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Original Investigation

Morphological Characteristics of the Posterior Cerebral Circulation: An Analysis Based on Non-Invasive Imaging

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ABSTRACT

AIM: To provide measurements of the posterior cerebral circulation using a non-invasive imaging modality.

MATERIAL and METHODS: One-hundred and twenty patients aged from 12 to 76 years were analyzed using computed tomography (CT) angiography. Measurements of vertebral arteries (VA), basilar artery, posterior cerebral arteries (PCA) and posterior communicating arteries were obtained. Basilar artery appearance and curvature were also noted. Differences between sides, genders and age groups were evaluated.

RESULTS: Mean diameter of left VA was 2.36±0.81 mm, and mean diameter of right VA was 2.14 ± 0.79 mm. Mean length of basilar artery was 34.07 ± 5.53 mm in males, and 30.79 ± 4.18 mm in females. There was a significant difference in basilar artery length between genders: males had a longer basilar artery ($p<0.01$). There was significant difference in basilar artery diameters between patients younger and older than 60 years: older patients had a statistically larger diameter, 3.17 ± 0.76 mm, than the 2.87 ± 0.57 mm in younger patients ($p<0.05$). The basilar artery was straight in 36.7%, convex to the right in 47.5% and convex to the left in 14.2% of the patients. Mean diameter of the left P1 was 1.80 ± 0.58 mm, and of the right 1.87 ± 0.54 mm. There was no statistically significant difference between the diameters of the left and right P1 segments of the PCA and also between genders ($p>0.05$).

CONCLUSION: Modern non-invasive imaging modalities can provide precise and useful information for vessels analysis. This information may be useful for planning and performing neuro-interventional procedures as well as posterior cranial fossa surgeries.

KEYWORDS: CT angiography, Neuroimaging, Posterior cerebral circulation, Vessel analysis

INTRODUCTION

The field of neurovascular therapy has expanded significantly with recent technological advances and the development of sophisticated devices that enable access to previously unapproachable vascular pathologies. As we probe further into the brain, the accurate knowledge of neurovascular anatomy is becoming increasingly important (13).

The vertebrobasilar arterial system is an essential vascular network that supplies blood to the posterior part of cerebral hemispheres, the cerebellum and the brainstem, delivering almost a quarter of the whole intracranial blood flow (1,11).

As is well known in the anatomical configuration, vertebral arteries (VA) unite at the base of the pons to form the basilar artery (BA). Unlike most systemic arteries, which have a tree-like branching pattern, the basilar artery is the only large artery in which two arterial flows merge. It then ascends by the anterior surface of the pons and supplies portions of the cerebellum through the anterior inferior cerebellar arteries and the superior cerebellar arteries. The basilar artery terminates into two posterior cerebral arteries (PCA) at the level of the proximal midbrain, just after passing the oculomotor nerves (Figure 1A, B) (1,4,7).

The anatomical features and variations of the vertebrobasilar arterial system and its branches have been described in a

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number of publications, largely based on cadaveric studies and catheter angiography findings (13,14,20).

With the recent advances in computed tomography technology, even fine vascular structures can be delineated easily; consequently, the number of invasive digital subtraction angiography (DSA) examinations is reduced. In our Institution, the number of DSA examinations has been reduced to a half since computed tomography angiography (CTA) examinations began five years ago. Nowadays, CTA and magnetic resonance angiography (MRA) are more often used for diagnostic imaging, as their advantages include non-invasive nature, shorter examination time and fewer complications. Although DSA is still a gold standard for the evaluation of vascular brain structures and pathologies, there are multiple studies – including a few conducted in our institution – that compared the pertinent procedures and found CTA and MRA to be effective and reliable methods for the evaluation of brain vascular structures (1).

Against such background, the aim of this study was to determine the normal anatomical features and variations of the vertebrobasilar arterial circulation and its branches using advanced non-invasive imaging tools in patients who underwent CTA of the brain vessels for various reasons.

