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How to Perform Ultrasound Tests

1 Principles of Extracranial Ultrasound Examination

Andrei V. Alexandrov[1], Alice Robinson-Vaughn[1], Clotilde Balucani[2] & Marsha M. Neumyer[3]
[1]University of Alabama Hospital, Birmingham, AL, USA
[2]University of Alabama Hospital, Birmingham, AL, USA and University of Perugia, Perugia, Italy
[3]Vascular Diagnostic Educational Services, Harrisburg, PA, USA

Introduction

A simple observation gives origins to clinical examinations, analysis and scientific exploration. Being able to observe Nature at work or in distress often offers clues that clinicians and scientists need to get an idea as to what could be going on and come up with a hypothesis to explain it. Ultrasound, with its unprecedented temporal resolution, is an elegant tool to probe living tissues. This first chapter describes how we evaluate the extracranial vasculature, then subsequent chapters continue the journey into cerebral vessels, hemodynamics and specific disease states.

Anatomy of the cerebrovascular arterial system

The choice of transducer placement and subsequent repositioning determines the success of visualizing the target structures and staying with the spatial course of the pre-cerebral vessels. Therefore, sonographers performing vascular ultrasound examinations must think "in 3-D," or three dimensions, about the vessel being investigated and put together transducer positioning with vessel intercept and further "go with the structure or flow" to complete scanning.

A sonographer should further imagine how this arterial segment would look on an angiogram. We strongly encourage those learning and interpreting ultrasound to be familiar with cerebral angiograms [1] since angiography is the gold standard for the assessment of the accuracy of ultrasound testing, and ultrasound performance is often judged by vessel appearance on invasive or non-invasive angiograms. The following section deals with normal vascular anatomy and describes a standard protocol for carotid and vertebral duplex testing on the neck. More details of anatomy and angiographic images are provided in Chapter 3.

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The common carotid artery

Scanning starts with a quick brightness-modulated (B-mode) surveillance in a transverse transducer position of the common carotid artery (CCA) up to its bifurcation. Color flow or power mode can be added to visualize flow in the vessel lumen (Figure 1.1).

On the right, the brachiocephalic trunk or innominate artery, arises from the aortic arch and then bifurcates into the subclavian artery and the CCA. On the left side, both the common carotid artery and the left subclavian artery usually originate directly from the aortic arch. The CCA is easily assessable on the neck where it runs in parallel with the jugular vein and the initial assessment starts right above the clavicle (Figure 1.2). It is further assessed in its mid-portion as the transducer slides cephalad over the sterno-cleido-mastoid muscle (Figure 1.3).

At approximately the level of the fourth vertebra, which is at the level of the upper border of the thyroid cartilage, the CCA bifurcates into the internal and external carotid arteries (Figure 1.4). The carotid bulb represents dilatation at the distal CCA extending into the proximal internal carotid artery. The carotid bulb bears unique flow patterns yielding a boundary separation zone and its wall has numerous baro- and chemo-receptors. The size and location of the carotid bulb are variable.

Most atherosclerotic disease occurs at the level of the bifurcation due to marked changes in vessel geometry resulting in increased shear stress, fluid stagnation and increased particle residence time on the postero-lateral wall of the bulb [2].

The internal carotid artery

Beyond the carotid bulb, the internal carotid artery (ICA) returns to a normal caliber (Figure 1.5) and courses in a relatively straight line up the neck into the skull to supply blood

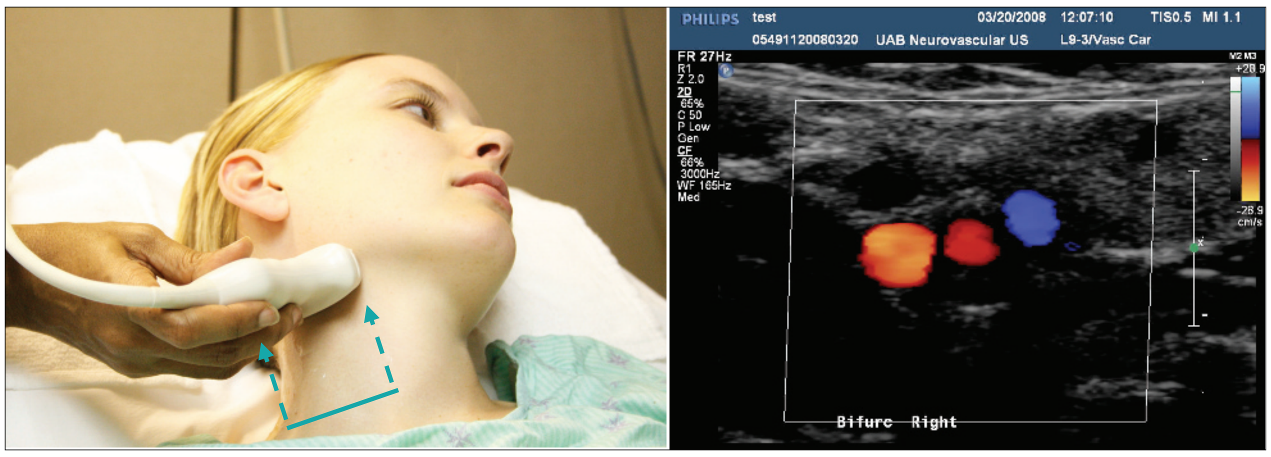

Figure 1.1 Transverse positioning of the duplex transducer depicts carotid bifurcation on the neck. Arrows indicate a proximal initial placement of the probe and its ascent to the bifurcation as the initial step to extracranial vascular examination. The left side of the ultrasound B-mode and color flow image is oriented towards the midline. Red color shows arterial flows, blue indicates the jugular vein.

