Arterial Imaging In Vascular Surgery

By

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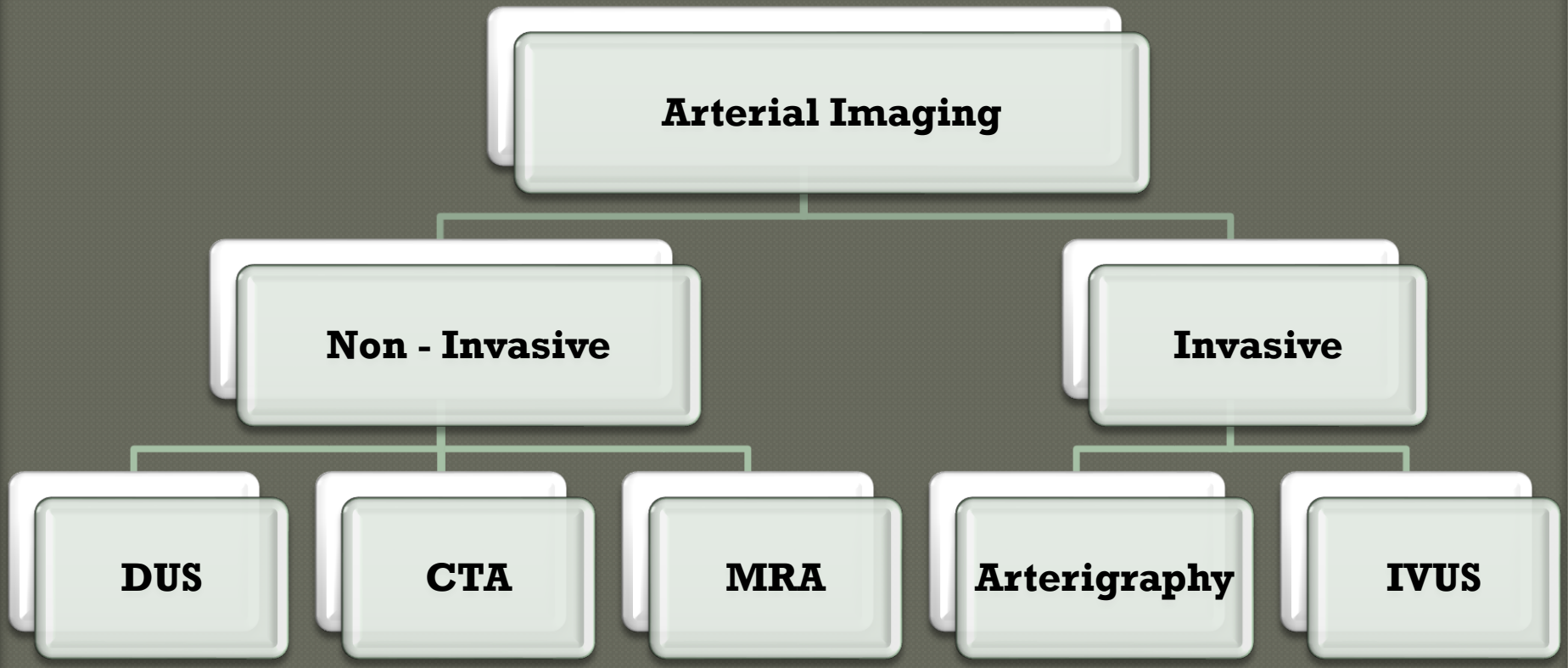
AGENDA


Arterial Imaging
Non - Invasive
Invasive
DUS
CTA
MRA
Arterigraphy
IVUS

DUPLEX ULTRASOUND (DUS)

- **Duplex ultrasound (DUS) is a type of diagnostic testing for the evaluation and management of arterial disease.**

- **It combines the acquisition of blood flow (pulsed Doppler spectral analysis) and anatomic (B-mode and color Doppler imaging) information.**

- **The initial clinical application used to assess the extracranial carotid artery bifurcation for the presence and extent of atherosclerotic plaque and developed velocity criteria to estimate internal carotid artery (ICA) stenosis.**

- **By the 1980s, clinical use of DUS rapidly expanded into peripheral arterial, visceral arterial, and peripheral venous applications.**

Patient Testing

- Arterial duplex scanning can be performed as a portable bedside or vascular laboratory examination.

- **Scanning should be :**

1. Conducted on a height-adjustable table or stretcher with a supine position.

2. A warm room temperature (75° F to 77° F) to avoid vasoconstriction of the extremities.

3. The typical examination time ranges from 30 to 60 minutes.

4. Stop tobacco use for at least 1 hour before the examination.

5. In abdominal or visceral artery testing, Fasting for 4 hours and should be performed in the morning to minimize accumulation of intestinal gas.

INSTRUMENTATION AND BASIC CONCEPTS:

DUS systems use transducers to convert electrical activity to mechanical energy (ultrasound) and vice versa, allowing to transmit and receive ultrasound signals to and from the patient to produce images of tissue anatomy as well as to characterize blood flow.

For carotid and peripheral testing linear array transducers with frequencies ranging from 5 to 12 MHz.

For visceral artery or abdominal imaging lower frequency transducers are needed because of the higher tissue attenuation; 2.5- or 3.5-MHz curved linear or phased array transducers are appropriate.

There are two types of Doppler ultrasound displays:

A. Color-flow Doppler :

shows the flow velocity distribution over a wide area displayed as a color-encoded map superimposed on the gray-scale B-mode tissue image.

B. Spectral Doppler:

shows the time-varying flow velocity distribution at a selected sample volume.

To obtain reliable information use Doppler angles of 60 degrees relative to the transducer insonation beam and arterial wall .

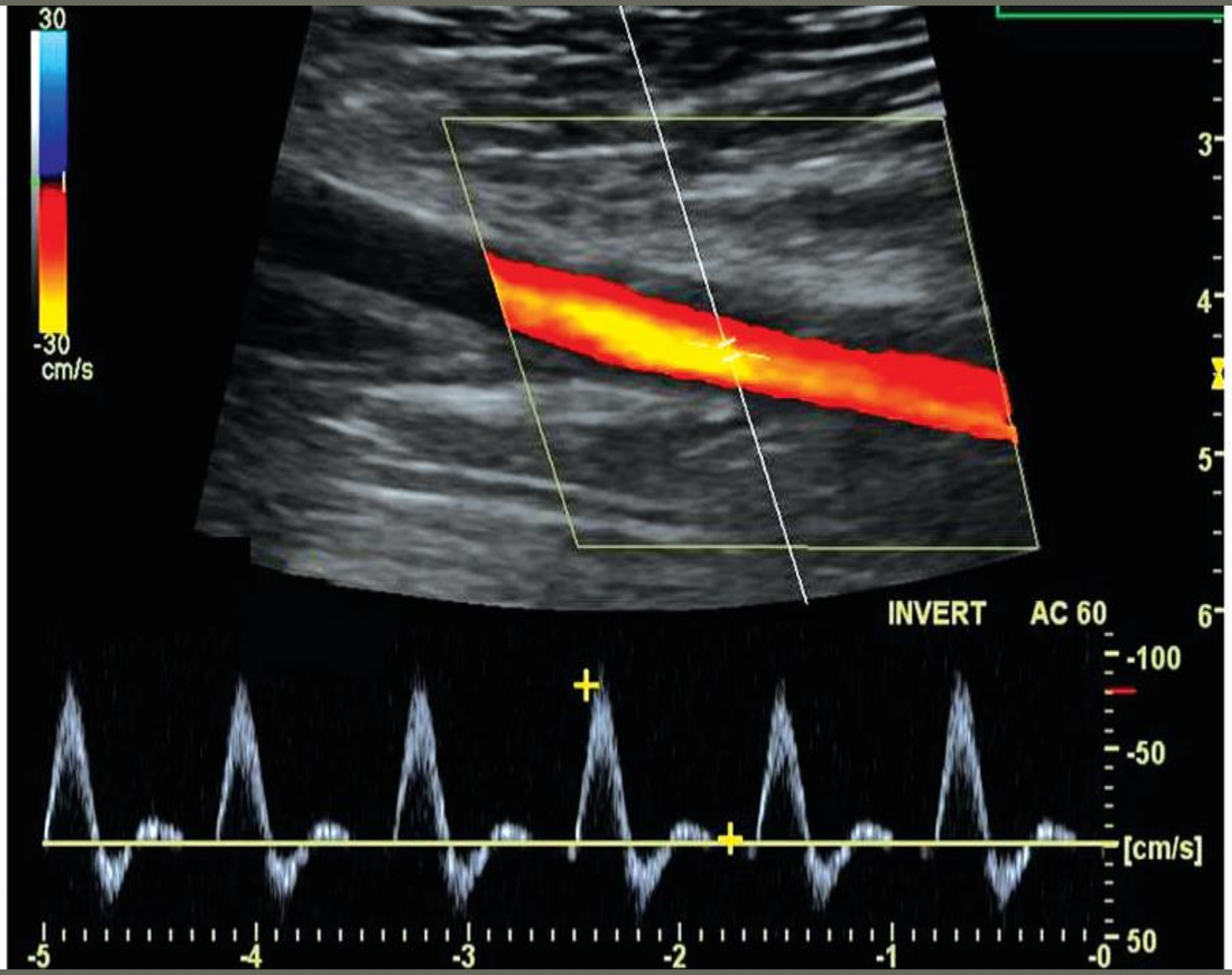
Blood Flow Imaging Techniques

A.Color Doppler Imaging

•Pixel encoding of blood flow based on a color bar that detect both flow direction (toward and away from the transducer) and mean velocity (MV) .