■ MATERIAL and METHODS

We initially analyzed 146 consecutive patients who, underwent CT angiography of the brain vessels, for various reasons, in our Institution in the period from January to April 2015. After the preliminary analysis, we excluded the cases with vascular abnormalities in the vertebrobasilar arterial system, such as aneurysms and cerebrovascular malformations, as well as the cases with acute or chronic infarctions in the areas supplied by the posterior circulation, such as the cerebellum, brainstem and posterior portions of cerebral hemispheres. A few additional cases were excluded due to the insufficient imaging quality or motion artifacts that were precluding a precise analysis of the vertebrobasilar arterial system and its branches.

This study ultimately included 120 patients. The CT angiography examinations were performed using a 128-multidetector scanner (Somatom Definition AS, Siemens Health-care, Erlangen, Germany). In our standard CT angiography protocol for brain vessels examination, a scanogram area from the aortic arch to the vertex level in a supine position was adopted as a field of view. During the examinations, an 18 to 20 gauge intravenous catheter, in the antecubital vein, was used to inject 60 mL of non-ionic iodinated contrast media (Ultravist 370, Bayer HealthCare Pharmaceuticals, Berlin, Germany), with an automatic injector at a rate of 4.5 mL/sec and 30 mL of saline solution at a rate of 4.5 mL/sec (Medrad® Stellant® Dual Syringe CT Injection System, Indianola, PA, USA), respectively. After obtaining an initial localizer at the C2-C3 level of the spine, the scan was manually initiated once the carotid arteries were fully opacified.

The obtained images were transferred to a Syngo workstation for analysis. In addition to the axial source data, post-processed multiplanar reformatted (MPR), maximum-intensity projection (MIP), and 3D volume-rendering (VR) images were evaluated by an experienced team consisting of a neuroradiologist and a radiology resident, and the decisions were made in a consensus.

The objective was to obtain measurements referring to the vessel length and diameter from the intracranial vertebral artery segment to the posterior cerebral arteries, while accounting for variations at the circle of Willis. The following measurements were obtained:

1. The diameter of both vertebral arteries, measured three millimeters prior to their terminus.
2. The length of the basilar artery, measured from vertebro-basilar junction to its terminus (Figure 2A).
3. The diameter of the basilar artery, measured five millimeters distal from vertebro-basilar junction (Figure 2B).
4. The diameter of both P1 segments of posterior cerebral arteries, measured three millimeters distal from their origin.
5. The length of both P1 segments of posterior cerebral arteries, but only if the posterior communicating artery existed.
6. The diameter of both posterior communicating arteries (PCoA), measured 3 mm from its junction with posterior cerebral artery, where existing.
7. The diameter of both P2 segments of posterior cerebral arteries, but only if the posterior communicating artery existed.

All statistical analyses were performed using SPSS release 20 program (SPSS for Windows; SPSS, Chicago, IL, USA). A p value of less than 0.05 were accepted as significant. Student's t test was used to determine possible differences between various groups.

■ RESULTS

One hundred and twenty patients (43 males and 77 females) were analyzed. The mean age of our patients was 52.90 ± 15.47 years, while the age range was from 12 to 76 years.

While the mean diameter of both VAs in total was 2.25 mm, the mean diameter of the left VA was 2.36 ± 0.81 mm, and the mean diameter of the right VA was 2.14 ± 0.79 mm. There was no statistically significant difference between the diameters of left and right VAs ($p>0.05$). There was also no statistically significant difference in the diameters of left and right VA between genders. The left VA and the right VA each ended as a posterior inferior cerebellar artery (PICA) of the same side in 14 cases (11.7%). In these cases, the mean diameter of contralateral VA was significantly higher (the left VA mean diameter was 2.84 mm, the right VA mean diameter was 2.57 mm). In 62.7% (75/120) of the patients, VA were co-dominant, whereas the left VA was dominant in 21.7% (26/120), and the right VA was dominant in 15.8% (19/120) of the patients (the diameter larger than 1 mm compared to the opposite side) (Table I).