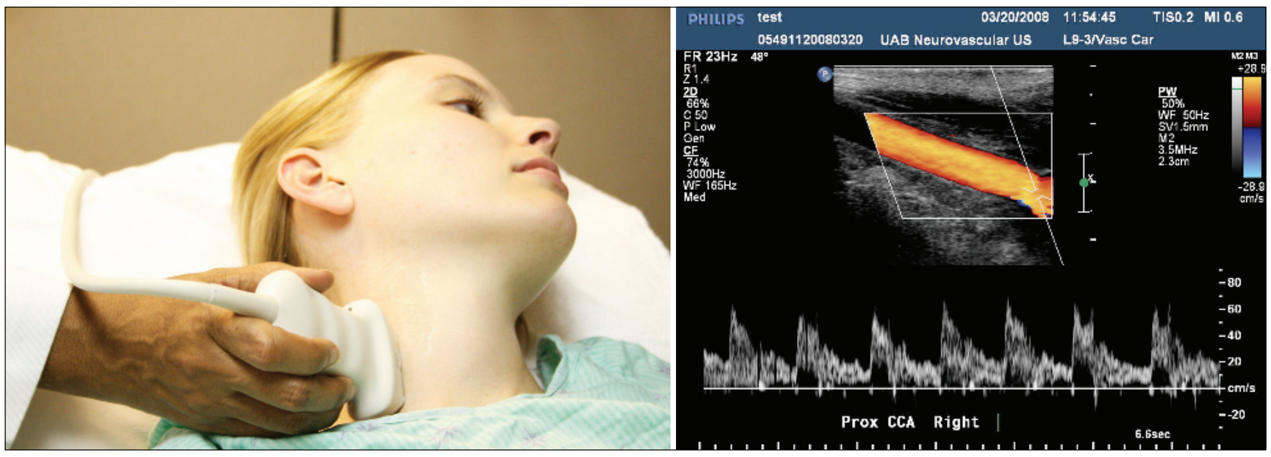

Figure 1.2 After transverse sweeps, a longitudinal position of the probe yields depiction of the proximal common carotid artery close to its origin from the brachio-cephalic trunk on the right side of the neck. Note that ultrasound image is aligned with the middle of the vessel by keeping “the ends of pipe open.” The left side of the ultrasound image is oriented cephalad. Doppler sampling shows the velocity spectra at a 60° angle of insonation.

Figure 1.3 A longitudinal view of the mid-cervical portion of the right carotid artery shows B-mode, color flow and Doppler spectra of the artery and flow through it.

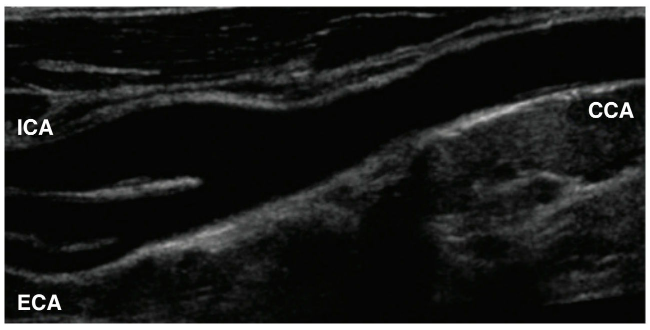

Figure 1.4 The "tuning fork" of the carotid bifurcation on B-mode.

flow to the eye and brain. As a rule, the ICA has no branches within the neck. After entering the skull, the ICA makes an S-shaped curve in the region of the carotid siphon. The ICA entrance to the skull marks a vulnerable area where arterial wall dissections may occur due to fixed ICA position. The first major branch of the ICA is the ophthalmic artery that supplies the eye. After giving off the ophthalmic artery, the ICA divides into the middle cerebral artery (MCA) and the anterior cerebral artery (ACA), a part of the circle of Willis. This is covered in Chapters 2 and 3.

The external carotid artery

The extracranial carotid artery (ECA) supplies the muscles of the face, forehead and scalp (Figure 1.6). To switch between the ICA and ECA, a sonographer often must reposition the transducer from lateral to more medial angulation since both vessels are seldom visualized together in one plane for sufficient interrogation. The ECA has branches that could be visible while scanning its proximal segment. The ICA divides into eight branches on the neck. Several of these branches, i.e. ascending pharyngeal, facial, internal maxillary and superficial temporal arteries, communicate via anastomoses with the ICA. The occipital artery is the only ECA branch that communicates with the vertebral artery circulation. It is important to recognize these branches because the ECA fairly often becomes a collateral source for blood flow to the brain when the ICA is critically stenosed or occluded.

The vertebral artery

The vertebral arteries (VA) arise from the subclavian arteries and its origin can be found with transducer sliding towards the clavicle and aiming deep and lateral to the CCA (Figure 1.7). The VA passes medially in the neck to enter the bony canal at the C6 vertebrae and it further courses cephalad through the transverse processes of the vertebrae (Figure 1.8). It enters the base of the skull by looping around the atlas and ascending through the foramen magnum. At this point, the right and left vertebral arteries join together to form the basilar artery. The basilar artery terminates in the posterior cerebral arteries, which make up the posterior portion of the circle of Willis.

Components of ultrasound examination

Continuous wave (CW) Doppler

Although this technology is now regarded more of historic interest due to technological advances in imaging, knowledge of CW Doppler is required for board examinations and occasionally the skill of using the so-called "pencil probe" may be useful.

Dr Eugene Strandness and co-workers first reported the use of a transcutaneous flowmeter to evaluate occlusive arterial disease in 1966 [3]. Extracranial carotid and vertebral examinations with CW Doppler were reported by Drs Merrill Spencer and Michael von Reutern and colleagues in the 1970s [4,5].