•When blood flow velocity exceeds the mean peak velocity threshold of the color bar, color aliasing "wrap around" occurs.

•Increasing the pulse repetition frequency and increasing the Doppler angle are two techniques that can be used to reduce the color-flow "aliasing" artifact.


30
-30
cm/s
3
4
5
6
INVERT
AC 60
-100
-50
[cm/s]
50
-5
-4
-3
-2
-1
-0

•Arterial stenosis is recognized as a **reduction** in the color-encoded flow lumen.

•At the site of a high-grade (>75% diameter reduction) stenosis, will appear as a whitened, color- desaturated **"flow jet".**

•The presence of **persistence of color aliasing**, and **changes in lumen diameter** on is indicative of abnormal flow patterns produced by **stenosis**.

•This diseased arterial segment examined with **pulsed Doppler spectral analysis** to measure changes in flow velocity, which are then used to estimate the severity of the stenosis.

B. Power Doppler Imaging

- It increases the sensitivity of flow detection three to five times with respect to color Doppler imaging.

- This mode is termed "color angio" and is used for imaging of small-diameter vessels, detection of slow flow, assessment of residual lumen diameter at a stenosis.

- Flow direction is not evident with the power Doppler imaging option, and the flow signal is less dependent on the Doppler angle.

C. B-Flow Imaging

- Shows blood flow in gray scale; that is, flowing blood and the surrounding structures are shown in shades of gray and no velocity information is provided.

- Relies on the amplification of weak echoes from moving red blood cells and is most useful in traversing atherosclerotic plaque.

- Can demonstrate the complex flow patterns seen at bypass graft anastomoses and arteriovenous fistulae and within dialysis access conduits, where color Doppler artifacts can obscure flow patterns.

D. Pulsed Doppler Spectral Analysis

- Velocity spectra recorded from a normal artery indicates that red blood cells are moving at a similar speed and direction in laminar flow pattern.

- If the "sample volume" of the pulsed Doppler is positioned adjacent to the arterial wall, it will be displayed as "broadening" or increased width of the velocity spectra.

Spectral broadening can also indicate "disturbed" flow or when it is recorded at bifurcations, regions of abrupt diameter change, and sites of stenosis

- **The "normal" appearance of arterial duplex flow varies with the artery being studied peripheral, carotid, renal, or mesenteric) but should demonstrate rapid systolic flow, narrow spectral width, and varied diastolic flow.**

- **The velocity spectrum of a normal peripheral (aorta, iliac,extremity, external carotid) artery is *triphasic* and consists of a systolic flow component, early diastolic flow reversal, and late diastolic forward flow.**

- **Arterial flow in the internal carotid, vertebral, renal, celiac, splenic, and hepatic arteries, is characterized by a single (systolic) phasic flow *monophasic***

Duplex Velocity Spectral Classification of Arterial Stenosis

By measuring changes in velocity proximal to and across stenosis, we can estimate its hemodynamic significance and predict reductions in diameter within specified ranges (e.g., 0% to 49% diameter reduction, ≥50%, 50% to 79%, ≥80%).

The ratio of PSV (Vr) across a stenosis used for grading the severity of a stenosis;
a Vr value ≥ 2 indicates ≥50% diameter reduction
value ≥ 4 indicate ≥ 75% diameter reduction
value 0 indicate total occlusion

CLINICAL APPLICATIONS

INDICATION

INTERPRETATION

TECHNIQUE

LIMITATION

Carotid Artery

Indications:

Results from two separate guidelines endorsed by SVS :

1. **Use of DUS as the *initial imaging modality for both asymptomatic and* symptomatic patients.**

2. Initial evaluation for patients with a carotid bruit and to observe known asymptomatic stenosis.

3. For screening carotid evaluation in patients with known PAD, IHD, or AAA.

Technique.

1. *A linear array transducer (5 to 10 MHz) is sufficient.*
2. **Assess IMT (normal, <0.8 mm), presence of atherosclerotic plaque (IMT >1.5 mm).**
3. **Accurate differentiation of the ICA from the ECA by :**

• location (the ICA is posterior and lateral to the ECA),

•Doppler flow resistance (the ICA has low resistance monophasic spectra, whereas the ECA has higher resistance multiphasic spectra)

•The presence of branches (the ECA has branches) .

4. **Atherosclerotic plaque features are evaluated.**
5. **Excessive calcification can limit assessment by blocking the ultrasound.**
6. **Notation of the carotid bifurcation relative to the angle of the mandible**

Table 16-2 Consensus Criteria for Interpretation of Carotid Duplex Imaging of Internal Carotid Artery Atherosclerotic Disease[11]

Disease Category (Diameter Reduction)	ICA PSV (cm/s)	ICA/CCA Ratio	ICA EDV (cm/s)	Plaque Imaging
Normal	<125	<2	<40	None
<50%	<125	<2	<40	IMT > 1.5 mm <50% DR
50%-69%	125-230	2.0 < 4.0	40-100	Present >50% DR stenosis
>70%	>230	>4.0	>100	>50% DR stenosis
Near-occlusion	May be low or undetectable	Variable	Variable	May show "trickle" flow
Occlusion	No flow	Not applicable	Not applicable	Occluded lumen

Limitations.

1. *Significant tortuosity result in* errors.
2. Recent surgery can limit imaging.
3. Contralateral severe stenosis or occlusion can falsely elevate ipsilateral velocities.
4. Proximal or distal lesions can prohibit accurate assessment of extracranial artery stenosis.
5. Overestimation of the degree of stenosis may be explained by angles >60 degrees.
6. Severe calcification may prevent accurate assessment of the entire lesion, potentially missing the greatest point of stenosis.

Peripheral Arteries

Indications:

1. Patients with chronic **PAD**.

2. Patients with suspected **acute limb ischemia**.

3. Patients with **pedal infection** without a palpable pulse.

4. Patients require **surveillance** after revascularization procedures.

5. Screening for **aneurysm**

Technique.

1. Scanning proceeds from proximal to distal, with notation of artery diameter, wall morphology& plaque or thrombus.

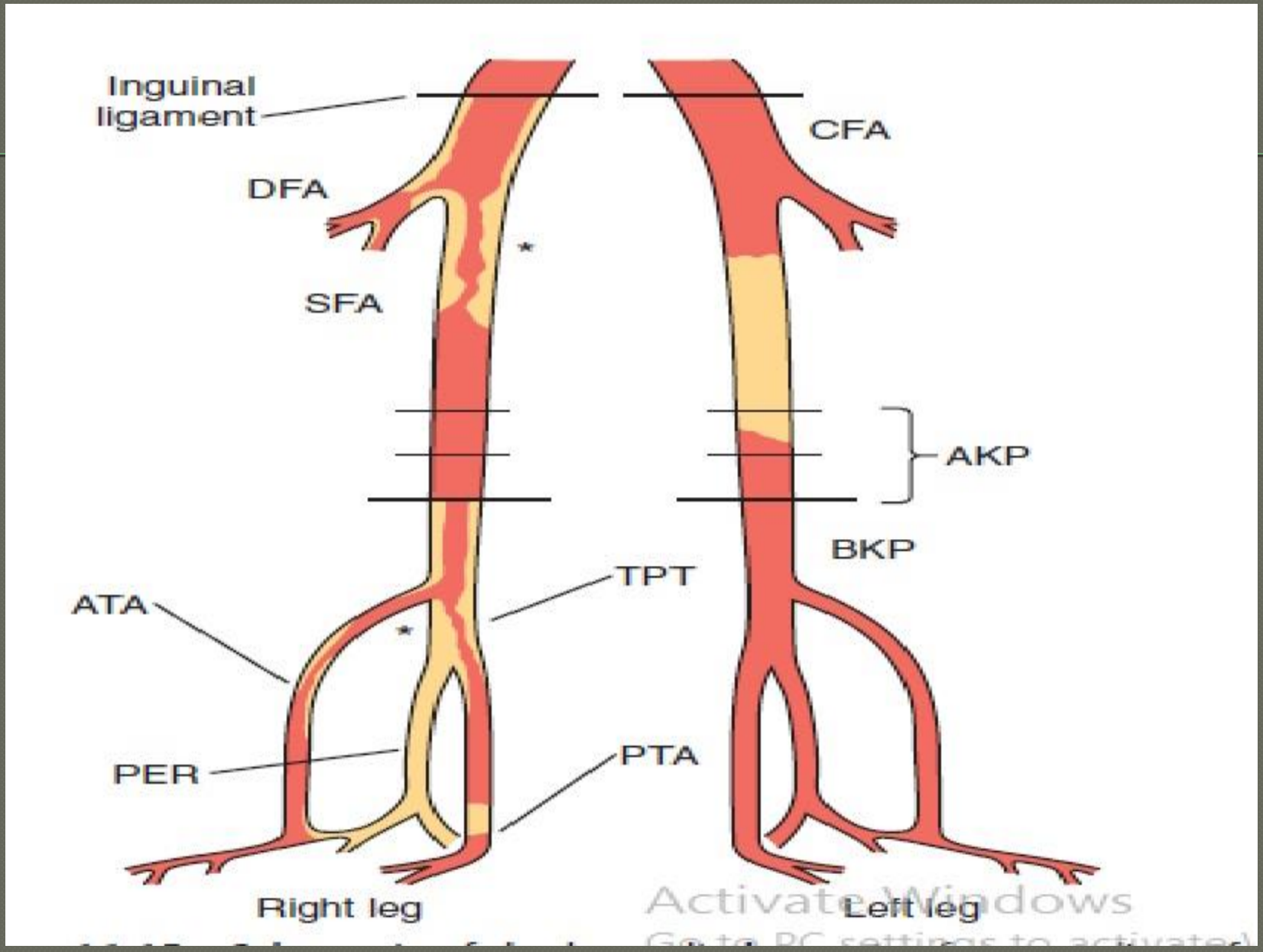
2. Abdominal imaging performed after fasting to minimize intestinal gas artifact.