The mean length of the BA was 31.98 ± 4.93 mm (in a range between 20.7 mm to 48.5 mm). The mean length in men was 34.07 ± 5.53 mm, while in women it was 30.79 ± 4.18 mm. There was a significant difference in the basilar artery length between men and women, whereby men had a longer basilar artery ($p<0.01$). The mean diameter of the basilar artery was 2.98 ± 0.68 mm (from 1.2 to 5.6 mm). The mean diameter in men was 3.00 ± 0.84 mm, while in women it was 2.97 ± 0.57 mm. In other words, there was no significant difference in the basilar artery diameter between genders in our study ($p>0.05$). Also, there was no significant difference in the basilar artery length between patients younger and older than 60 years

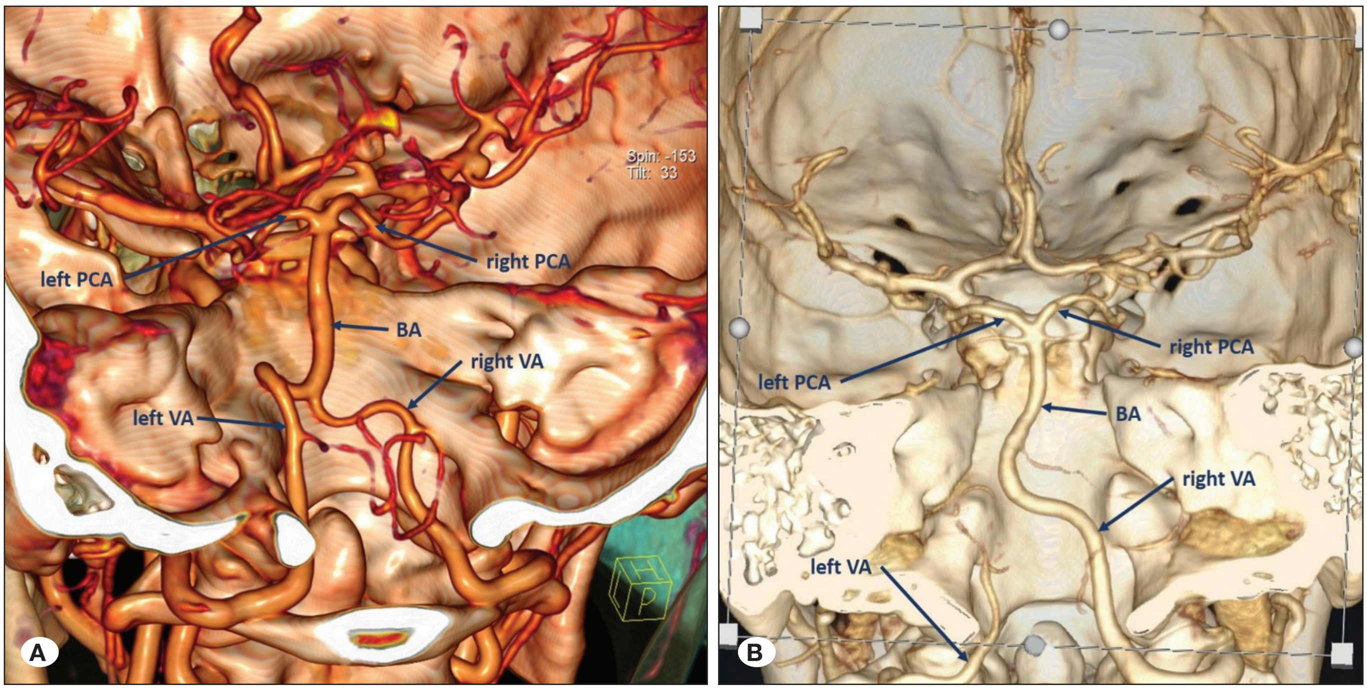

Figure 1: CT angiography of the posterior cerebral circulation **(A)**, variation in anatomy of the posterior cerebral circulation, with left VA ending as PICA **(B)**.