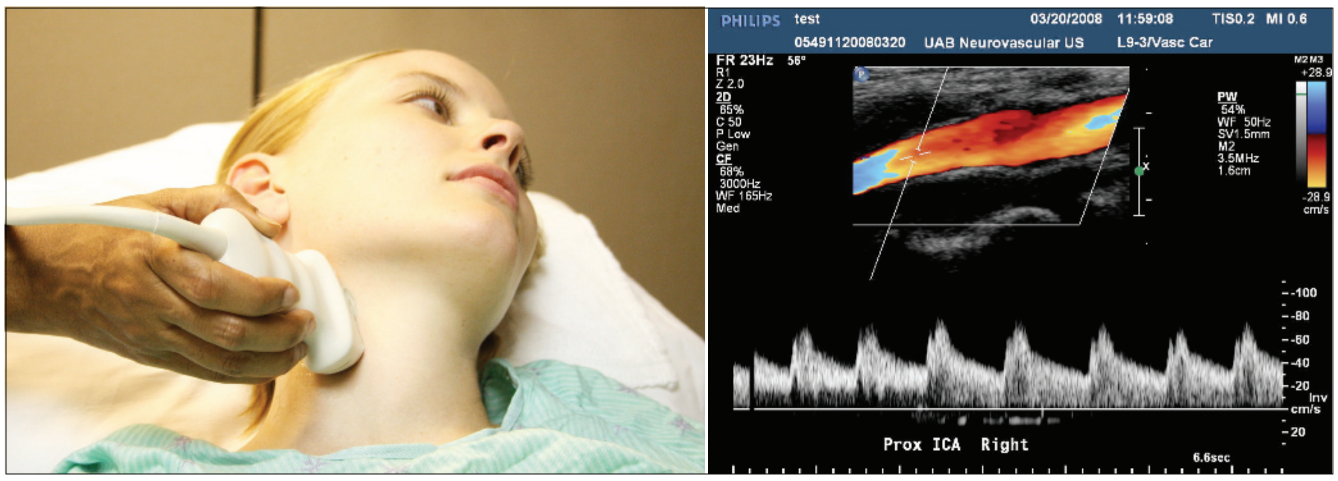

Figure 1.5 Insonation of the proximal ICA just after the bulb.

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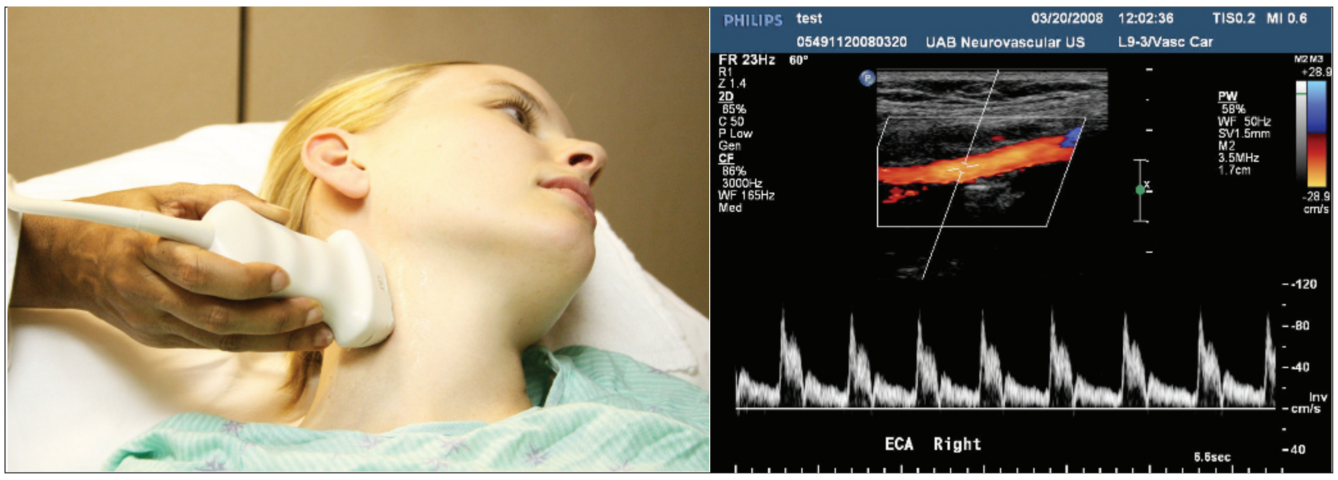

Figure 1.6 Insonation of the ECA: color flow image shows a branch while Doppler spectra display a characteristic high resistance waveform.

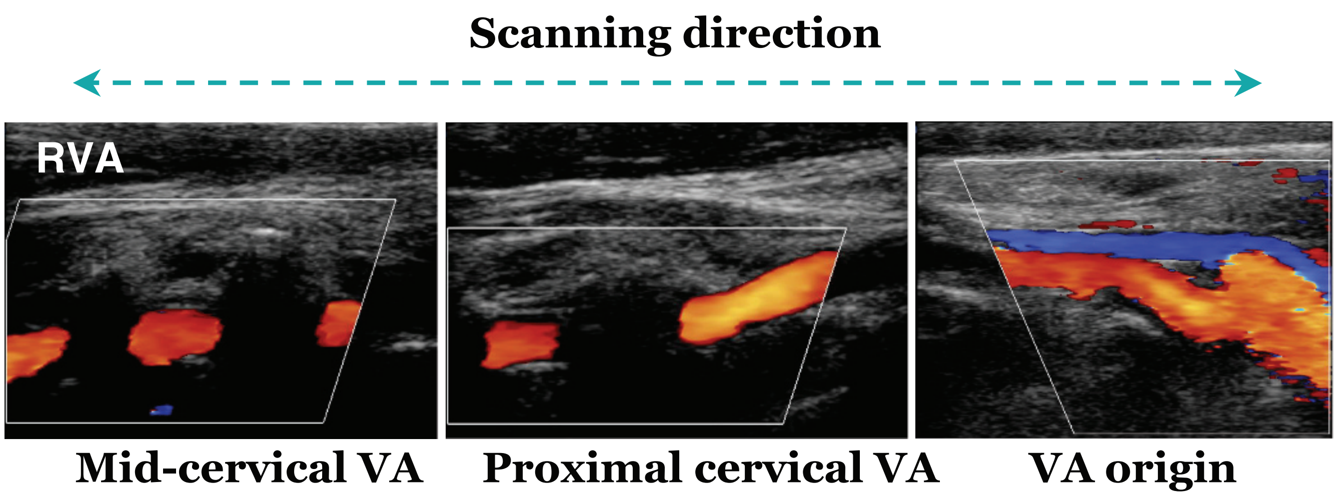

Figure 1.7 Insonation of the origin of the vertebral artery. Arrows show the further extent of the vertebral artery examination on the neck.

