A Spectrum of Doppler Waveforms in the Carotid and Vertebral Arteries

Eric M. Rohren¹, Mark A. Kliewer², Barbara A. Carroll³, Barbara S. Hertzberg³

Received March 2, 2001; accepted after revision April 28, 2003.

¹Mayo Clinic, 200 1st St., SW, Rochester, MN 55905.
²Department of Radiology, University of Wisconsin, E3/311, 600 Highland Ave., Madison, WI 53792-3252. Address correspondence to M. A. Kliewer.
³Department of Radiology, Duke University Medical Center, Rm. 2526 Blue Zone, Box 3808, Durham, NC 27710.


The central focus of carotid Doppler sonography studies is the detection and characterization of atherosclerotic disease and stenosis. Doppler sonography samples are used primarily to quantify velocity elevations at sites of stenosis. However, more subtle clues to disease are contained in the shape and contour of the Doppler sonography waveform itself. Aberrations of waveform morphology can signal regional disease in the carotid and vertebral vessels, remote cardiovascular disease, and iatrogenic conditions.

Typical Carotid and Vertebral Artery Waveforms

Although slightly variable in appearance from patient to patient, the spectral waveforms of the common, external, and internal carotid arteries and the vertebral artery largely reflect the character of the vascular bed being supplied (Fig. 1). Departure from these prototypic waveforms requires explanation.

Waveform Changes in Systole

Pulsus Parvus and Pulsus Tardus

Diminished and delayed arterial pulsations have been termed pulsus parvus and pulsus tardus [1] (Fig. 2). During carotid Doppler sonography, the parvus–tardus waveform is characterized by a small, smooth, and rounded systolic peak and is observed distal to severe atherosclerotic stenoses in approximately 91% of cases [1]. When bilateral parvus–tardus waveforms are encountered, central causes of obstruction should be suspected, including aortic valvular or central arterial stenosis.

Pulsus Bisferiens

Two prominent systolic peaks with an interposed mid systolic retraction are termed pulsus bisferiens [2], which is Latin for “beat twice” (Fig. 3). This waveform is seen in approximately 50% of patients with aortic valvular disease and is also found with hypertrophic obstructive cardiomyopathy [2]. The presence of concomitant aortic stenosis and aortic insufficiency magnifies the bisferiens effect.

Pulsus Alternans

Pulsus alternans denotes alternating peak systolic heights with a regular cardiac rhythm (Fig. 4). Intrinsic myocardial disease (ischemia, cardiomyopathy, or valvular heart disease), metabolic disease (hypocalcemia), or impairment of venous return (inferior vena cava compression or obstruction) can produce this waveform [3]. The sensitivity of the finding is unknown.

Prestole Waveforms

Spectral waveforms in the vertebral arteries will occasionally assume an appearance popularly referred to as the “bunny” waveform (Fig. 5). The depth of mid systolic velocity decline correlates to the degree of subclavian arterial stenosis in all cases of one series [4]. Provocative maneuvers can convert a presteal waveform to a complete steal (Fig. 6). It is postulated that the subclavian stenosis creates a high-velocity jet of blood directed across the origin of the left vertebral artery during systole, causing a transient pressure drop in the vertebral artery and concomitant decline in flow in mid systole because of the Venturi effect. Although more commonly seen in the vertebral vessels, these presteal waveforms also appear in the right carotid artery and are produced by an analogous mechanism (Fig. 7).

Waveform Changes in Diastole

Internalization of the External Carotid Artery

The conversion to a low-resistance Doppler sonography waveform in the external carotid...
artery has been termed “internalization” because the abnormal spectral tracings in the external carotid artery mimic the spectral tracings in a healthy internal carotid artery [5]. This change is often because of complete occlusion of the internal carotid artery with subsequent development of low-resistance collateral pathways between the ipsilateral external and internal circulations (Fig. 8), usually through the ophthalmic bed [6] or between contralateral external circulations through a superficial vascular network [7] (Fig. 9).

Water-Hammer Pulse

Normal or elevated peak systolic velocity followed by a precipitous decline and reversal of flow during diastole is often seen with severe, isolated aortic valvular regurgitation (Fig. 10), mirroring the findings on physical examination.

To-and-Fro Flow

In the neck of pseudoaneurysms, blood flows toward the pseudoaneurysm in systole and returns to the parent artery in diastole. These alternating currents can be reflected in the lumen of a parent artery and detected on spectral Doppler sonography (Fig. 11). Pseudoaneurysms of the carotid arteries occur as a consequence of trauma, surgery, or misplaced central venous lines.

