

Vertebral Artery Doppler Ultrasonography: Anatomy, Examination Technique and Clinical Applications

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Abstract

The vertebral arteries form an essential part of the posterior cerebral circulation, supplying the brainstem, cerebellum, occipital lobes, and portions of the thalami. In routine neurovascular work, Doppler ultrasonography offers a safe, repeatable, non-invasive, and relatively inexpensive way to assess vertebral artery anatomy and flow patterns. CTA and MRA provide superior anatomic detail, particularly for distal

and intracranial segments, but duplex ultrasound remains valuable as an initial and follow-up examination in selected patients with suspected vertebrobasilar disease. This educational article reviews segmental anatomy, scanning technique, expected Doppler parameters, common anatomic variants, vertebral artery hypoplasia, atherosclerotic stenosis, occlusion, dissection, subclavian steal syndrome, frequent interpretive pitfalls, and a practical diagnostic algorithm. The aim is to provide a concise working guide for neurologists, radiologists, residents, and other clinicians involved in cerebrovascular imaging.

Keywords: *vertebral artery; Doppler ultrasound; posterior circulation; vertebrobasilar disease; stenosis; hypoplasia; subclavian steal syndrome.*

Introduction

The vertebrobasilar system accounts for roughly 20-25% of cerebral blood flow, yet it supplies structures whose ischemia may produce disabling or life-threatening symptoms, including the brainstem, cerebellum, occipital lobes, and thalami [1,2]. Clinical presentation is often variable. Vertigo, dizziness, diplopia, dysarthria, ataxia, syncope, visual field disturbance, transient ischemic attack, and posterior circulation stroke may all be encountered [1,2].

Compared with carotid disease, pathology of the vertebral arteries tends to receive less attention in everyday ultrasound practice. Several reasons explain this: the arteries are smaller and deeper, their course is partly hidden by the cervical transverse processes, and Doppler criteria are less firmly standardized than those used for carotid stenosis. Despite these limitations, duplex ultrasound can provide useful information on vessel patency, flow direction, waveform morphology, and hemodynamic asymmetry when it is performed systematically [3,4].

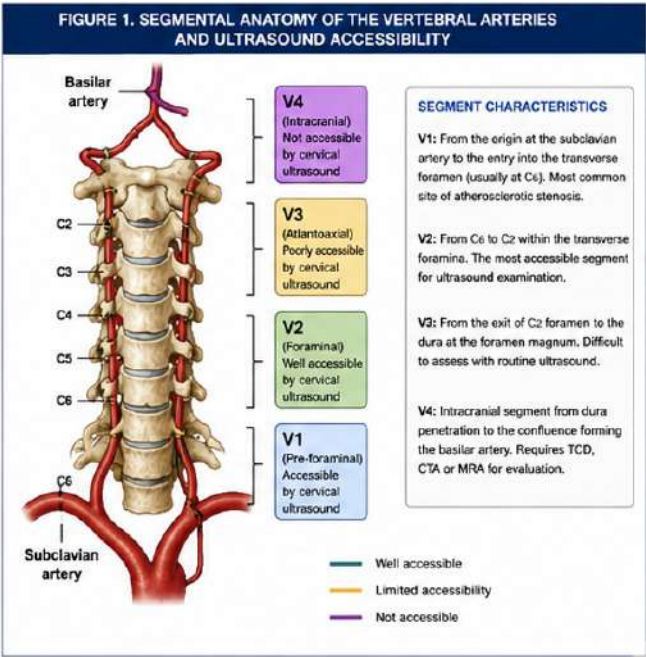
This article is intended as a practical educational review rather than a formal systematic review. It brings together the anatomic and Doppler findings that are most useful at the workstation, with emphasis on what should be recognized, what should not be overcalled, and when CTA or MRA should be recommended. The figures are placed next to the corresponding sections to reinforce the main diagnostic point of each finding. The supporting literature was identified through PubMed/MEDLINE and Scopus searches combining the terms “vertebral artery,” “Doppler ultrasound,” “posterior circulation,” “stenosis,” “hypoplasia,” and “subclavian steal,” supplemented by standard cerebrovascular ultrasound reference texts and citation tracking; the review was prepared in line with the SANRA criteria for narrative reviews.