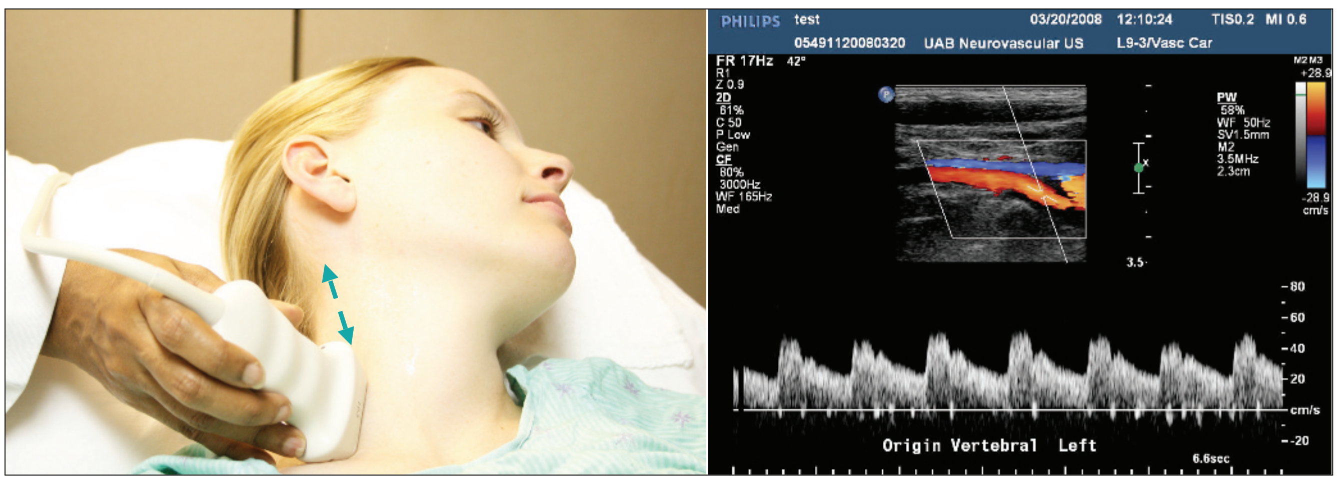

Figure 1.8 Doppler spectra in a proximal cervical segment of the vertebral artery visualized with B-mode and color flow.

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Insonation with CW probe

Figure 1.9 Insonation with continuous wave (CW) transducer.

With this technology, one crystal continuously emits the signal and another crystal continuously receives returned echoes, and this "non-imaging" transducer looks like a pencil (Figure 1.9). CW Doppler displays Doppler frequency shifts including maximum frequency trace without an artifact due there being no limitations related to pulse repetition frequency. Current CW systems can differentiate between positive and negative Doppler shifts and create a bi-directional spectral signal that shows flow direction as towards or away from the transducer. However, CW Doppler shows no information regarding the structure, i.e. image, or the depth from which the signals originated.

The advantage of this ultrasound test is its ability to display Doppler frequency shifts from moving objects without an artifact called aliasing. With the recent development of direct imaging and pulsed wave Doppler methods, CW Doppler is rarely performed and is not reimbursed in the United States as a *sole* test used for evaluation of the carotid vessels. Perhaps the only remaining indications for CW Doppler for carotid arteries are extensive (>2 cm) shadowing of the bifurcation, arterial lesions extending above the level of lower jaw or a quick bifurcation screening before or with (not as a substitute for) direct imaging investigation.

The B-mode image

The B-mode image is created from the amplitude of backscattered echo signals that are displayed in gray scale along beam propagation (depth) and the length of transducer/skin interface (Figures 1.1 and 1.2). The gray shade of the signal on-screen displays the strength of the returning echo while its location relates to the depth of tissue reflector. Several crystals are sequentially activated with electronic pulses or the transducer is rotated mechanically (steering) to create multiple scan lines. The scan lines are put together to generate an image (or "frame"). Since the average speed of sound propagation in soft tissues is 1540 m s^{-1} ("a mile per second"), multiple frames are generated in a second, creating an illusion of a real-time picture ("movie making" with ultrasound).

The maximum depth of sound penetration is determined by the emitting frequency of the ultrasound transducer, which is usually 4–12 MHz for extracranial imaging and 2–4 MHz for intracranial imaging. Higher frequencies have smaller pulse lengths and allow better spatial resolution but less penetration due to increased sound scattering. Time-gain compensation (TGC) is applied to improve visualization of structures with increasing depths of insonation. The smallest distinguishable distance between two reflectors along the ultrasound beam axis (axial resolution) is directly proportional to the spatial length of the pulse. Lateral resolution (or resolution perpendicular to the direction of an ultrasound beam) is also dependent on transducer geometry since it is the highest in the focal zone. The focal zone is determined as the narrowest point between converging (near-field) and diverging (far-field) parts of the ultrasound beam. Note that an ultrasound scanner can create multiple focal zones to optimize different parts of the image. Therefore, linear or curved array transducers with larger surface, dynamic electronic focusing and multiple narrow width beams have better lateral resolution.