3. L.L testing use (3- to 5-MHz phased, curvilinear, or linear array transducer) & should include imaging of the abdominal aorta and iliac arteries for aneurysm and occlusive disease.

4. From the inguinal ligament distally, a 5- to 7-MHz linear array transducer is used.

5. PSV and EDV should be reported.

6. The findings recorded in a schematic of the extremity arterial tree, analogous to an arteriogram.


Inguinal ligament
DFA
SFA
ATA
PER
TPT
PTA
Right leg
CFA
AKP
BKP
Left leg

Interpretation.

DUS allows classification of occlusive disease in aortoiliac, femropopliteal, and popliteal-tibial based on (TASC) guidelines

Standardized values for diameter and PSV in the L.L reported for healthy subjects under resting conditions.

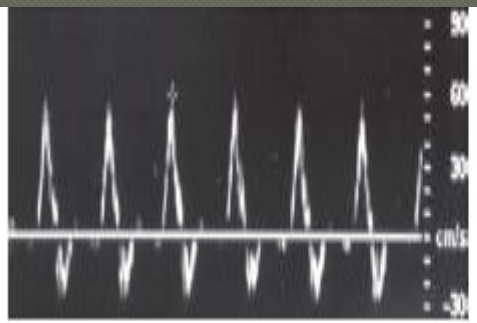
Table 16-4	Artery Diameters and Peak Systolic Velocities in Healthy Subjects	
Artery	**Diameter (cm)***	**Velocity (cm/s)***
Infrarenal aorta	2 ± 0.2	55 ± 12
Common iliac	1.5 ± 0.18	70 ± 18
External iliac	0.8 ± 0.13	115 ± 21
Common femoral	0.8 ± 0.14	114 ± 24
Superior femoral	0.6 ± 11	90 ± 14
Popliteal	0.5 ± 0.1	68 ± 14
Tibial arteries	0.3 ± 0.4	55 ± 10

*Values are means ± standard deviation.

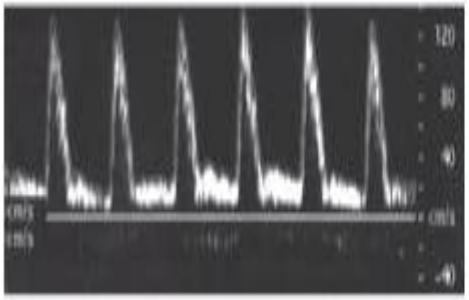
Table 16-5 Duplex Classification of Peripheral Artery Occlusive Disease[61]

Stenosis Category	Peak Systolic Velocity (cm/s)	Velocity Ratio (V_r)	Distal Artery Spectral Waveform
Normal	<150	<1.5	Triphasic, normal PSV
30%-49%	150-200	1.5-2	Triphasic, normal PSV
50%-75%	200-400	2-4	Monophasic, reduced PSV
>75%	>400	>4	Damped, monophasic, reduced PSV
Occlusion	No flow; length of occlusion estimated by distance from exit and reentry collaterals		Damped, monophasic, reduced PSV

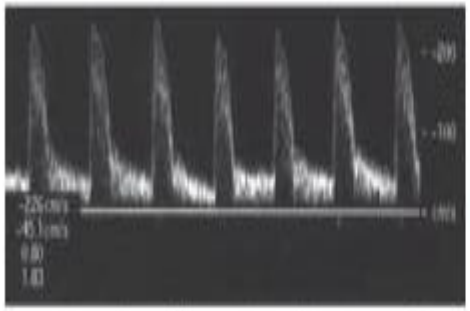
PSV, Peak systolic velocity.



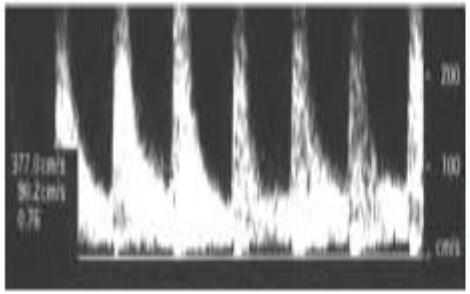
Normal, no stenosis, no plaque



PSV <150 cm/sec, V_r >1.5
<20% stenosis



PSV 200–300 cm/sec; V_r >2
>50% stenosis



PSV >300 cm/sec, EDV ≥40–100 cm/sec; V_r >4
>75% stenosis

Limitations.

1.For aortoiliac segment, body habitus is the main limitation.

2. For infrainguinal stenosis, the major limitation is presence of proximal stenosis, which falsely decrease distal velocities.

3. Incomplete vessel imaging may occur as a result of patient poor cooperation or acoustic shadowing caused by plaque calcification.

4. Arterial segments difficult to image include the proximal external iliac artery, internal iliac origin, and tibioperoneal trunk.

Aneurysms

Indications:

1. **Screening** of patients high risk for aneurysm
2. evaluation of patients with symptoms potentially attributable to aneurysms.
3. Patients with **pulsatile masses** in the carotid or peripheral artery should be evaluated for the presence of aneurysms.

Technique.

1. A transducer with 1- to 5-MHz used for aortoiliac segment in transverse and longitudinal planes with B-mode.

2. The suprarenal, infrarenal, bifurcation, and iliac arteries imaged perpendicular to their centerline.

3. Diameters in anteroposterior and transverse projections are recorded with assessment of presence of mural thrombus.

4. Color flow is then used to determine the degree of mural thrombus present.

5. C/S image for measurement of maximum diameter.

6. Carotid and peripheral artery aneurysms can be assessed with higher frequency probes.

Interpretation.

1. **Maximum aneurysm diameter** should be reviewed with confirmation of **adventia-adventia** measurements perpendicular to the centerline axis.

2. Aneurysm report of (abdominal aorta, iliac, femoral, popliteal) should include a description of its **morphology** (saccular versus fusiform) **extent** and of the presence of **mural thrombus** or **dissection**.

Limitations.

1. **Tortuous anatomy** lead to inaccurate dimensional measurements.

2. In abdomen, the presence of **bowel gas** and **obesity** can decrease image quality.

3. Interobservational **differences** with ultrasound or CT imaging are generally **≤ 2 mm** but can be up to 5 mm.

4. **Inflammatory aneurysms** may also have poorly defined tissue definition, and adventitia-to-adventitia measurements can be obscured.

Mesentric Arteries

Indications:

1. Screen patients with "abdominal angina," weight loss, and sitophobia (fear of food) for occlusive visceral artery disease with suspected acute or chronic mesenteric ischemia or ischemic colitis

2. Patients with abdominal pain should be assessed for a hemodynamically significant visceral lesion.

3. Patients are often evaluated preoperatively before liver transplantation.

Technique.

1. 2- to 5-MHz curvilinear array transducer is used.

2. Supine position in a fasting patient typically recommended.

3. Transverse and sagittal planes are used while the probe is placed just inferior to the xiphoid process.

4. The origins of celiac and SMA are best seen in sagittal view, with the major celiac branches (hepatic, splenic, and left gastric) viewed from a transverse imaging plane.

5. Assessment made in both gray scale and color Doppler & PSV and EDV should be recorded.

Interpretation.

BOX 16–1

MESENTERIC DUPLEX CRITERIA FOR NORMAL AND STENOTIC CELIAC, SUPERIOR MESENTERIC, AND INFERIOR MESENTERIC ARTERIAL FLOW[100,105]

NORMAL

Celiac: PSV = 90–110 cm/s; low-resistance flow pattern

SMA: PSV = 95–150 cm/s; high-resistance flow pattern in the fasting state with an EDV > 0 after a meal

IMA: PSV = 90–180 cm/s; high-resistance flow pattern

DIAGNOSTIC TESTING (FASTING)

<70% Stenosis

- Celiac: PSV <200 cm/s, EDV <55 cm/s; resistive index similar to that of the ICA
- SMA: PSV <300 cm/s, EDV <45 cm/s with diastolic flow reversal in the distal SMA
- IMA: PSV <200 cm/s with antegrade resistive flow (like the SFA)

>70% Stenosis

- Celiac: PSV >200 cm/s, EDV >55 cm/s with retrograde hepatic artery flow and severe stenosis or celiac artery occlusion
- SMA: PSV >300 cm/s, EDV >45 cm/s with loss of diastolic flow reversal
- IMA: PSV >200 cm/s, antegrade flow with loss of diastolic flow reversal

Mesenteric-aortic ratio >3

Velocity spectra changes with a test meal

- Increase in PSV at sites of stenosis with damping of the distal waveform—used most frequently to assess the significance of occlusive SMA disease

EDV End-diastolic velocity; ICA, internal carotid artery; IMA, inferior

Limitations.