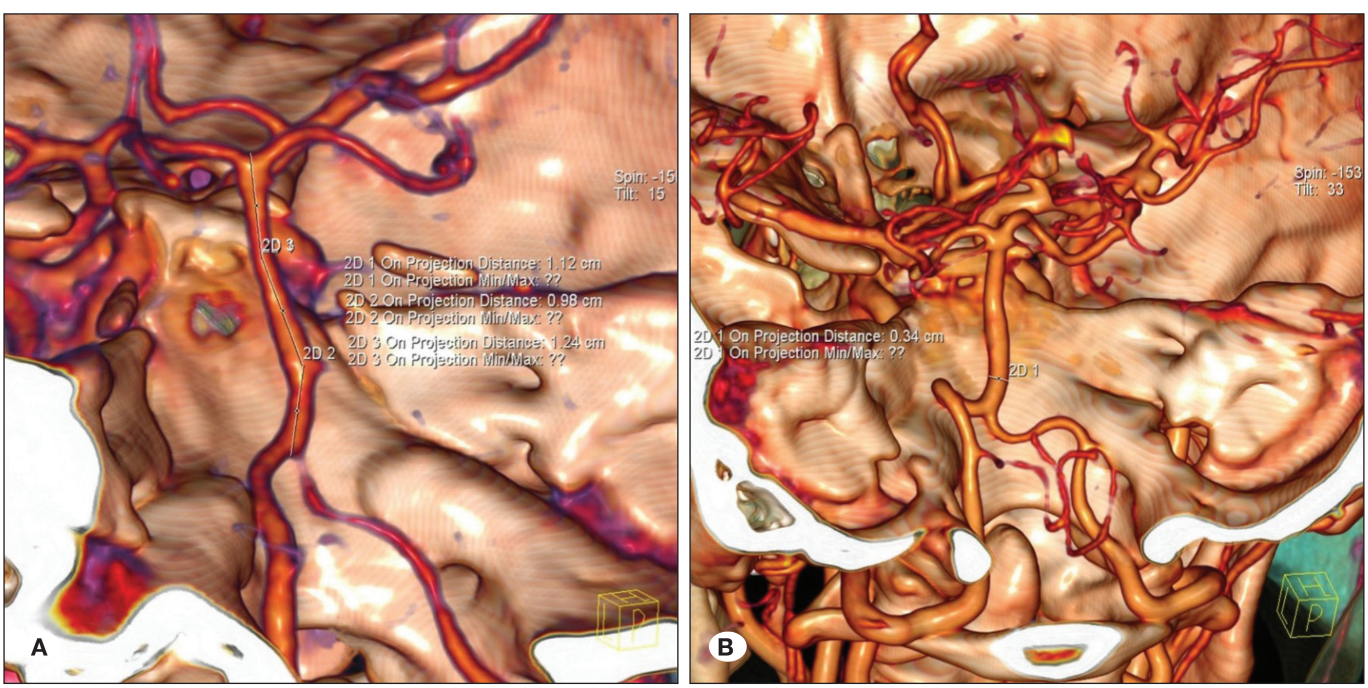

Figure 2: Measuring length **(A)** and diameter **(B)** of the basilar artery.

Table I: Side by Side Measurements in the Posterior Cerebral Circulation (mm)

	Diameter (mean ± sd)					Length (mean ± sd)	
	VA	BA	P1 PCA	PCoA	P2 PCA	BA	P1 PCA
Left	2.36 ± 0.81	2.98 ± 0.68	1.80 ± 0.58	1.45 ± 0.54	1.80 ± 0.43	31.98 ± 4.93	7.65 ± 3.39
Right	2.14 ± 0.79		1.87 ± 0.54	1.48 ± 0.48	1.99 ± 0.41		7.83 ± 2.42

Table II: Basilar Artery Measurements (mm)

	Diameter (mean ± sd)	Length (mean ± sd)
Man	3.00 ± 0.84	34.07 ± 5.53
Woman	2.97 ± 0.57	30.79 ± 4.18
>60 years	2.87 ± 0.57	31.68 ± 4.77
≤60 years	3.17 ± 0.76	32.57 ± 5.32
Total	**2.98 ± 0.68**	**31.98 ± 4.93**

***VA:** Vertebral artery, **BA:** Basilar artery, **PCA:** Posterior cerebral artery, **PCoA:** Posterior communicating artery.*

(p>0.05). However, there was a significant difference in the BA diameter between the age groups, with older patients having a statistically larger diameter: the mean diameter in the older group was 3.17 ± 0.76 mm, while in the younger group it was 2.87 ± 0.57 mm (p<0.05) (Table II).