B-mode imaging artifacts include the following:

1 Shadowing (no image can be generated along ultrasound beam axis behind a bright reflector). Changing the transducer position and planes of insonation may minimize shadow appearance. Shadows can originate from perpendicular insonation of vessel walls, plaque calcification (Figure 1.7) and transverse vertebral processes (Figure 1.3).

2 Reverberation (multiple bright echoes that often have a regular shape and layered position are displayed along the axis of ultrasound beam when echoes bounce many times between two strong reflectors).

3 Mirror image [a false image (also known as phantom image or reflection artifact) is created when obliquely scanning a strongly reflecting boundary]. Vessel visualization in transverse and longitudinal planes often resolves confusion associated with this artifact.

4 Plane-of-section (three-dimensional structure is inadequately displayed on a two-dimensional monitor). Using imagination for three-dimensional spatial relationships, the transducer position should be changed to generate adequate sectional planes.

B-mode imaging is used to identify the carotid and vertebral arteries, carotid intima–media complex, atherosclerotic plaques and anatomic anomalies. B-mode imaging can also be used to perform intracranial studies where it shows contralateral skull line, midline structures including the third ventricle and brain parenchymal structures.

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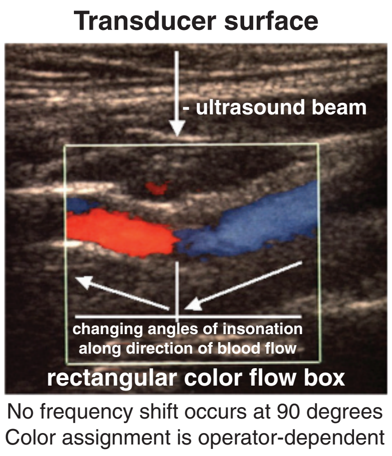

Figure 1.10 Changes in color flow assignment relative to the middle of the transducer within a rectangular color flow box.

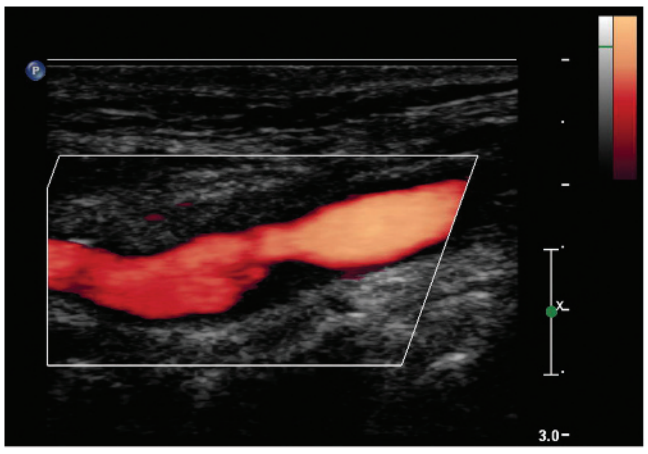

Figure 1.11 Power mode image of the distal CCA, proximal ICA and a small hypoechoic plaque at the ICA bulb.

The color-flow Doppler image

Color-coded Doppler flow image (CDFI) displays the average (or mean) shifts in the frequency of returned echoes backscattered from moving objects, usually red blood cells. The color scale can be selected manually, ranging from two colors (red and blue) to a rainbow palette. At least two distinctly different colors are used to display clearly the direction of flow relative to transducer midline (Figure 1.10). According to the Doppler effect, objects moving towards the transducer will increase the frequency of backscattered echoes relative to emitted frequency and vice versa. However, color assignments are operator dependent.

Therefore, CDFI is used to identify moving blood and display the direction of flow. No Doppler frequency shift occurs at a 90° angle between ultrasound beam and moving blood stream (Figure 1.8). CDFI often contains artifacts:

1 Aliasing (abrupt change from the maximum velocity in one flow direction to the maximum velocity in the opposite direction without crossing the zero line). It can be present in a normal vessel if the scale settings are inadequately low to display flow velocity, i.e. a sonographer uses a low pulse-repetition frequency (Figure 1.9). It can also be present with maximum scale settings in stenosed vessels due to elevated flow velocities. Scale setting control and comparison of vessel course and B-mode findings help to differentiate imaging artifact from pathological finding.

2 "Bleeding" (the presence of moving blood outside the vessel). This artifact can be produced by an oblique strong reflector (mirror image) or by tissue motion adjacent to the vessel. In both circumstances, changing the transducer position and color gain setting helps to optimize the image (Figure 1.10).

Occasionally, CDFI may be unable to depict blood flow since its spatial resolution is lower than the B-mode image. Also, there is a trade-off between B-mode and superimposed CDFI images: larger CDFI boxes require slower frame rates that decrease B-mode resolution and vice versa. CDFI may not be able to display blood flow adequately in tortuous and deep-located vessels and also vessels affected by the low flow states, i.e. near-occlusion. Other forms of flow imaging may be used in these circumstances.

The power Doppler image

Power Doppler imaging displays color-coded intensities of the returned echoes that contain Doppler frequency shifts. Unlike CDFI, power mode Doppler shows direction-independent changes in the energy of signals backscattered by moving objects. Therefore, power mode images are usually created with brightness-adjusted uni-color scales (Figure 1.11). Power mode images show the course of the vessel without color change due to flow direction. Power mode can be used to visualize tortuous and deep-located vessels, branches and slow-moving blood. "Flashing" is the most common artifact that is created by tissue motion and, similarly to "bleeding," displays artifactual flow signals outside the vessel lumen. This can be corrected by changing the gain settings and color box size.

The color velocity image

The color velocity imaging (CVI) display is similar to CDFI; however, the color-encoded velocities are derived from time-domain processing of returned echo signals. For example, the CVI image represents the movement of red blood cell clusters in time along the vessel course. It allows a better trade-off between B-mode and color flow information in terms of image resolution due to better utilization of scan lines. CVI can also display functional flow lumen better. It is also used in some laboratories to calculate flow volume estimates in the carotid arteries.