Segmental anatomy and ultrasound accessibility

The vertebral arteries most often originate from the superior-posterior aspect of the subclavian arteries and then ascend toward the skull base, where they unite to form the basilar artery. For imaging and reporting purposes, each vertebral artery is divided into four segments: V1, V2, V3, and V4 [3].

V1 extends from the origin at the subclavian artery to the point where the vessel enters the transverse foramen, usually at C6. This proximal segment is clinically important because it is a frequent site of atherosclerotic narrowing. V2 runs within the transverse foramina, typically from C6 to C2, and is the segment most consistently assessed during routine cervical duplex ultrasound. V3 curves around the atlas from C2 to the dura at the foramen magnum, while V4 is intracranial and continues to the vertebrobasilar junction [3].

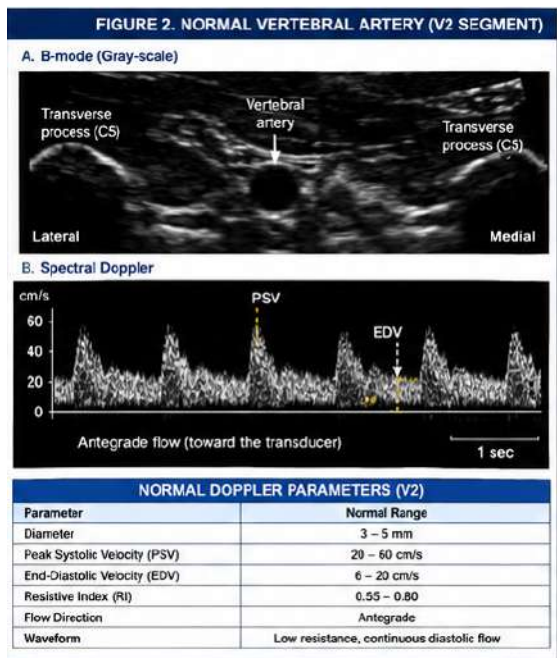
FIGURE 1. Segmental anatomy of the vertebral arteries and ultrasound accessibility. V1 and V2 can usually be evaluated by cervical duplex ultrasound, whereas V3 and V4 are less accessible and often require CTA, MRA, or transcranial Doppler for complete assessment [3].



Examination technique

The examination is generally performed with a high-frequency linear probe, most often in the 5-12 MHz range. The patient lies supine, with the neck slightly extended and rotated gently away from the side being assessed. A complete study should combine gray-scale imaging, color Doppler, and spectral Doppler, because no single component is sufficient on its own [3]. In most patients the vertebral artery is easiest to find in the V2 segment, between the acoustic shadows of the transverse processes. During acquisition, the operator should document whether the vessel is patent, its diameter, flow direction, waveform shape, peak systolic velocity, end-diastolic velocity, and the presence of turbulence or aliasing. Angle correction is important; whenever possible, the Doppler angle should remain below 60 degrees to avoid unnecessary velocity error [3]. Both sides should be examined. A difference between the two vertebral arteries is common and may simply reflect dominance or hypoplasia. For this reason, asymmetry should be interpreted together with vessel caliber, velocities, flow volume, waveform morphology, and the clinical presentation rather than as an isolated abnormal finding.

FIGURE 2. Normal vertebral artery appearance in the V2 segment. The B-mode panel shows the artery between the cervical transverse processes. The spectral Doppler panel demonstrates antegrade low-resistance flow with preserved diastolic flow, typical of the posterior cerebral circulation [3,6].



Normal Doppler parameters

In a normal study, vertebral artery flow is antegrade, directed cranially toward the posterior circulation. The spectral waveform is usually low resistance, with maintained diastolic flow. Published ranges vary according to equipment, technique, and patient factors, but the values summarized in Table 1 are useful as a practical frame of reference [3,6,9].

TABLE 1. Practical reference values for vertebral artery Doppler assessment. Values should be interpreted in clinical context and with attention to technique [3,6,9].

