arteries, which are not rare conditions in humans and animals, are commonly seen in the cerebral ar-

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teries and usually do not cause neurological symptoms. While mild tortuosity is asymptomatic, severe tortuosity can lead to ischemic attacks in distal organs.[3-5] Even though tortuosity and kinking are asymptomatic and without clinical relevance in the normal subject, they should be identified prior to surgical procedures.[6,7] Tortuosity and kinking of major cerebral vessels are commonly found in the neck and less frequently within the skull, most commonly for the internal carotid artery (ICA) before it enters the skull, and for the V1 and V2 segments of the VA. After two findings on carotids, the third commonest site was in the V1 segment of the VA.[8] High incidence of vascular abnormalities and tortuosity has been reported with different frequencies throughout all VA segments.[4,7] Tortuosity and kinking are more frequently observed in V1 segment than in V2 or V3 segments.[9] The location of V1 tortuosity was often at or near the point of its origin ("ostium" or V1) from the subclavian artery, and kinks at the ostium (V0 - V1) can be in cases of posterior or lateral branching of the VA.[10] Additionally, the V1 segment from its origin to the C6 foramen is frequently affected by atherosclerosis and stenosis, including its point of origin.[2]

The phenotypes of tortuous vessels were named by various, sometimes overlapping or interchangeable terms, most commonly as tortuosity, loop, coiling (looping), (spiral) twisting, simple or multiple angulation/kinking, curving/curling, and Han[3] presented clear schematics of various forms of tortuous vessels. The definitions can be confusing, and despite significant differences, kinking and coiling are sometimes grouped together under the umbrella term of tortuosity.[11,12] Some of the maldevelopment anomalies of VA are truly pathological, i.e. symptomatic. In another group of primary anomalies (width and length anomalies, tortuosity and kinking), the physiological increase in arterial pressure, and age-related atherosclerotic modifications can play an aggravating role.[7] Coiling is the elongation or redundancy or excessive length of the artery resulting in an exaggerated S-shaped curve or circular configuration[6,11,13], and is of embryologic origin, may persist in the adult, but is not a pathologic condition[12]. All these formations, including dolichoectasia, which sometimes also coils, can be considered in the exclusion of arterial aneurysm.[6]

Detailed cross-comparison between different studies is required to work towards age and sex-specific normal ranges for tortuosity indices in different vascular beds.[14] However, the reports about VA tortuosity include all of its segments, and are either case reports[4,5,8,14] or obtained in patients with cerebrovascular or vestibular signs and symptoms[6] and not in the subjects without cerebrovascular and other related disorders. All these facts were the reasons for this systematic computerized tomographic angiographic (CTA) morphological study of V1 segment of the VA.

AIM

The aim of the present study was to investigate systematically the frequencies of tortuosity (kinking and coiling) of the V1 segment in the sample with excluded patients with cerebrovascular complaints and other relevant conditions. By this approach, more specific details about V1 tortuosity could be obtained, including the diameters, and potential left-right and sex differences.

MATERIALS AND METHODS

Sample

Between February 2016 and September 2017, 1009 patients with a variety of complaints underwent a neck computed tomography angiographic study at the Department of Clinical Radiology in Banja Luka. From this large group in our previous study of VA[15], we excluded patients with atherosclerotic changes of VAs, with previous or current cerebrovascular accidents, of cervical, vertebrobasilar insufficiency, with developmental abnormalities and injuries of cervical region and spine, with severe spondyloarthrosis, and those without registration of VA. Therefore, the current investigated sample finally included 100 subjects (200 VAs - 100 right and 100 left) of 55 males and 45 females between 33 and 75 years (mean age 66.40; SD=10.412 years; SE of mean 1.041). After the CTA imaging, the data were collected and stored in accordance with the Helsinki Declaration[16] with additional verbal informed consent obtained from the participating subjects.