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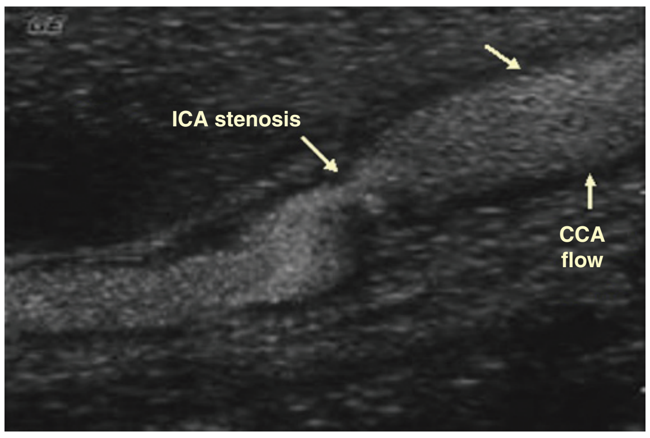

Figure 1.12 B-flow imaging of the carotid stenosis.

B-Flow and compound imaging

Brightness-mode display can also be used to generate flow images since moving blood changes the strength of reflected signals relative to surrounding structures. Combined with electronic focusing and multiple focal zones, such images can provide high-resolution structural scans (Figure 1.2) and superimpose flow signals in gray scale over a B-mode image (Figure 1.12). The B-flow scans avoid aliasing and offer potentially better trade-off between tissue motion and moving blood signals.

Harmonic imaging

An emitted frequency of a diagnostic ultrasound pulse wave passing through tissue can change due to reflection off a moving object (Doppler shift) or during faster sound transmission through fluid compressed at the peak intensity of the ultrasound wave (harmonics). This frequency change occurs mostly during wave propagation (less during reflection). The result is the appearance of the second harmonic frequency that is twice the emitted frequency. This mechanism of non-linear interaction of ultrasound with body tissues allows the use of harmonic frequencies to image tissues with and without contrast substances, and new-generation duplex scanners provide this option. Potential clinical utility of harmonic imaging in cerebrovascular ultrasound includes application of contrast agents for tissue perfusion studies, including brain parenchyma, differentiation of a complete occlusion from subtotal stenosis and better delineation of plaque and vessel wall morphology.

Doppler velocity spectral display

A pulse-wave ultrasound beam can also be used to detect Doppler shift in the returned echoes since moving blood or tissues will change the emitted frequency. This phenomenon is used to measure flow velocity simultaneously with structural and color flow imaging. To obtain velocity values close to real speed of blood, angle correction is applied, which is discussed in the scanning protocol in the next sub-section.

Extracranial duplex ultrasound examination technique and scanning protocol

The extracranial duplex examination should include transverse and longitudinal B-mode scans of the vessels. Examination can start with transverse scanning since it allows fast identification of CCA, jugular vein, the level of bifurcation and the presence of atherosclerotic disease. The transverse examination begins with the most proximal segment of the common carotid artery following its course towards the distal portion, passing through bifurcation and ending at the level of the mandible with visualization of the distal cervical segment of the internal carotid artery (Figure 1.13). The transverse plane permits appreciation of vessel diameter, presence of pathology and anatomic anomalies. The examination is repeated in the longitudinal plane (Figures 1.1 and 1.2), beginning again with the most proximal segment of the CCA and extending the scan throughout the bifurcation, internal and external carotid arteries. The vertebral artery is examined at its origin and also in the mid-cervical segment of the neck (Figure 1.3).

To optimize the gray-scale image, set the dynamic range to 40–50 dB and the time-gain compensation (TGC) as appropriate to the depth of the common carotid and vertebral arteries.

Imaging in the transverse plane

1 With the patient's head turned slightly away from the side being examined, place the ultrasound probe low on the neck, anterior to the sterno-cleido-mastoid muscle, just above the clavicle. The left side of the image should be oriented towards midline structures, i.e. trachea.
2 Locate the proximal segment of the CCA in the transverse plane. Slowly move the probe along the length of the CCA.
3 At the distal end of the CCA, locate the dilatation that identifies the carotid bulb.
4 Slowly move the probe through the region of carotid bulb and note the bifurcation into the internal (ICA) and external (ECA) carotid arteries.
5 Follow the course of the ICA and ECA to the level of mandibule. Document any evidence of pathology, vessel tortuosity and abnormal anatomy.

Imaging in the longitudinal plane

1 Return to the proximal segment of the CCA with the ultrasound probe rotated to image in the longitudinal axis. The left side of the image should be oriented cephalad.
2 Begin with the probe placed anterior to the sterno-cleido-mastoid muscle.

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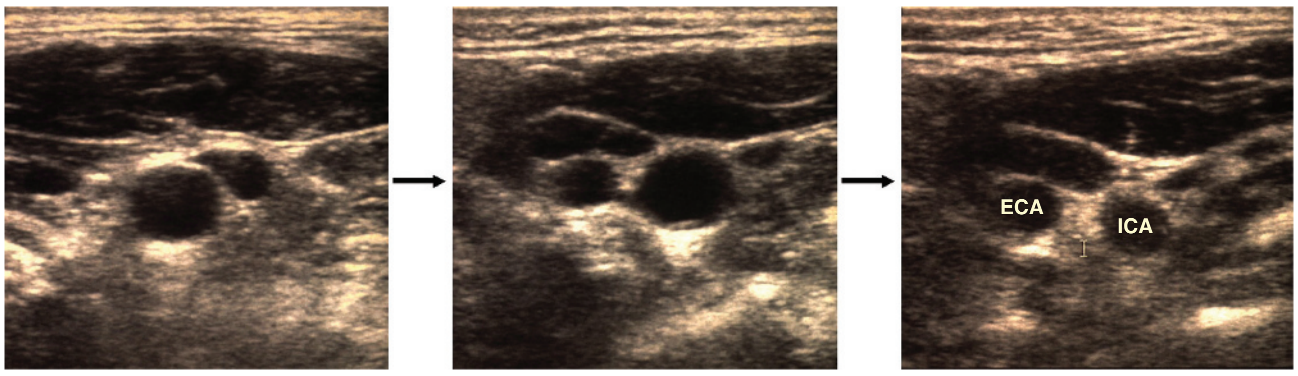

Figure 1.13 Transverse scanning of the proximal CCA, bifurcation, ECA and ICA (from left to right).