1. Anatomic variants of the mesenteric circulation, present in up to 20% of patients, can contribute to interpretation errors.

2.Body habitus and overlying bowel gas can obstruct view of the vessels and underlying structures, limiting the evaluation.

Renal Arteries

Indications:

1. **Early-onset hypertension (<35 years of age).**

2. **ARF with aortic dissection.**

3. **Unexplained size discrepancy between kidneys (>1.5 cm difference).**

4. **Patients with malignant or resistive hypertension or worsening chronic hypertension.**

Technique.

1. In morning after an overnight fast to minimize intestinal gas and to provide optimal conditions for imaging.

2. In the supine position with the head slightly elevated 20 degrees, which allows the viscera to descend in the abdomen.

3. A midline scanning, 3- to 5-MHz abdominal transducers are used to identify aorta, (SMA), and proximal renal arteries.

4. Patients raise their arms over the head elevates the ribs and improves transducer access for imaging of the renal arteries.

5. Aorta is scanned from the level of the diaphragm to the origins of the iliac artery.

Technique.

6. Identification of celiac artery and SMA arising anteriorly helps in locating the **renal artery origins**.

7. Transverse color imaging of aorta at level of SMA will locate the **anteriorly positioned left renal vein** and the proximal right and left renal arteries arising below the SMA takeoff and slightly posterior to the aorta.

8. The course of the **right** renal artery is **posterior to the inferior vena cava.**

9. Use of color or power Doppler helps trace the renal artery course for **velocity spectral recording** along its length to the extent possible.

Interpretation.

Table 16-7 Duplex Criteria for Classification of Renal Artery Stenosis[90]

Classification	RAR	PSV	PST
Normal	<3.5	<120 cm/s	Absent
<60% stenosis	<3.5	>180 cm/s	Absent
>60% stenosis	>3.5	>180 cm/s	Present
Occlusion	N/A Low-velocity, low-amplitude parenchymal signals	N/A	N/A

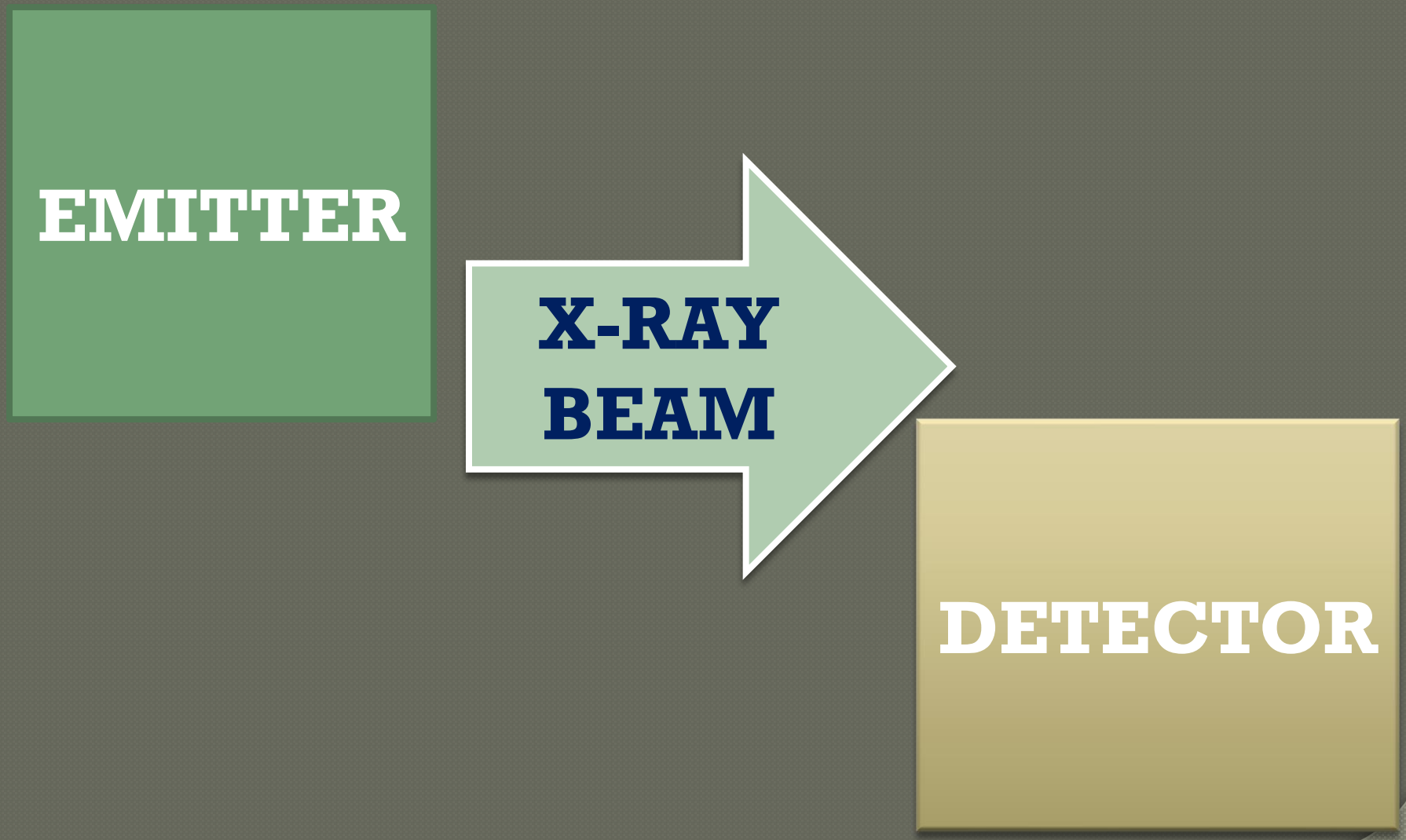
RAR, Renal-aortic velocity ratio; *PSV*, peak systolic velocity; *PST*, post-stenotic signal; *N/A*, not applicable.

Limitations.

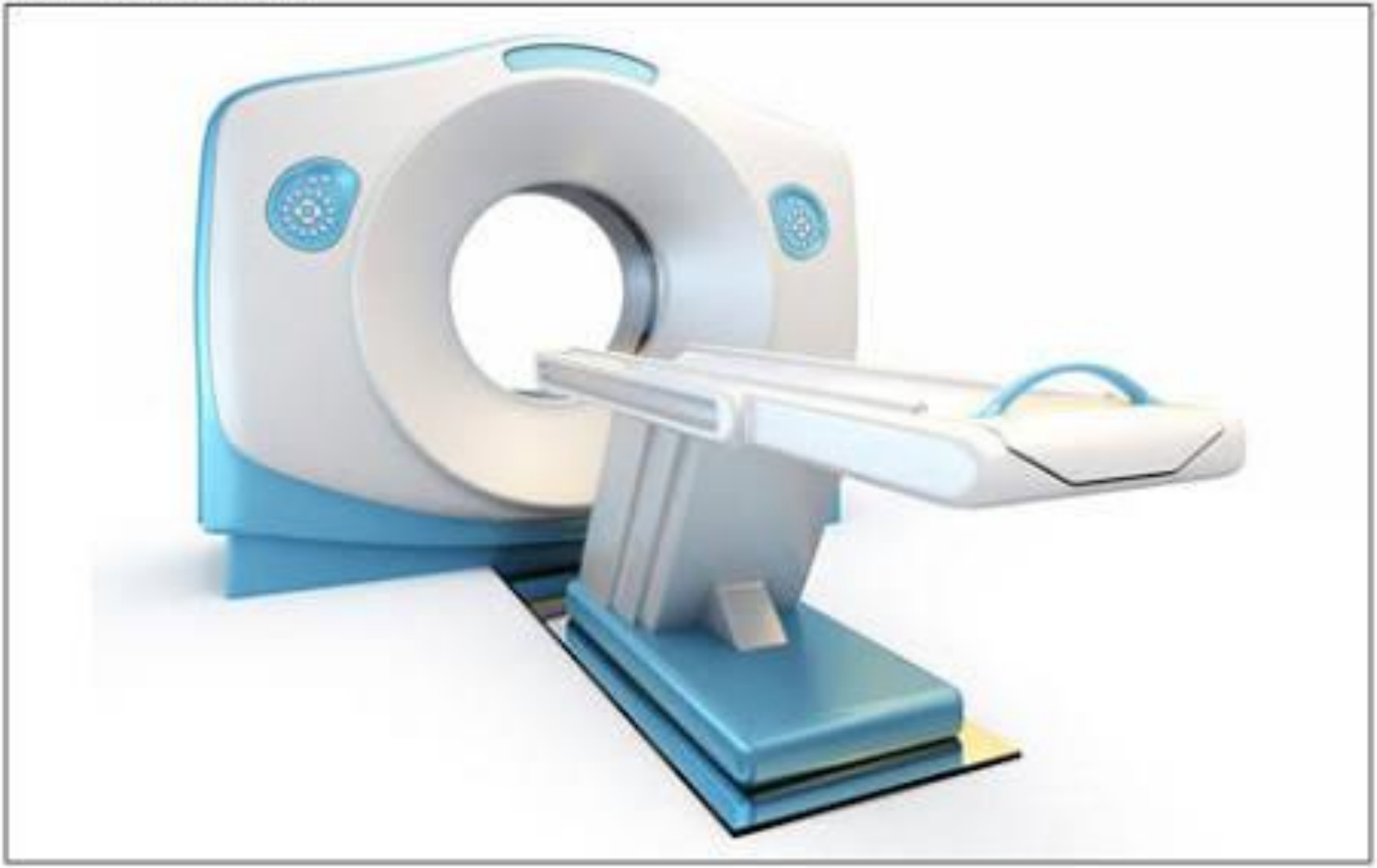
1. **Body habitus** and bowel gas can compromise imagingquality and therefore examination accuracy.