Fig. 1.—76-year-old asymptomatic man with normal carotid and vertebral spectral tracings. A, Doppler sonogram shows normal internal carotid artery that supplies low-resistance vascular bed of brain and therefore has low-resistance waveform. Note sharp rise in flow velocity during systole and gradual tapering of continuously forward flow throughout diastole. Internal carotid artery waveform tends to display more blunted systolic peak and greater diastolic flow than is seen in external carotid artery waveform. B, Doppler sonogram shows external carotid artery that supplies high-resistance vascular beds of osseous and muscular structures of head and neck; thus, waveform is characterized by sharp rise in flow velocity during systole, rapid decline toward baseline, and diminished diastolic flow. Transient reversal in early diastole can be seen normally. C, Doppler sonography waveform of common carotid artery represents amalgamation of flow profiles of internal carotid artery and external carotid artery. Normally, common carotid artery waveform assumes relatively low resistance character because of preponderance of carotid flow entering internal carotid artery (≈ 80%). Occasionally, transient flow reversal may be seen in healthy people. Peak systolic velocities in common carotid artery can be high in young patients with compliant vessels; such velocities tend to decrease with age. D, Doppler sonogram shows normal vertebral artery waveforms that resemble those of internal carotid artery, because vertebral artery also supplies low-resistance vascular bed of brain. Typical vertebral artery waveform is low resistance with continuous forward flow during diastole.
Fig. 2.—66-year-old woman with high-grade atherosclerotic stenosis of proximal right internal carotid artery and parvus–tardus waveforms in mid internal carotid artery. Spectral Doppler sonography tracings distal to stenosis show diminished peak systolic amplitude (pulsus parvus) and prolonged systolic acceleration evident in delayed systolic upstroke and rounded systolic peak (pulsus tardus). This waveform most often results from high-grade stenosis, which may occur anywhere from aortic valve to carotid arteries. If stenosis is central, such as aortic valvular disease, parvus–tardus waveforms are often identified within both carotid arteries.

Fig. 3.—78-year-old woman with severely stenotic aortic valve complicated by aortic regurgitation. Doppler sonography waveforms from arteries (right common carotid artery is shown as example) show bisferiens pulse, with prominent mid systolic retraction (arrow) distinct from dicrotic notch (arrowhead). Dicrotic notch is normal finding and is because of closure of aortic valve, temporary cessation of forward flow, followed by resumption of forward flow driven by elastic rebound of aortic wall. Mechanism of pulsus bisferiens in aortic insufficiency is not well understood. One view is that first peak represents initial high-volume ejection of blood, which is followed by abrupt mid systolic flow deceleration caused by regurgitant valve, and second peak represents tidal wave reflected from distended aorta as it relaxes or from periphery of body. Others argue that rapid ejection of large volume of blood (increased preload of left ventricle) creates transient suction (Venturi) effect in aorta, which in turn produces mid systolic retraction in carotid artery waveform.

Fig. 4.—47-year-old man with pulsus alternans caused by idiopathic dilated cardiomyopathy. Doppler sonogram shows peak systolic velocities in external carotid artery that oscillate between two levels on sequential beats (arrows). Note that cardiac rhythm remains regular throughout.
Fig. 5.—54-year-old woman with asymptomatic left subclavian stenosis and presteal waveforms in vertebral artery.  
A, Doppler sonogram shows midsystolic velocity deceleration (arrow) present in left vertebral artery (VERT). Note echocardiogram tracing indicating beginning of systole at QRS complex (arrowhead).  
B, Drawing shows contour of spectral tracing in presteal states that has been fancifully compared to rabbit in profile. Making this imaginative leap facilitates recognition of otherwise complex waveform pattern.