Imaging generation and visualization

Patients were placed in the supine position with the head and neck kept at a neutral position. The imaging examination was performed using a 64-detector row CT scanner (GE Lightspeed CT, GE Healthcare, Milwaukee, USA) using the following scanning protocol: 120 kVp, 697 mAs, beam collimation 64×0.625 mm, gantry rotation time 0.4 s, section thickness of 0.625 mm, pitch 0.969:1, and reconstruction interval of 0.625 mm. Nonionic iodinated contrast medium was infused (80 mL) followed by saline (40 mL) injected via injector into the patient's antecubital vein at a rate of 4 mL/s. Post-processing of source images was performed by using a multi-planar reformation, thin maximum intensity projection, multi-planar reconstruction, and volume rendering algorithms.

The diameters of the left and right V1 segments of VA were measured at the level of the inferior margin of its entrance into transverse foramen (mainly C6) in all subjects **(Fig. 1)** with notification of the sex and side of registered variation. The level below the entrance into transverse foramina was used because of a hypothetical change in the diameter (narrowing) of VA related to kinking or coiling.

Statistical analysis

The statistical analysis included the presence (unilateral and/or bilateral) of kinking and coiling of VA1, as well as

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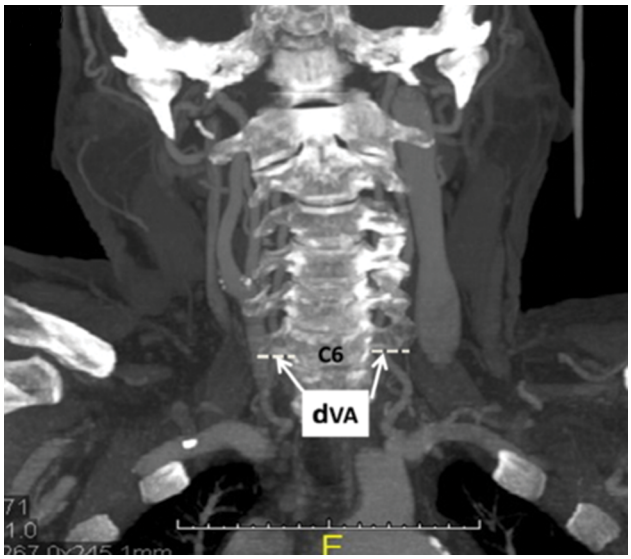

Figure 1. Measuring points of V1 diameter (dVA) at the lower margins of the C6 transverse foramen.

comparisons of the arterial diameters, all in relation to sex and side. In the analysis of differences in diameters and type of V1 kinking and coiling, we used the *t*-test for independent variables with the level of significance $p \leq 0.05$.

RESULTS

Unilateral or bilateral kinking and coiling of VA1 were registered in 36 of 100 subjects (18 men and 18 women, including bilateral tortuosity in 6 women). Of these 36 subjects, tortuosity was unilateral (right or left) in 30 subjects **(Table 1)**.

On the right side, V1 kinking was present in one male only, and right-sided coiling was not registered in either males or females. Contrary to this, on the left side, V1 kinking was found in 18 subjects (12 unilateral and 6 bilateral) and coiling in 17 subjects **(Table 1)**. Obviously, with the exception of only one (male) kinking on the right side, all other unilateral kinking and coiling were on the left side **(Table 1)**. Therefore, in **Tables 2** and **3**, we present the results for the left V1 only.

Bilateral V1 kinking was present only in 6 women and not in men **(Fig. 3)**.

In one case, a double kinking of the left V1 was found, which was included in the statistics in the cases on the left **(Fig. 4)**.

Table 2. Presence of kinking and coiling in the left V1 (including bilateral cases)

Tortuosity		Frequency (%)
Kinking	Present	12%
	Absent	88%
	Total	100%
Coiling	Present	17%
	Absent	83 %
	Total	100%