3 Image the widest longitudinal axis of the CCA by directing the sound beam perpendicular to the anterior wall of the vessel.
4 Optimize the image so that the normal linear reflectivity of the arterial wall is apparent.
5 Slowly move the probe along the course of the vessel and into the carotid bulb.
6 With the distal CCA and bulb in view, slowly rock the transducer side-to-side to reveal the origins of the internal and external carotid arteries. Care must be taken to angle the probe along the origins to avoid transecting the views of each artery.
7 In turn, follow the courses of the ICA and ECA, optimizing the image for accurate evaluation of anatomy and pathology. Document any evidence of pathology, vessel tortuosity or abnormal anatomy.

Color flow ultrasound evaluation of flow dynamics

1 Return to the longitudinal image of the proximal CCA.
2 Choose the appropriate color pulse repetition frequency (PRF) by setting the color velocity scale for the expected velocities in the vessel. For normal adult arteries, the velocity range is usually around or under 100 cm s^{-1} (or 2.5 kHz Doppler frequency shift). Note that most criteria will use a 125 cm s^{-1} cut-off for velocities elevated due to carotid stenosis. Adjust the scale further to avoid systolic aliasing (low PRF) or diastolic flow gaps (high PRF or filtering) in normal vessels.
3 Optimize the color power and gain so that flow signals are recorded throughout the lumen of the vessel with no "bleeding" of color into the surrounding tissues.
4 Avoid using large or wide color boxes since this will slow frame rates and resolution of the imaging system. Use color boxes that cover entire vessel diameter and 1–2 cm of its length. Align the box, i.e. select appropriate color flow angle correction, according to the vessel geometry and course.
5 Slowly move the probe throughout the course of the CCA, bulb, ICA and ECA.
6 Identify and record regions of flow disturbance, inappropriately high or low velocity signals or the absence of flow signals.
7 To find the vertebral artery, return to the CCA (longitudinal view, transducer position anterior to the sterno-cleido-mastoid muscle). Steer the color beam towards the proximal CCA. Rock the probe slightly to the lateral aspect of the neck to image the vertebral artery as it courses through the transverse processes of the vertebrae ("shadows"). "Heel–toe" the probe above the clavicle to image the origin of the vertebral artery as it arises from the subclavian artery. Confirm that the direction of flow in the VA is the same as the CCA.

Doppler spectral evaluation of flow dynamics

1 Return to the longitudinal image of the CCA.
2 Use the color flow image as a guide for Doppler examination (Figure 1.14).
3 Begin the examination using a Doppler sample volume size of 1.5 mm positioned in the middle of a normal vessel (Figure 1.14).
4 Consistently follow one of the choices for angle correction: parallel to the vessel walls or to the color flow jet.
5 Adjust the Doppler spectral power and gain to optimize the quality of the signal return.
6 Slowly sweep the sample volume throughout the length of the CCA, bulb, ICA and ECA.
7 Perform temporal artery tapping when insonating ECA to differentiate between the ECA and ICA flows. Also note the presence of arterial branches that may be present at the proximal ECA stem.
8 Identify regions of flow disturbance or where flow is absent.
9 Record flow patterns in the proximal and distal CCA, the proximal, mid and distal ICA and the proximal ECA

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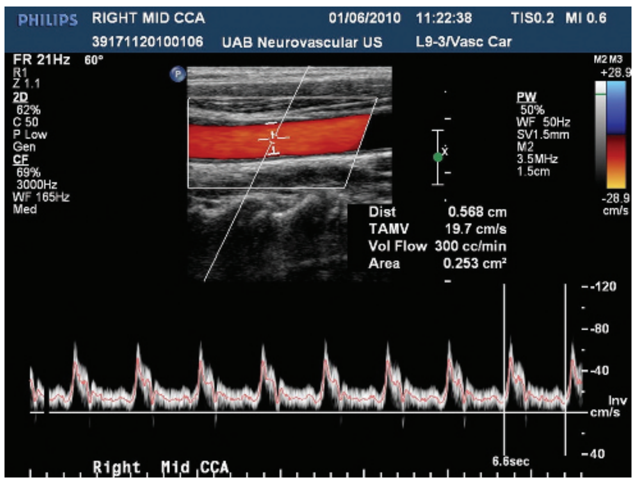

Figure 1.14 Placement of sample volume in the CCA using color flow image as a guide. A small (1.5 mm) gate is used for Doppler spectral measurement and a large (10 mm) gate is used for the flow volume measurements.

at appropriate angles of insonation. Additionally, include Doppler spectral waveforms proximal, within and distal to all areas where flow abnormalities were observed.

10 Locate the origin or proximal segment of the vertebral artery (Figure 1.7). Record flow patterns paying careful attention to flow direction. Follow accessible cervical segments of the vertebral artery (Figure 1.8). Change the angulation of the color box and Doppler sample along with the course of the artery.

Extracranial duplex examination should provide the following data

1 Peak systolic velocity in all vessel segments.
2 End-diastolic velocity in all vessel segments.
3 Ratios of the ICA to CCA peak systolic velocities.
4 Documentation of the Doppler spectral waveform morphology from the CCA, ICA and ECA.
5 Flow direction and peak systolic velocity of the vertebral arteries.
6 Views demonstrating the presence and location of pathology.
7 Images of plaque morphology and surface features.