Fig. 6.—83-year-old woman with known atherosclerotic disease of left subclavian artery.  
A, Doppler sonogram shows conversion of presteal waveform to complete vertebral steal. Spectral tracings from left vertebral artery show waveform characterized by pronounced mid systolic cleft (arrow) and transient reversal of flow during systole. This wave pattern indicates bidirectional flow, represented above and below baseline. This transient reversal represents progression of mid systolic cleft noted in early presteal waveform illustrated in Figure 5. Note that flow in artery is antegrade for most of cardiac cycle.  
B, Doppler sonogram shows that when blood pressure cuff is inflated on left arm, then rapidly deflated, there is conversion of waveform in left vertebral artery from presteal pattern to complete steal pattern, in which there is total reversal of flow throughout cardiac cycle. Blood pressure cuff maneuver induces reactive hyperemia in arm and increases blood flow across subclavian stenosis. Higher velocities within subclavian artery result in complementary drop in pressure and redirection of blood flow in ipsilateral vertebral artery toward its now-lower-pressure subclavian origin.
Doppler Waveforms in Carotid and Vertebral Arteries

Fig. 7.—Presteal Doppler sonography waveform appearance in right external carotid artery of 54-year-old man with atherosclerotic disease of right brachiocephalic artery. Spectral tracings from right external carotid artery show waveform similar in appearance to presteal waveforms described in vertebrobasilar arteries (Fig. 5). Doppler sonography tracings from left carotid artery were normal. Stenosis of brachiocephalic artery is thought to cause jet of flow across origin of right common carotid artery, leading to transient drop in pressure at peak systole. Mid-systolic retraction is evident in Doppler sonography waveforms.

Fig. 8.—73-year-old woman with internalization of left external carotid artery because of complete occlusion of left internal carotid artery. Doppler sonogram shows that external carotid artery waveform has assumed contour similar to that of healthy internal carotid artery, with increased diastolic flow. Most often, collateral blood supply to intracranial arteries from external carotid system traverses ophthalmic bed.

Fig. 9.—78-year-old man with retrograde flow in left external carotid artery caused by complete occlusion of left common carotid artery. 
A, Spectral Doppler sonography tracing from left external carotid artery shows blood flow directed toward transducer (note positive velocities on scale). Therefore, flow in external carotid artery is retrograde toward carotid bulb and then antegrade in internal carotid artery. 
B, Spectral Doppler sonography tracing from internal carotid artery shows flow away from transducer (display has been inverted to show waveform above baseline; note negative velocity measurements on scale). Therefore, flow in internal carotid artery is antegrade, reconstituted via retrograde flow in external carotid artery. Note that reconstituted flow in external carotid artery and internal carotid artery displays low-resistance waveform with diminished systolic amplitude and delayed systolic upstroke similar to parvus–tardus waveform. This waveform is seen in 70% of proximal occlusions, presumably resulting from filtering out of higher frequency velocities by collateral network supplying external carotid artery, often from contralateral external carotid artery system.
High-flow and low-resistance waveforms with nearly uninterrupted forward flow are seen in cases of vascular shunting caused by arteriovenous shunting (Fig. 12). There is coexisting pulsatility of venous waveforms and often a soft-tissue bruit, which is the color speckling at the site of the fistula caused by tissue reverberation from the adjacent highly turbulent flow.

**Waveform Changes Throughout the Cardiac Cycle**

**Highly Resistive Dampened Waveforms**

Small, blunt percussive waveforms with little or no diastolic flow (also called “knocking” or “stump-thump” waveforms) occur proximal to a complete or nearly complete vascular occlusion [8] (Fig. 13). These waveforms are characterized by a high-resistance pattern with diminished or reversed diastolic flow. This appearance can also be a sign of dissection (~ 76% of cases) and should prompt a search for an intimal flap [8].

---

**Fig. 10.**—Water-hammer spectral appearance on sonography of 83-year-old man with severe aortic regurgitation. Spectral Doppler sonography tracing from proximal right common carotid artery shows widened pulse pressure signaled by sharp systolic peak, precipitous deceleration of flow in late systole, and sustained reversal of flow through diastole. The spectral waveforms mirror physical examination finding of water-hammer pulses in patients with severe aortic regurgitation.

---

**Fig. 11.**—45-year-old man with history of central venous line inadvertently placed in artery.

**A.** Color Doppler sonogram shows large pseudoaneurysm (arrows) with swirling flow in patient’s neck. Further examination revealed neck of pseudoaneurysm arises from mid common carotid artery (not shown).

**B.** Proximal to pseudoaneurysm, Doppler sonogram shows pulse contour in common carotid artery (CCA) is irregular and jagged, and there is reversal of flow in diastole (arrow), resembling to-and-fro pattern produced by exchanging currents in pseudoaneurysm neck.
similar pattern can be seen at bends, kinks, and side branches.