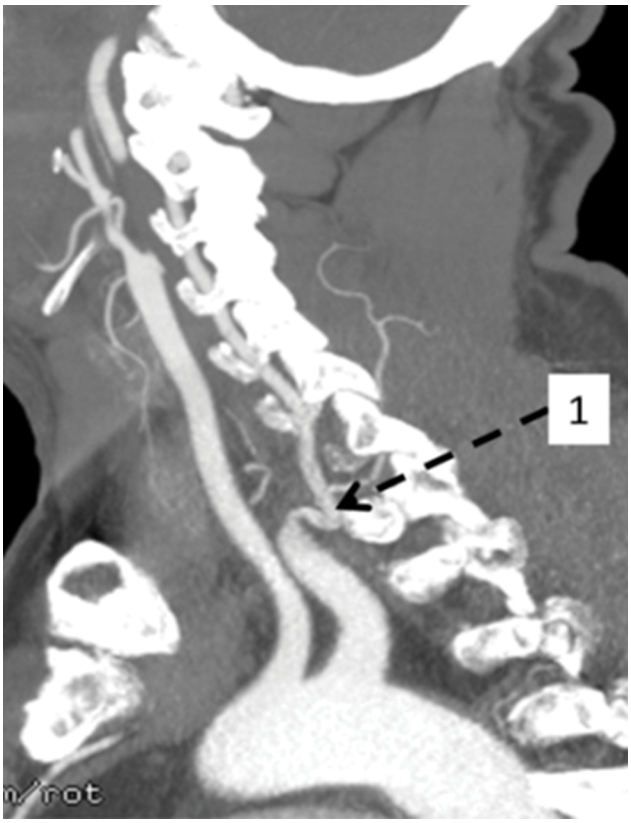

Figure 2. Kinking of left V1 (male, 66 years: CTA; volume rendering).

Table 1. Distribution of V1 kinking and coiling in relation to sex and side

Tortuosity type	Men (55)			Women (45)			Total N=100
	Unilateral		Bilateral	Unilateral		Bilateral	
Side	Right	Left		Right	Left		
Kinking	1	8	0	0	4	6	19
Coiling	0	9	0	0	8	0	17
Present	1	17	0	0	12	6	36
Absent	99	83	0	100	88	94	64

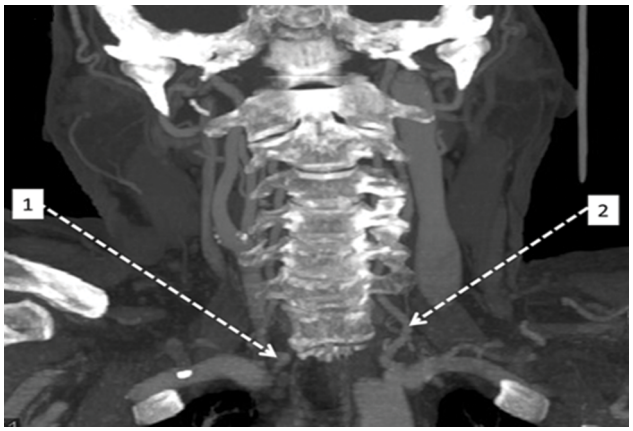

Figure 3. Bilateral V1 kinking VA (female, 72 years; CTA; volume rendering).

Figure 4. Double kinking (1 and 2) of left V1 (female, 66 years; CTA – volume rendering).

The *t*-test for independent variables did not show statistically significant (p>0.05) intrasex differences in either men or women between the average diameters of left V1 with kinking and with coiling **(Table 3)**.

Comparisons of average diameters by the *t*-test for independent variables did not show statistically significant differences (p>0.05) between the diameters of left V1 with kinking and with coiling **(Table 4)**.

DISCUSSION

Unlike carotid arteries, whose tortuosities are not uncommon (mainly reported as tortuosity, coiling and kinking)[11,17], coiling or kinking of VAs are rarely reported because they remain asymptomatic and have no clinical relevance[18]. The frequency of V1 kinking and coiling (36%) that was found by CTA is within a wide range of results published by others, but obtained by various methods and on very different samples. So, the tortuous morphology of the carotid or VA system is seen in 10%–43% of angiograms[18] and is considered a common condition (10%–45%).[11] In subjects having cerebrovascular disease, the VA tortuosity was observed in 13% of the angiographies[8], kinked extracranial carotid and VAs in 10% to 16% of the cerebral angiograms[12], and combined tortuosity and kinking of VAs and carotid arteries in 7% of the cases[6]. One CTA study showed higher frequency of VA kinking in 39.5% of the patients[19], which is close to our results. Kinking was identified in 7% of patients having the history of vertebrobasilar disease, with the vast majority in the V1 portion near its origin.[9] Using magnetic resonance angiography, we found VA loop in the V1 segment in 78.3% of patients and in 21.6% of the patients in the V2 segment.[20] However, the experience with VA kinking (1059 operations) showed its widespread existence in the population.[10] The mild tortuosity in the right V1 was present in 25.5% and single loop in 7.6% of cases, while in the left V1 mild tortuosity was present in 27.4% and single loop in 13.9 %.[21] In ischemic cerebrovascular patients, V1 kinking on the right side was found by CTA in 0.2% (our sample 1%), and on left in 2.1%