In 36.7% (44/120) of the patients the basilar artery was straight, in 47.5% (57/120) it was convex to right, while in 14.2% (17/120) of the patients it was convex to left. In two patients, the basilar artery was of the "S" shape. Among the patients with the basilar artery convex to right (n=57), in 44 (77.2%) cases the left VA was wider than the right one. Conversely, among the patients with the basilar artery convex to left (n=17), in 13 (76.5%) cases the right VA was wider than the left one. In two cases, we noticed fenestration of the basilar artery (in both cases in the proximal third).

While the mean diameter of both P1 segments of PCAs in total was 1.83 mm, the mean diameter of the left P1 was 1.80 ± 0.58 mm, and that of the right P1 was 1.87 ± 0.54 mm. There was no statistically significant difference between the diameters of left and right P1 segments (p>0.05). There was also no statistically significant difference in the diameters of left and right P1s between genders. In 10 patients, P1 segments of the left PCA were absent, and in 8 patients P1 segments of the right PCA were absent. In these patients (14.2%), PCAs with the fetal origin were demonstrated, and all of these patients had well-developed PCoAs. There was one case with the absence of both P1s, where both PCAs originated from the well-developed PCoAs. In that patient, with bilateral fetal origin PCAs, the diameters of VAs and BA were significantly smaller (the VA diameter was only 1.3 mm). The impact of a single fetal origin PCA was less significant, both on the diameter of the VA and on the BA.

In cases where both P1 segments of PCA and PCoAs were present on the same side, it was possible to determine and measure the length of the P1 segment. This was performed in 19 cases on the left side, where the mean length of the P1 segment was 7.65 ± 3.39 mm, and in 18 cases on the right side, where the mean length was 7.83 ± 2.42 mm. There was no statistically significant difference between the lengths of the left and right P1 segments (p>0.05).

In 27 patients there were PCoAs present on the left side, with a mean diameter of 1.45 ± 0.54 mm, and in 29 patients PCoAs were present on the right side, with a mean diameter of 1.48 ± 0.48 mm. There was no statistically significant difference between the diameters of the left and right PCoAs (p>0.05). In 9 patients PCoAs were present on both sides. In these patients, the diameters of the right PCoAs were statistically significantly higher than those of the left PCoAs (p<0.05).

In 93 patients (77.5%) the left P2 segment of the PCA was supplied only from the vertebrobasilar circulation system, and in 19 patients (15.8%) the left P2 segment was supplied via both the vertebrobasilar and carotid circulation, and in 8 patients (6.7%) the left P2 segment was supplied only from the carotid circulation.

In 91 patients (75.8%) the right P2 segment of the PCA was supplied only from the vertebrobasilar circulation system, in 18 patients (15%) the right P2 segment was supplied via both vertebrobasilar and carotid circulation, and in 11 patients (9.2%) the right P2 segment was supplied only from the carotid circulation.

In the patients where the P2 segment was supplied via both vertebrobasilar and carotid circulation (19 on the left side, 18 on the right side), it was possible to differentiate and measure the diameter of the P2 segments – the mean diameter of the left P2 segment was 1.80 ± 0.43 mm, and the mean diameter of the right P2 segment was 1.99 ± 0.41 mm.

In our study group, 73 patients (60%) had only vertebral supply of the vertebrobasilar arterial system; in others, this supply was contributed from both the carotid and the vertebral arterial system, while in one case it was contributed only from the carotid arterial system (fetal type).

■ DISCUSSION

A precise understanding of the vertebrobasilar vasculature is fundamental for planning and performing endovascular procedures and neuro-interventions, as well as for the accurate interpretation of ischemic areas. In this respect, it is essential to know the positions, diameters, origins, irrigation areas, and variations in the vertebrobasilar circulation.