2. **Multiple renal arteries** can exist, and missing the main renal artery can provide misleading results.

COMPUTED TOMOGRAPHY



CT scanner

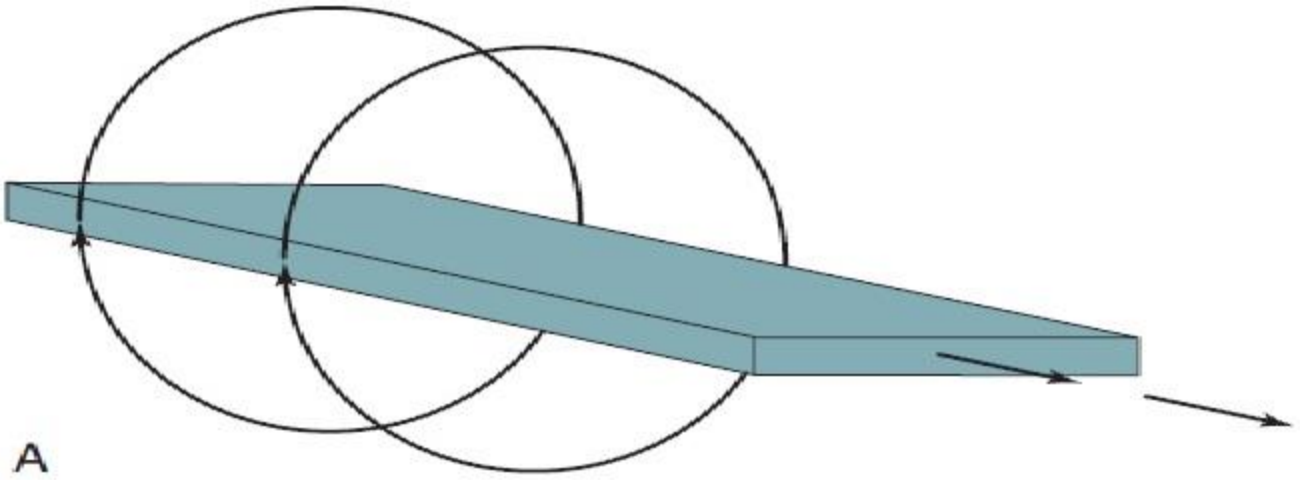


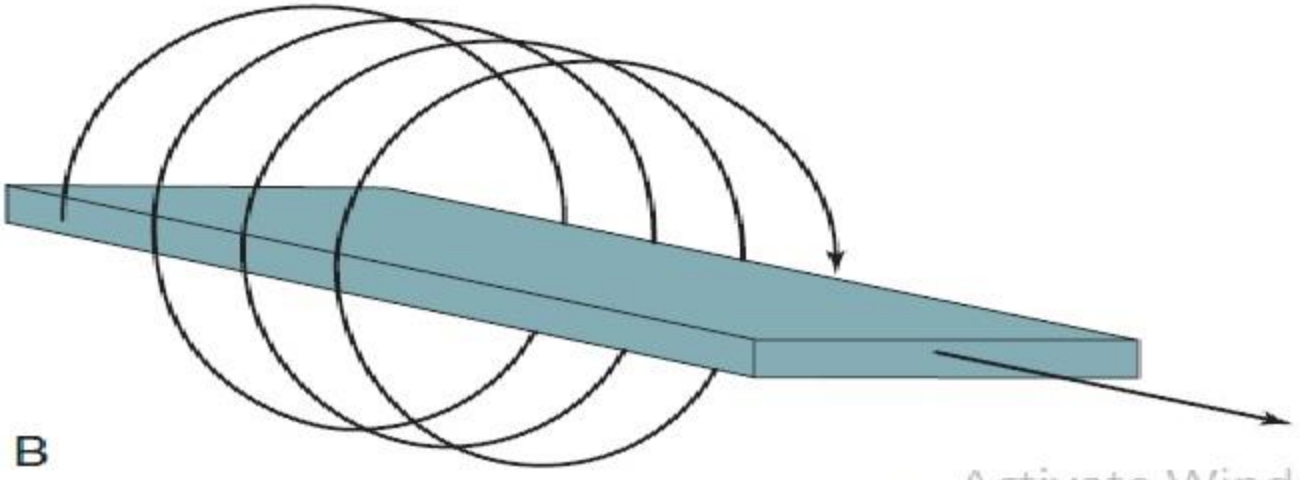
Types of Scanners

Single-Slice Sequential Conventional CT

Spiral (Helical) CT

Multislice (Multidetector) CT





Conventional CT (**A**) versus spiral CT (**B**)

CT Angiography

1. Visualization of vessels on CT is limited due to similar densities of blood and soft tissue.
2. Administration of IV contrast can overcome problem .
3. Optimal visualization of vessels [CTA] was not possible until the availability of spiral CT.
4. The main advantage of spiral CT Is fast scanning allows visualization of the vessels during the short period that a bolus of contrast passes the imaged volume.
5. Fast scan times and increased numbers of detectors will allow a larger part of the body to be image.
6. Timing of initiation of image acquisition relative to contrast injection is crucial for maximizing opacification of vessels in the scanned volume

CLINICAL APPLICATION

The most common noncardiac, nonbrain vascular imaging indications for CTA are :

1. Aortic disease (aneurysm, dissection,trauma)
2. Peripheral arterial occlusive disease PAOD.
3. Renovascular disease.
4. Venous disease.
5. Rarely, vascular malformations.

Aortic Disease

CTA is the primary imaging modality for aortic disease.

1. **Excellent resolution and 3D image** for preoperative planning of EVAR & postoperative follow-up.

2. **Imaging of small branches** as intercostal arteries (important for prevention of spinal cord infarction during thoracic aortic repair)

3. CTA **acquisition speed** allows accurate imaging of aorta in **acute cases** such as ruptured aneurysm, aortic dissection, and trauma.

4. Advantage of CTA over MRA is ability to **image calcium**.

5. CTA is preferred over MRA when endovascular devices are in place because **metal artifacts** are rarely a problem.

PAOD

Advantage:

1. CTA can image the arterial tree from aorta to pedal vessels in a single acquisition run.

2. Planning for open and endovascular intervention.

3. Differentiate occlusion from high-grade stenosis.

4. Accurate in imaging tibial artery runoff.

Disadvantage:

1. interpretation of CTA images in small arteries hardly diff between calcium and contrast.

2. Overestimation of severity of a calcified stenosis .

Venous Disease

Advantage:

1. CT is an excellent modality to evaluate a variety of venous pathologies, including MVT.

2. Proper injection protocol with sufficient delay is chosen.

3. Evaluation and detection of pulmonary emboli, CT has replaced lung perfusion and ventilation studies.

Disadvantage:

❖ For peripheral evaluation of venous disease (in legs, iliac veins, subclavian veins), the optimal imaging modality is still duplex ultrasound because this also provides essential flow information.