Table 4. Mean diameters of left V1 between kinking and coiling (including left artery in bilateral cases)

Left V1	Type	N	Mean (mm)	SD	SE mean
(mm)	Kinking	18	3.467	0.5412	0.1276
	Coiling	17	3.635	0.7407	0.1797

Table 3. Mean diameters (in mm) of tortuosity of only left V1 (N=35) (including left artery of bilateral cases) in males and females

Sex	Type	N	Mean	SD	Levene's test	Mean difference	T test (df=17)	Sig
Men	Kinking	8	3.738	0.5829	0.547 Sig.=0.471	−0.1292	−0.344	0.471
	Coiling	9	3.867	0.9069				
Women	Kinking	10	3.250	0.4143	0.156 Sig.=0.698	−0.1250	−0.639	0.532
	Coiling	8	3.375	0.4097				

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(our sample 12% without bilateral), while unilateral coiled right V1 was found in 9.3% (our sample 0%) and unilateral left V1 coiled in 12.6% (in our sample unilateral only in 17%) of cases.[6] The CTA as a useful modality in the detection of changes in the extracranial VAs[6] and the best imaging modality for demonstrating the course of the VA should be recommended before surgery[22]. Generally, by CTA, the ostium and various pathologies of V1 segment are better demonstrated than by digital subtraction angiography.[5,13] Of the 36 subjects, unilateral (right or left only) V1 tortuosity was found in 30, and bilateral in 6 subjects (only women), with nearly equal numbers of kinks (19%) and coils (17%) **(Table 1)**. In fact, we found only one right kink (in a man) while all other cases of tortuosity were detected on the left or only in women bilaterally. Our CTA findings of the absolute left-sided predominance of V1 kinking and of exclusive presence of unilateral coiling on the left side cannot be simply explained. Slightly different from this was the finding that the incidence of the left side VA loop was twice as high as on the right side.[20] The assumed etiology and pathogenesis of VA tortuosity (includes a very long list of at least 14 items).[2-4,7,8,10,11,14,19] is not unilateral. The unilateral absence of the brachiocephalic trunk on the left can be implicated as an underlying anatomical difference. The question is whether the anatomy is enough for an explanation of how the mechanical factors suggested by Han[3] could cause much more tortuosity on the left side. Our findings of only left V1 coiling, and of almost all kinking of the left (and bilateral) V1 can be related to the finding that all variations in VA origin were observed only in left VA.[15] Related to this, our results of no significant differences in mean diameters in subjects with and without V1 tortuosity do not support pure mechanical influences. Specific embryogenesis of VAs is characterized by a great variety of malformations, dimorphic variants and anomalies that can be important for surgeons and interventional radiologists.[7] Most VA loops are congenital and encountered in childhood (also the coils), although some of them could be acquired due to elongation of V1 segment.[11] It was suggested that the tortuosity in V1 segment is common and frequently observed in elderly patients.[21] Considering all of the above, we believe that the VA complex development could be among the main causes of the prevalent left-sided frequency of kinking and coiling.

For the ICA, it was suggested an embryological origin of coiling and acquired for kinking. Kinking, which occurs more frequently late in life, is always associated with a preexistent tortuous, coiled, and dilated segment of artery.[23] Also, various extrinsic mechanical factors can be implicated, and the kinked V1 segment can be due to extravascular compression, fixation, strangulation, bony spurs, and relative elongation of VA as a result of shortening of the neck (in the senile population).[12,14]

Our finding of bilateral V1 kinking exclusively in females but not in males is an important sex difference. This can be related to the report that symptomatic kinked extracranial cerebral vessels are found predominantly in women, often in the absence of significant atherosclerotic carotid lesions.[12]