Tips to improve accuracy

1 Consistently follow a standardized scanning protocol.
2 Perform a complete examination of the carotid and vertebral arteries.
3 Sample velocity signals throughout all arterial segments accessible.
4 Use multiple scan planes.
5 Take time to optimize the B-mode, color and spectral Doppler information.
6 Videotape or create a digital file of the entire study including sound recordings.
7 Always use the highest imaging frequencies to achieve higher resolution.
8 Account for any clinical conditions or medications that might affect velocity.
9 Integrate data from the right and left carotid and vertebral arteries.
10 Do not hesitate to admit uncertainty and list all causes for limited examinations.
11 Expand Doppler examination to intracranial vessels when indicated.

Tips for optimizing color flow set-up

1 According to standardized protocols, the carotid bifurcation should be to the left of the image. This orientation should then clearly indicate the appropriate direction of flow in the common carotid artery and jugular vein. The arterial and venous flow directions are then given color assignments with respect to flow towards or away from the transducer. Traditionally, flow towards the transducer is assigned red (common carotid) and flow away from the probe is assigned blue (jugular vein). The direction of flow relative to the probe will change if the probe is rotated 180° or if the color box is steered in the opposite direction, i.e. the vein will appear red whereas the artery will appear blue. When this occurs, the color should be changed back to the original assignment to avoid confusion. It must also be noted that the color will change along the course of an artery if the flow direction varies throughout the cardiac cycle (triphasic, to-and-fro) or if the vessel changes direction relative to the orientation of the sound beam.

2 The zero baseline of the color bar (PRF) is set at approximately two-thirds of the range with the majority of frequencies allowed in the red direction (for flow towards the brain). This setting allows you to display higher arterial mean frequency shifts (velocities) without aliasing artifacts. You should make allowance for some flow in the reverse (blue) direction to allow for changes in flow direction (i.e. ICA bulb, post-stenotic dilatation). When the transducer is rotated 180°, the color will change (note point 1 above) and the zero baseline will shift with the color changes to accommodate flow in the forward direction. You will need to adjust both the color assignment and the zero baseline to the initial set-up for consistency.

3 The color PRF and zero baseline may need to be readjusted throughout the examination to allow for the changes in velocity that occur with tortuousity and stenosis. It is important to adjust the PRF in the following situations:

Examination of the carotid bulb –
The color differentiation scale should be set to detect and clearly visualize the slower flow in the boundary separation zone. The range (PRF), however, may need to be set higher to detect increased velocities in the region adjacent to the flow divider.

In the presence of stenosis –
The color PRF should be increased to display the high velocities and to avoid aliasing.

In the post-stenotic zone –
The color PRF should be decreased to observe the lower velocities and flow direction changes, if any, found in the region of turbulent flow just distal to the stenosis.

When bruits are encountered –
The color PRF should be decreased to detect the lower frequencies associated with a bruit. Usually, the frequency of these bruits is less than 1 kHz.

When occlusion is suspected –
The color PRF should be decreased to detect the pre-occlusive, low velocity, high resistance signal associated with critical stenosis or occlusion and to confirm absence of flow at the site of occlusion.

4 The color wall filter should be set as low as possible. You should note that the color wall filter may automatically increase as you increase the PRF. You may need to decrease the wall filter manually when you decrease the color PRF.

5 The ensemble length (color sensitivity) should be around 12 in systems where this is an adjustable control. You can increase the ensemble length in regions where you want more sensitive color representation. It is important to remember that the frame rate will decrease when the ensemble length is increased (see also point 8 below). There are no circumstances when the ensemble length would be decreased during an extracranial carotid duplex examination.

6 The angle of the color box should be changed to obtain the most acute Doppler angles between the scan lines and the direction of blood flow. This will result in better color display because of more suitable Doppler angles. The angle should always be equal to or less than 60°. Because linear array transducers are steered at angles of 90 and 70° from the center of the array, this may require a "heel–toe" maneuver with the transducer on the surface of the skin to adjust the position of the vessel within the color box. An alternative would be to change physically the orientation of the transducer 180°.

7 The desaturation of color from darker to lighter hues on the color bar indicates increasing Doppler frequency shifts, i.e. increasing velocities. Note that close to the zero baseline, the colors are the darkest. As the velocity increases, the color becomes lighter. You should select colors so that the highest frequency shifts in each direction are of high contrast to each other so that you can readily detect aliasing. For example, you could set the color selections so that low to high velocities are seen as dark blue to light green to aqua in one direction and red to orange to yellow in the opposite flow direction. Aliasing would then appear as aqua adjacent to yellow.

8 The frame rate should be kept as high as possible to capture the very rapid change in flow dynamics that occur with stenosis, especially in the region of the carotid bulb. Remember that frame rate is affected by:

PRF –
Frame rate decreases with decreasing PRF.

Ensemble length –
Increasing the color ensemble length will decrease the frame rate.

Width of the color box –
Increased width will decrease the frame rate.

Depth –
Deep insonation decreases frame rate.

9 The color box should be kept to a size that is adequate for visualizing the area of interest and yet small enough to keep the frame rate at a reasonable number, approximately 15 or more, to ensure adequate filling of the vessel. The frame rate is usually displayed in hertz on the monitor.

10 The color gain should be adjusted throughout the examination to detect the changing signal strength. If the color gain is not properly adjusted, some color information may be lost or too much color may be displayed. In this case, you will see color in areas where there should be no flow. The gain should initially be adjusted to an "over-gained" level, with color displayed in the tissue and then turned down until the tissue noise just disappears or is minimally present. This is the level at which all color images should be assessed. In situations where there is very low flow or questionable occlusion, an "over-gained" level may be advantageous to show any flow that might be present, e.g. total occlusion versus a near-occlusion or critical stenosis.

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