LIMITATIONS AND RISKS

1. Radiation Dose

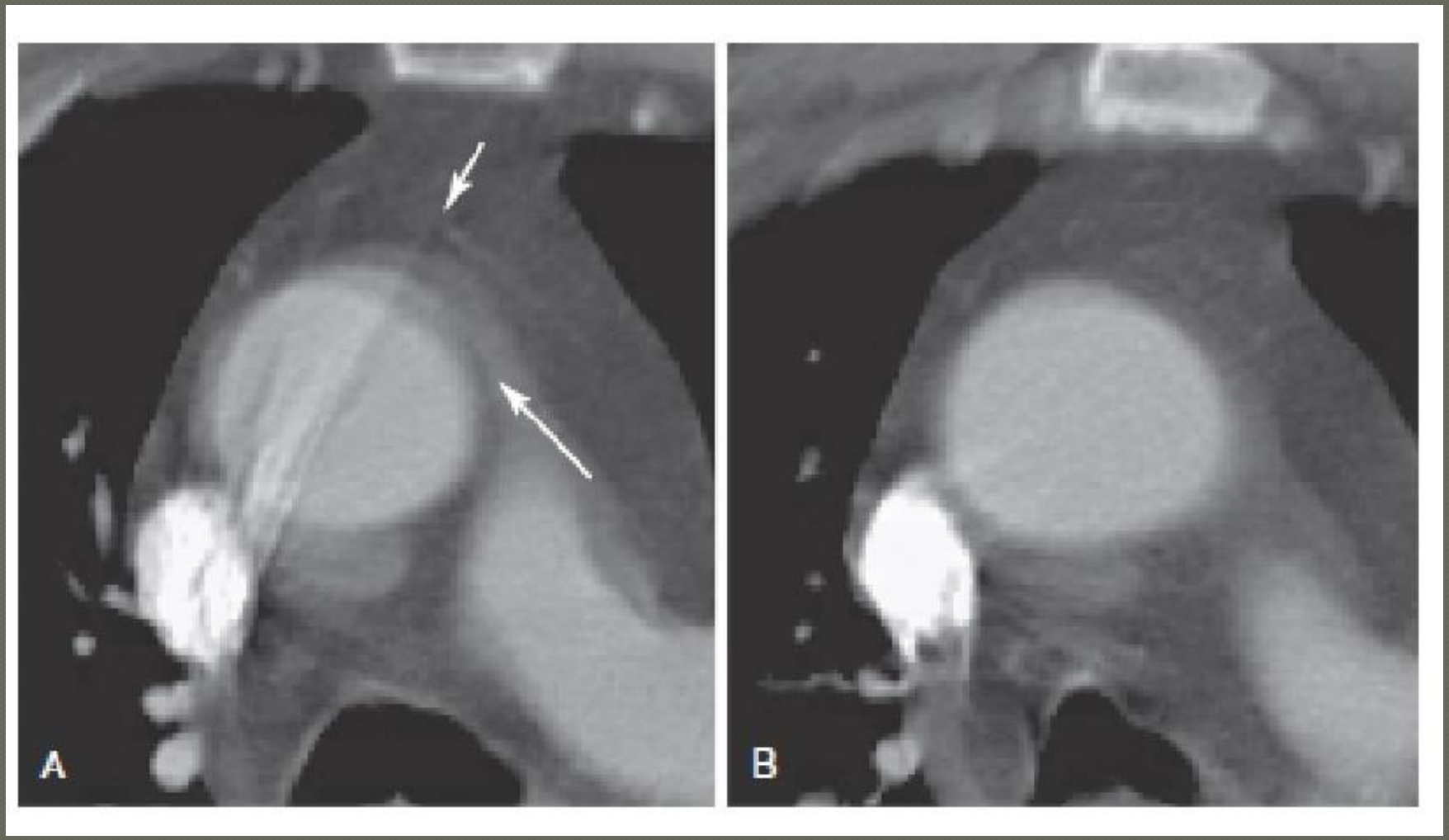
2. Contrast-Induced Nephropathy

3. Beam-Hardening Artifacts (Metal)

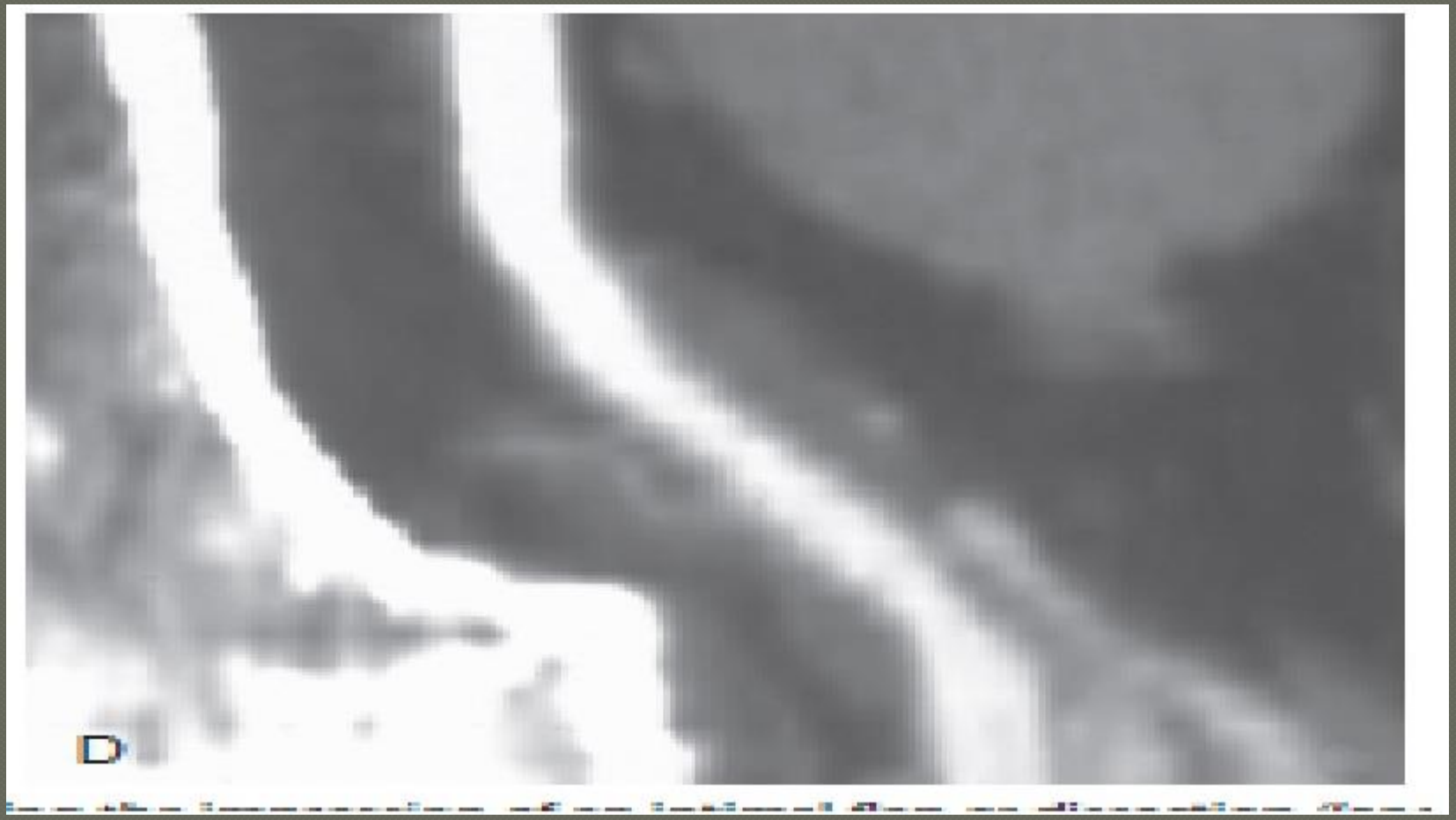
4. Motion Artifacts (Patient Move & Resp)