One of the most serious difficulties in comparing published results is the confusion in the usage of the terms tortuosity, coiling, and kinking[13], which requires standardization in terms of definition, measurement, and normalcy criteria[14]. We used the terms kinking and coiling according to the originally created definitions for ICA[23] and later also applied to extracranial VAs[6], and not the more general term tortuosity. However, unlike the original classification[23], some authors under the term tortuous assumed all irregularities in the direction of vessels (curving, angulation/kinking, looping, and spiral twisting) or taking the form of simple or multiple kinking, coiling, or looping[3,14,18]. The tortuosity, a rare morphological entity in the form of simple or multiple kinking, coiling, or looping, remains asymptomatic, has no clinical relevance, and usually has no connection with neurological symptoms.[5,18] However, "kinking", as angulation of arteries involves more or less serious interruption of blood flow, is an unusual form of arterial stenosis and occlusion without intrinsic narrowing of the lumen[6,11,12] and severe tortuosity may lead to arterial kinking (acute angulation) which causes artery occlusion associated with severe symptoms[19]. Knowledge of the pathological findings in the extracranial VAs (the V0–V3 segments) as the cause of stroke remains relatively sparse[6] and contrary to ICA, kinking of VA and white matter lesions are not related[21]. Reported symptomatic cases of VA tortuosity were combined with the presence of carotid anomalies, and were not limited to V1 segment.[4,5,12,20] Finally, let us emphasize that in our sample, the patients with cerebrovascular disease were excluded and therefore our results are more reliable for the general population.

CONCLUSIONS

In this extensive CTA study of the first (V1) segment of VA in subjects without cerebrovascular disorders, unilateral kinking was found on the left side only, with the exception of one male, coiling was found exclusively on the left V1, while bilateral kinking was found only in females. The absolute general predominance of left-sided kinking and coiling, as well as the bilateral presence of kinking in females only, remains unclear because the generally known and accepted etiologies of tortuosity are not unilateral. Hence, we strongly believe that any morphological classification of tortuosity must be supplemented by related etiology data.

Author contributions

G.S.: conception and analysis of data; S.M.: writing the manuscript; S.V.: study design and collation of data; D.J.: study design and methods used; Z.V.: acquisition and collation of data; S.V.: analysis and methods used.

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Competing Interests

The authors have declared that no competing interests exist.

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Перегибы, изгибы и диаметры первого сегмента позвоночной артерии, и их взаимосвязь с полом и стороной

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Резюме

Введение: В литературе об извилистости предпозвоночного (V1) сегмента позвоночной артерии (ПА) в основном приводятся клинические случаи без систематизированных данных об их наличии, видах, диаметрах, половых или лево-правых различиях.

Цель: Оценить частоту извитости V1 (перегибы и закручивания) и изучить результаты в отношении пола и левой и правой стороны.

Материалы и методы: Это компьютерно-томографическое ангиографическое (КТА) исследование включало 100 взрослых (55 мужчин и 45 женщин в возрасте от 33 до 75 лет). Из исследования были исключены лица с цереброваскулярными и другими сопутствующими расстройствами. Регистрировали наличие или отсутствие перегиба и извитости сегмента V1, а также их стороны и пол испытуемых и измеряли диаметры в конце части V1.

Результаты: В общей выборке (100 случаев) обнаружено 36 извитостей (19 перегибов и 17 завитков). Правосторонний односторонний изгиб присутствовал только у одного мужчины, а все остальные изгибы были либо односторонними только с левой стороны (8 мужчин, 4 женщин), либо двусторонними (только у 6 женщин). При абсолютном преобладании левой извилистости V1 односторонний перегиб встречался в 12%, а извитость - в 17% случаев. Обнаружение двустороннего перегиба только у женщин является заметным половым различием. Не было существенной разницы в диаметрах левого V1 между случаями перегиба и закручивания (включая двусторонние случаи).

Заключение: Это первое детальное исследование скручивания и закручивания V1 с помощью КТА у населения западных районов Боснии и Герцеговины показало абсолютное левостороннее преобладание извитости V1. Наши результаты убедительно свидетельствуют о том, что в будущих исследованиях извилистости ПА необходимо анализировать отдельно данные, касающиеся пола и стороны.

Ключевые слова

позвоночная артерия, сегмент V1, извитость, половые различия, лево-правые различия