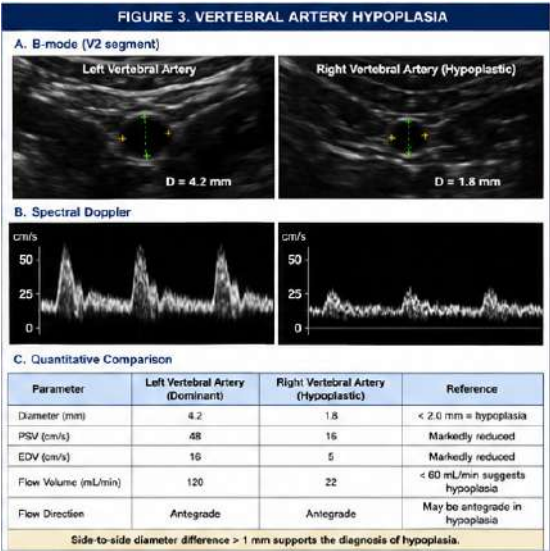
Parameter	Typical normal range
Diameter	3-5 mm
Peak systolic velocity (PSV)	20-60 cm/s
End-diastolic velocity (EDV)	6-20 cm/s
Resistive index (RI)	0.55-0.80
Flow direction	Antegrade
Waveform	Low resistance with preserved diastolic flow

Vertebral artery hypoplasia

Vertebral artery hypoplasia is a common anatomic variant. Many authors use a diameter below 2.0 mm as a practical cut-off, although definitions differ between studies. A side-to-side diameter difference greater than 1 mm is also helpful, particularly when one artery is clearly dominant. Hypoplasia is often an incidental finding, but in selected patients it has been associated with posterior circulation ischemia [5].

Sonographically, a hypoplastic vertebral artery is small in caliber and usually shows lower velocities and reduced flow volume, while the direction of flow remains antegrade. The main difficulty is separating a very small patent artery from an occluded one. Careful optimization of color gain, low pulse repetition frequency, power Doppler, and targeted spectral sampling may reveal residual flow. When doubt persists, especially in a symptomatic patient, CTA or MRA is appropriate.

FIGURE 3. Vertebral artery hypoplasia. Side-to-side comparison demonstrates marked caliber asymmetry with reduced Doppler velocities and flow volume in the hypoplastic artery. A diameter below 2 mm supports the diagnosis, but clinical context is essential [5,9].



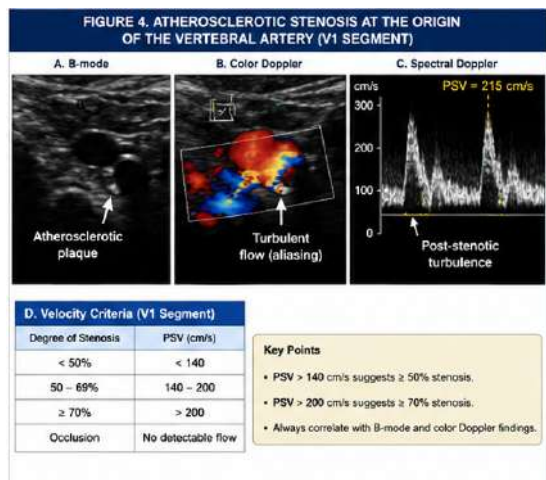
Atherosclerotic stenosis of the vertebral artery

Atherosclerotic disease most often affects the vertebral artery origin, corresponding to the V1 segment [4,7,10]. The risk profile is similar to other atherosclerotic territories and includes hypertension, diabetes mellitus, smoking, dyslipidemia, and increasing age.

Diagnosis should not rely on one Doppler number alone. Gray-scale imaging may show plaque, calcification, or visible luminal narrowing. Color Doppler can demonstrate focal aliasing or a mosaic pattern, and spectral Doppler may show focal acceleration, spectral broadening, and post-stenotic turbulence [4,7]. The confidence of the examination increases when these findings are concordant.

Unlike carotid stenosis, vertebral artery stenosis has less universally accepted velocity criteria. A focal PSV rise is suspicious when it occurs at the vertebral origin and is accompanied by plaque and disturbed post-stenotic flow. In many educational protocols, PSV greater than 140 cm/s is used to suggest at least 50% stenosis, while PSV greater than 200 cm/s raises concern for more severe stenosis. These thresholds should be applied with caution and correlated with CTA or MRA if treatment decisions depend on the result [4,7,10].

FIGURE 4. Atherosclerotic stenosis at the origin of the vertebral artery. The key finding is the concordance between plaque on B-mode, aliasing and turbulent flow on color Doppler, and focal PSV elevation on spectral Doppler [4,7].



Vertebral artery occlusion and dissection

Complete occlusion may occur as a consequence of advanced atherosclerosis, thromboembolism, dissection, trauma, or inflammatory vascular disease. On ultrasound, the expected findings are absence of color Doppler flow and absence of a spectral Doppler signal; echogenic intraluminal material may occasionally be seen. The distinction from severe hypoplasia can be difficult when the vessel is very small or the acoustic window is limited.