5. Stair-step artifact (reconstruction interval on a spiral CT scan is too large

6. Averaging artifact ("missing" a small vessel because of surrounding soft tissue and collimation)



Motion Artifacts



Stair-step artifact

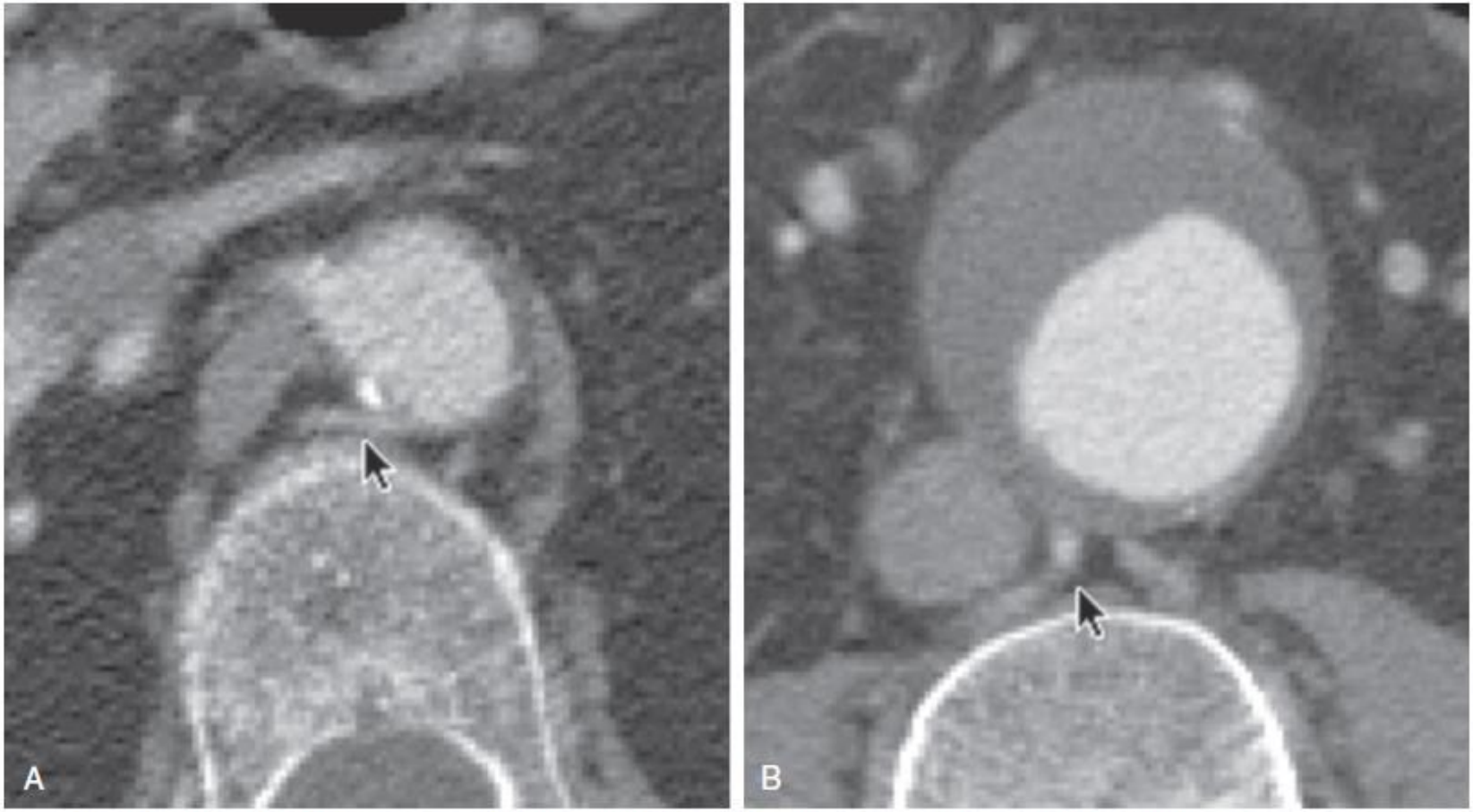
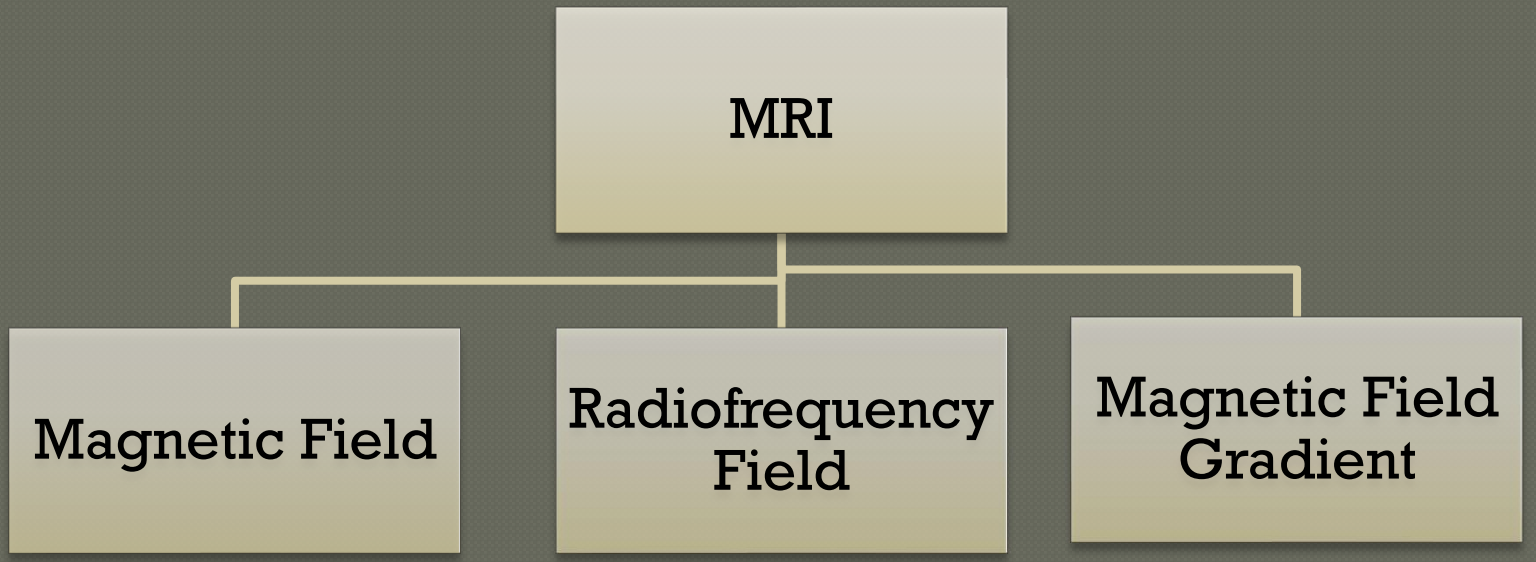


Figure 22-14 Clinical example of the effects of collimation for the display of small vessels. **A,** A small lumbar artery is seen easily in a CT slice at a location where the collimation is 3 mm *(arrow)*. Its contrast density is similar to that of the aorta. **B,** This larger lumbar artery *(arrow)* should be more prominent relative to the contrast within the aortic lumen, but at this location the collimation is 7 mm. With 7-mm or thicker collimation, a small lumbar artery or a small accessory renal artery can easily be missed.

Averaging artifact and Collimation

Magnetic Resonance Imaging



Characteristics of MR Images:

- MR images depends on the character of object being imaged and the sequence itself.

- Images are either T1 weighted or T2 weighted.

- T2-weighted images display simple fluids as urine, bile, and CSF, as bright and other tissues as lower signal but is not used for angiographic imaging.

- T1-weighted images display fat, methemoglobin, flow effects, and MRI contrast agents as bright.

- MRA and (MRV) are performed with T1-weighted image.

Characteristics of MR Images:

- The sequence refers to combination of RF and gradients.
- Sequences variation are spin-echo or gradient-echo.
- Spin-echo methods use RF alone to produce the signal.
- Gradient-echo use RF and gradients to produce signal.
- As a rough generalization,
  - ✓Spin-echo produce T2-weighted images
  - ✓Gradient-echo create T1-weighted images.

MRA

Non–Contrast-Enhanced MRA (time of flight (TOF)

- TOF uses a rapid T1-weighted sequence.
- When data are gathered rapidly, the protons within the slice lose much of their magnetization.

- Thus, there is much less signal from protons, and the corresponding tissues are not well seen.

- Fully magnetized protons in a vessel produce much greater signal than surrounding tissue appear much brighter than surrounding tissue.

- New technique uses electrocardiographic gating and subtracts diastolic from systolic images, leaving signal only in arteries.

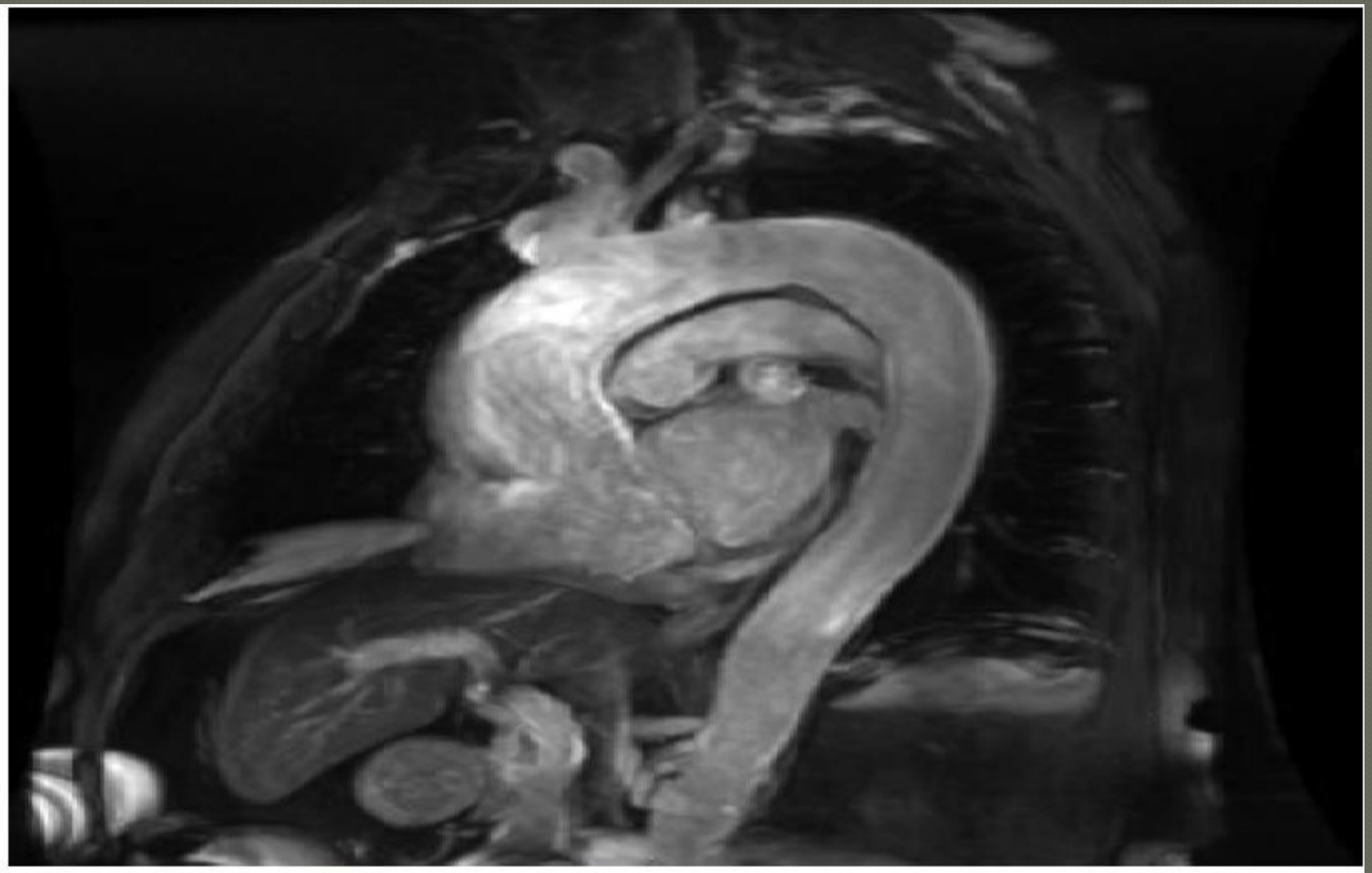


Figure 23-1 Oblique sagittal non–contrast-enhanced steady-state free precession MR angiogram of the thoracic aorta. The signal from flowing blood appears bright.