Measurements and precise findings about the posterior cerebral circulation are lacking in the literature. They are mainly based on post mortem and DSA analysis, with only few exceptions based on CTA findings. We used CTA because of its non-invasive nature and widespread use. The role and accuracy of CTA in the cerebral vasculature is well established, and it is increasingly being used for the screening and investigation of neurovascular pathologies. The CTA image quality nowadays is approaching the conventional DSA examinations, especially with the use of bone subtraction algorithms allowing for a better visualization at the skull base. The major disadvantage of this technique, particularly compared with MRA, is the requirement for ionizing radiation and iodinated contrast media that have potential nephrotoxic effects. Also, some of the branches of the vertebrobasilar circulation with fine calibration might not be visualized by CTA (1,9,13,15,16).

Contrary to previous similar studies, in our study there was no statistically significant difference between the diameters of the left and the right VA. There was also no statistically significant difference between genders, which is consistent with the findings of a similar study by Akgun et al. (1). Also in line with that study, the majority of our patients had a co-dominant VAs, followed by a left VA dominance (1,10).

We found a statistically significant difference in the basilar artery length between men and women, whereby men had a longer basilar artery, but there was no significant difference between genders with respect to the basilar artery diameter. Also, we found that patients older than 60 years had a statistically larger basilar artery diameter compared to the ones younger than 60 years, which corroborates the findings of some previous studies (13,18).

In most of our patients, the basilar artery was convex to right, which is in accordance with the study of Hong et al. (4). It is interesting that the majority of patients with the basilar artery convex to right had the left VA wider than the right one. Conversely, the majority of patients with the basilar artery convex to left had the right VA wider than the left one. As already stated in the study of Hong et al. (4), in a theory in which the vector of BA flow merging from unequal VAs makes the BA flow curve to the side of the weaker VA, and the chronic processes caused by asymmetric VA flow can induce greater curving of the BA wall, and subsequently, such deformation of the BA can cause atherogenesis, leading to ischaemic stroke in the vertebrobasilar system (4).

Contrary to previous reports, the diameters of both PCAs in our study were significantly smaller – the mean diameter was 1.83 mm compared to 2.2 mm in Rai et al. (13), and to 2.52 mm in Akgun et al. (1). But similar to these studies, we found no significant difference of diameters between the right and the left PCAs, nor between genders.

The degree of contribution from the vertebrobasilar or carotid systems to the origin of the PCA is of clinical and anatomical importance and may have clinical implications (3). Several studies have found a relationship between the anomalies of the circle of Willis and the development of aneurysms producing haemodynamic changes in blood flow and inducing strain on the weak point of the arteries bifurcation. When the PCA is dominantly supplied by the internal carotid artery (ICA), increased flow must occur in the internal carotid artery proximal to the PCoA and in the PCoA itself, resulting in increased shear stress, which tends to promote aneurysm formation at these sites. Complex turbulent flow will also occur in the carotid siphon, which may be involved in aneurysm formation, even on the wall unrelated to the bifurcation (1,5,8,17).

While perfusion imaging is getting more frequently used for the management of acute stroke, for the radiologist performing and interpreting perfusion images it is crucial to know that the unilateral fetal-type PCA produces substantial left-right asymmetry on perfusion imaging, since such asymmetry may mimic cerebrovascular pathology (19).

When the PCA derives from the ICA, thrombosis or embolism affecting the carotid territory may result in the infarction of the occipital pole of the cerebrum, and consequently such anatomy will prevent occipital pole infarction in vertebrobasilar thrombosis. Several studies in the past have indicated a correlation between the fetal type of PCA and occipital lobe infarcts. Since the internal carotid artery contributes to the blood flow in the PCA, ICA stenosis should be considered as a cause of the occipital lobe infarct, and in these patients carotid endarterectomy has proven beneficial for the prevention of recurrent stroke (2,3,6,12).

■ CONCLUSION

Modern non-invasive imaging procedures can provide precise and useful information for vessels analysis. Our study showed that anatomical features of the vertebrobasilar circulation often differ from the well-known normal anatomy. This information may be useful for planning and performing neuro-interventional procedures and posterior cranial fossa surgeries, as well as for the accurate interpretation of ischemic areas and the development of endovascular devices.

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