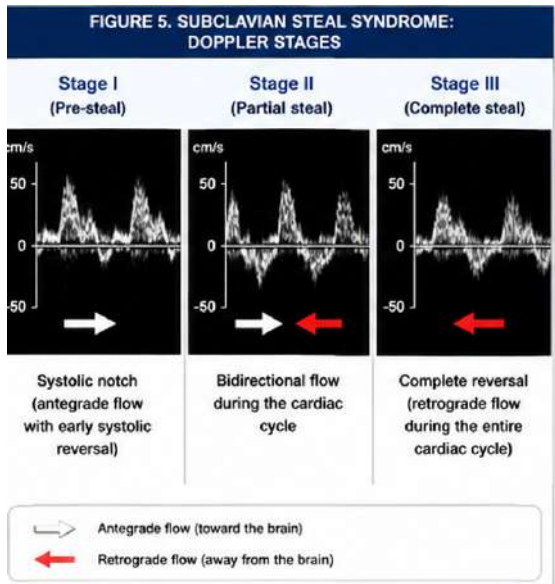
Vertebral artery dissection deserves particular attention because it is an important cause of posterior circulation stroke in young and middle-aged adults [2]. It may be spontaneous or follow cervical trauma, abrupt neck movement, sports injury, or neck manipulation. Ultrasound may raise suspicion when it shows long-segment narrowing, irregular stenosis, an intramural hematoma, or turbulent flow. Nevertheless, CTA and MRA remain the main confirmatory examinations, especially if V3 or V4 involvement is suspected [2,7].

Subclavian steal syndrome

Subclavian steal syndrome develops when a severe stenosis or occlusion of the proximal subclavian artery reverses flow in the ipsilateral vertebral artery. In this setting, blood is diverted from the posterior circulation toward the upper limb. Patients may report dizziness, vertigo, syncope, visual symptoms, or arm claudication, although the finding may also be detected incidentally [8].

Ultrasound is particularly helpful in this situation because it shows the direction of flow in real time. The waveform may progress from an early systolic notch in the pre-steal stage, to bidirectional flow in partial steal, and finally to retrograde flow throughout the cardiac cycle in complete steal.

FIGURE 5. Doppler stages of subclavian steal syndrome. The sequence moves from pre-steal to partial steal and complete reversal; persistent retrograde vertebral flow is the hallmark of complete steal [8].



Flow volume assessment

Flow volume can add useful context, especially when one vertebral artery is dominant, when hypoplasia is suspected, or when symptoms suggest vertebrobasilar insufficiency. The calculated value depends on both vessel diameter and mean velocity. Reference data proposed by Seidel and colleagues support the use of vertebral artery flow volume as part of posterior circulation hemodynamic assessment [9].

Reduced flow volume may support hypoplasia, severe stenosis, or a low-flow state, but it should not be interpreted in isolation. Because the calculation is highly sensitive to small errors in diameter measurement, the result should always be checked against waveform morphology, side-to-side comparison, and the clinical context.

Pitfalls and artifacts

Several technical and interpretive pitfalls are worth emphasizing. Incorrect angle correction may either overestimate or underestimate PSV. Cervical osteophytes may obscure the V2 segment. A markedly hypoplastic artery may be mistaken for occlusion. Color aliasing alone is not proof of stenosis unless spectral Doppler confirms focal acceleration. Finally, normal side-to-side asymmetry should not be labelled as disease without supporting hemodynamic or clinical evidence.

A reliable examination therefore starts with anatomic identification of the vessel, followed by confirmation of flow direction, optimization of color settings, careful angle correction, bilateral comparison, and correlation with symptoms and vascular risk factors.