**Swirling or Bidirectional Flow**

Apart from the normal boundary layer separation at the carotid bulb, flow reversal within a carotid artery segment raises concern for the presence of tandem stenoses or dissection (Fig. 14). The abnormal hemodynamic pattern created at one lesion can overlap that of a second and produce abnormal waveforms and eddy currents. A similar pattern can be seen at bends, kinks, and side branches.

**Cyclical Flow Perturbations**

The presence of an intraaortic balloon pump can dramatically alter the appearance of carotid and vertebral Doppler waveforms because of the sequential inflation and deflation of the balloon (Fig. 15). In these patients, it is important to recognize the cause of these perturbations because they can lead to overestimation or underestimation of true flow velocities through an arterial segment.

**Transmitted Percussion Waves**

Small, regular percussion waves are seen when the examiner performs a temporal tap maneuver to identify the external carotid artery

---

**Fig. 12.**—19-year-old man who sustained gunshot injury to neck. 
A, Doppler sonography waveforms in right vertebral artery show extremely high flow velocities during both peak systole and diastole, indicating shunt of arterial flow into low pressure system. 
B, Doppler sonography waveforms in right internal jugular vein show high volume of disordered, pulsatile flow. 
C, Color Doppler sonogram reveals traumatic vertebrojugular arteriovenous fistula (arrows) that was confirmed on follow-up angiography. JUG V = jugular vein, VERT = vertebral artery.
Fig. 13.—Blunt, percussive waveforms in 29-year-old man with complete occlusion of right common carotid artery because of Takayasu’s arteritis. Spectral Doppler sonography waveforms obtained immediately proximal to occlusion show only diminutive and damped percussion and no visible flow during diastole.

Fig. 14.—Bidirectional flow in internal carotid artery of 78-year-old woman with prior right carotid endarterectomy and recurrent amaurosis fugax. 

A, Spectral Doppler sonography tracings from proximal internal carotid artery show high-velocity antegrade flow, suggesting high-grade stenosis. Note presence of intermittent cardiac arrhythmia.

B, Spectral Doppler sonography tracings from mid internal carotid artery show retrograde flow in posterior portion of vessel. This finding suggests second tandem stenosis distally, producing swirling current of blood in interposed arterial segment.

C, Right carotid arteriogram confirms proximal and distal internal carotid artery stenosis (arrows).
Fig. 15.—Superimposed cyclic flow perturbations in common carotid artery because of presence of intraaortic balloon pump. 
A, Doppler sonogram shows 55-year-old man with ischemic cardiomyopathy. Waveforms in right common carotid artery show second peak of forward flow (arrow) during systole corresponding to inflation of intraaortic balloon. At end of diastole, and immediately preceding next beat, there is transient reversal (arrowhead) that corresponds to deflation of balloon. 
B, Doppler sonogram shows 36-year-old man with ischemic cardiomyopathy and intraaortic balloon pump. Less-organized wave pattern is seen in left common carotid artery of this patient. Presence of balloon pump complicates analysis of underlying carotid disease, and measurement of flow velocities may necessitate temporary deactivation of balloon pump.

Fig. 16.—68-year-old asymptomatic woman with percussive waves because of temporal tap maneuver. 
A, Spectral Doppler sonography tracing obtained during temporal tap (T) shows external carotid artery. Serrate distortion of pulse contour produced by tapping temporal artery is well defined, with deflection occurring predominantly toward baseline. 
B, Spectral Doppler sonography tracing obtained during temporal tap (T) shows internal carotid artery. Changes produced by tapped percussions are evident in internal carotid artery and external carotid artery tracings and therefore have been transmitted around carotid bulb. It is important to examine both carotid vessels under consideration. If these perturbations are found in only one of two vessels in question, that vessel is always external carotid artery. When percussive waves are detected in both vessels, waves are sharper and of higher amplitude in external carotid artery in 74% of cases.
and discriminate it from the internal carotid artery. The reflected pulsations from this tap will be propagated along the vessel in both directions and can be detected caudally at the transducer (Fig. 16). Although often seen only in the external carotid artery, less defined and smaller waves can occasionally be identified in the internal carotid artery.

Conclusion

The shape and character of carotid and vertebral Doppler waveforms can disclose a variety of underlying cardiovascular abnormalities. Systemic circulatory disorders and regional flow disturbance in the vessels of the neck can be suspected and diagnosed with close inspection for changes in the pulse contour.

Acknowledgments

We thank Susan Murray and Carrie Poole for assistance with manuscript preparation.

References