Role of CTA and MRA

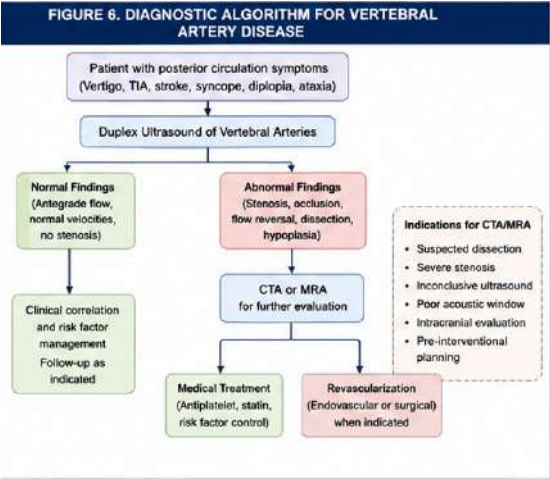
Duplex ultrasound and cross-sectional angiography answer related but different questions. Ultrasound is dynamic, inexpensive, repeatable, and well suited for assessing flow direction; however, it is operator dependent and has limited access to distal V3 and intracranial V4 segments. CTA offers high spatial resolution and is often useful for vertebral origin stenosis, calcified plaque, dissection, and pre-interventional mapping. MRA avoids ionizing radiation and may be preferable when iodinated contrast is contraindicated, although availability, cost, and flow-related artifacts can be limiting.

CTA or MRA is reasonable when ultrasound suggests severe stenosis, occlusion, dissection, or intracranial disease, or when the ultrasound result is inconclusive despite persistent posterior circulation symptoms [2,7,10].

Practical diagnostic algorithm

Evaluation usually begins with the clinical question. In patients with symptoms suggestive of posterior circulation involvement, such as vertigo, diplopia, ataxia, dysarthria, syncope, transient ischemic attack, or stroke, duplex ultrasound can be used to assess the carotid and vertebral systems. Normal findings may be managed according to clinical risk and symptom evolution. Abnormal or uncertain findings--including suspected stenosis, occlusion, dissection, flow reversal, or marked hypoplasia--should lead to CTA or MRA when the result is likely to affect treatment or follow-up.

FIGURE 6. Diagnostic algorithm for suspected vertebral artery disease. Duplex ultrasound can serve as an initial test, while CTA or MRA is recommended for abnormal or inconclusive findings, suspected dissection, severe stenosis, intracranial assessment, or pre-interventional planning [2,7,10].



Structured reporting template

A useful report should state whether both vertebral arteries are visualized and patent, which side is dominant, the vessel diameter, PSV, EDV, waveform morphology, and flow direction. It should also mention any evidence of focal stenosis, occlusion, dissection, or a subclavian steal pattern. When a clinically relevant abnormality is found, the report should indicate whether CTA or MRA is recommended.

Example: Right vertebral artery: diameter 3.8 mm, antegrade low-resistance flow, PSV 42 cm/s, EDV 14 cm/s, without Doppler evidence of hemodynamically significant stenosis. Left vertebral artery: diameter 1.8 mm, antegrade low-volume flow, in keeping with hypoplasia. No Doppler evidence of subclavian steal. Recommendation: clinical correlation; CTA/MRA if symptoms persist or posterior circulation ischemia remains suspected.

TABLE 2. Summary of vertebral artery Doppler findings by condition. Findings should always be interpreted together with clinical context and, where indicated, confirmed with CTA or MRA.

Condition	Diameter	Typical Doppler Findings
Normal	3–5 mm	Antegrade low-resistance flow
Hypoplasia	<2 mm	Reduced PSV and flow volume
Stenosis	Variable	Focal PSV increase, turbulence

Occlusion	Not measurable	Absent flow signal
Dissection	Variable	Irregular narrowing / turbulence
Subclavian steal	Variable	Retrograde flow

Conclusion

Vertebral artery Doppler ultrasonography remains useful in daily cerebrovascular imaging because it provides information that is not limited to anatomy: patency, flow direction, waveform morphology, and hemodynamic asymmetry can all be assessed at the bedside or in the vascular laboratory. Its strongest applications include recognition of vertebral artery hypoplasia, stenosis at the origin, occlusion, and the different stages of subclavian steal. The method also has clear limitations, particularly for distal V3 and intracranial V4 segments, and abnormal or equivocal findings should be integrated with CTA or MRA when management may change. Accurate interpretation depends on careful technique, knowledge of segmental anatomy, and avoidance of common pitfalls.

Declarations

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- Ethics approval and consent:** Not applicable. This is an educational review of published literature and did not involve new studies on human participants or animals performed by the authors.
- Author contributions:** All authors contributed to the conception of the review, the literature review and interpretation, drafting and critical revision of the manuscript, and approved the final version.
- Data availability:** Data sharing is not applicable; no new datasets were generated or analysed. All sources are cited in the reference list.

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