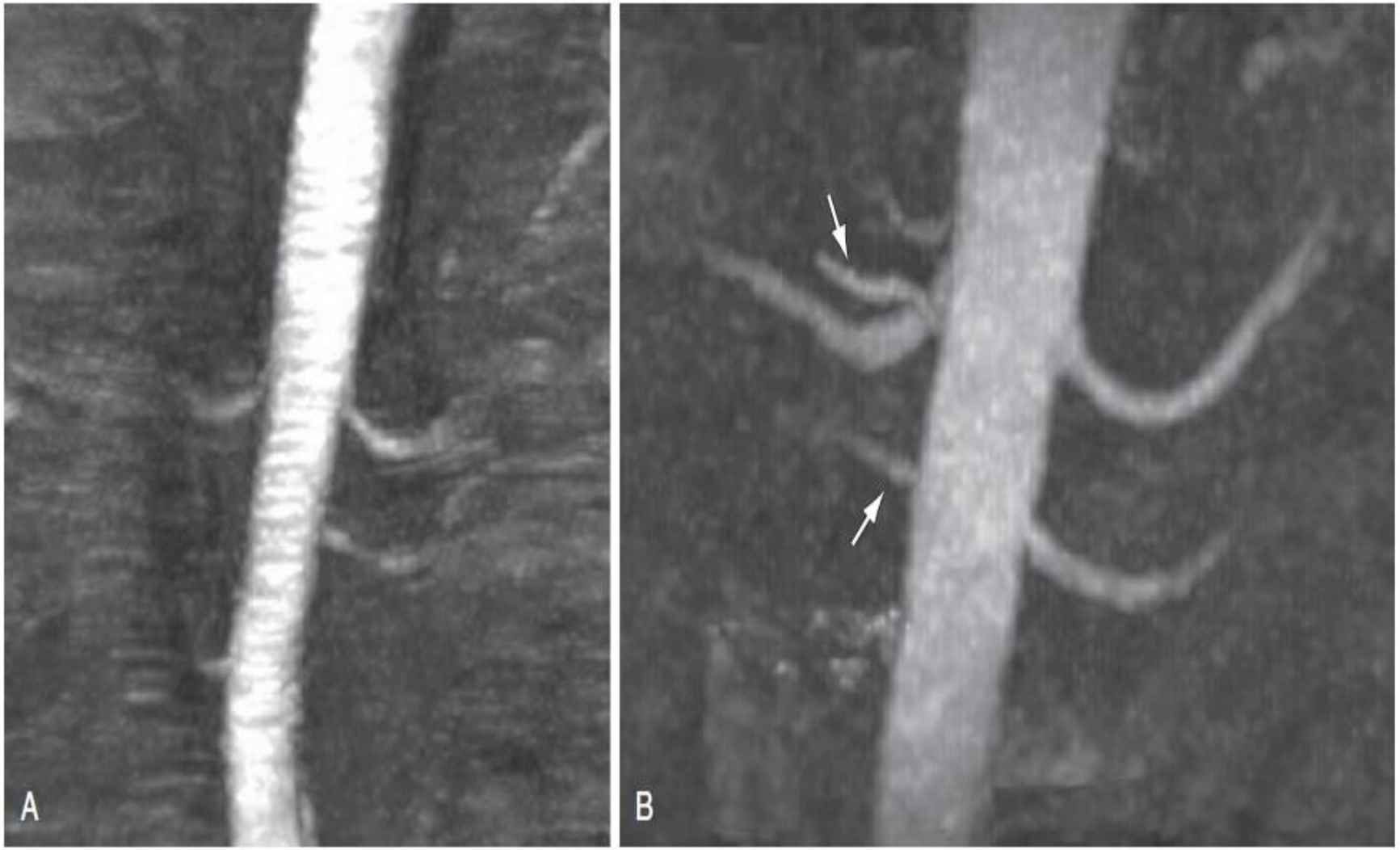


Figure 23-2 **A,** Coronal maximum intensity projection of time-of-flight MRA of the renal arteries. **B,** Coronal maximum intensity projection of non–contrast-enhanced MRA acquired with a newer method that uses electrocardiographic gating to subtract diastolic from systolic images, leaving only arterial systolic flow. Note markedly improved visualization of accessory right renal arteries compared with time-of-flight technique *(arrows).*

Contrast-Enhanced MR Angiography

- **MR contrast agents approved by (FDA) include several in which gadolinium combined with another substance to avoid release of toxic free gadolinium into the body.**

- **Differences between MR contrast agents and iodinated contrast material used for (CTA),**

  - ✓ **First, MRI is designed not to image the agent but to image its effect on protons in the surrounding water so a very small amount of MR contrast material may be detected by its effect on multiple water molecules.**

  - ✓ **The second is decreased nephrotoxicity and a lower incidence of reactions to the contrast agent.**

Step-Table MR Angiography

- Imaging a large volume, as from aorta to peripheral runoff study, acquisition of data from the entire volume of interest is impractical and decrease image quality.

- So use a steptable acquisition in which anatomy of interest are imaged sequentially, with the scanner table moving between stations to place the specific anatomy of interest near the isocenter of the magnet.

- A peripheral runoff study may include four step-table stations—abdomen/pelvis, thighs, calves, and feet—each imaged with a specific coil.

CLINICAL APPLICATION OF MR ANGIOGRAPHY

The most common vascular imaging indications for MRA are :

1. **Renovascular disease.**
2. **Peripheral arterial occlusive disease PAOD.**
3. **Carotid Vascular Disease**
4. **Aortic Vascular Disease**
5. **Mesenteric Vascular Disease**

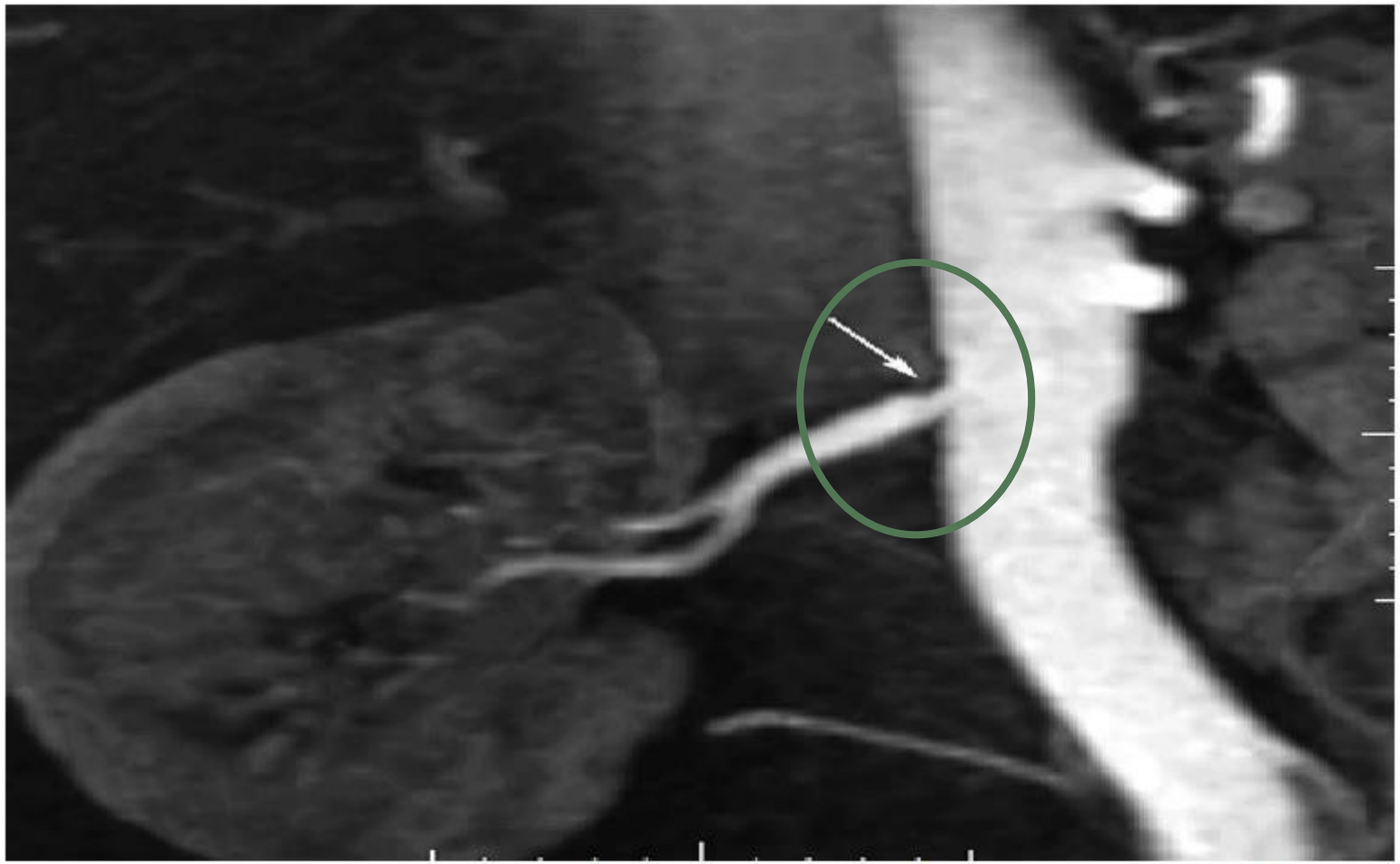
Renovascular Disease

- For evaluation of renovascular disease, 3D gadolinium enhanced MRA has become a clinical standard.

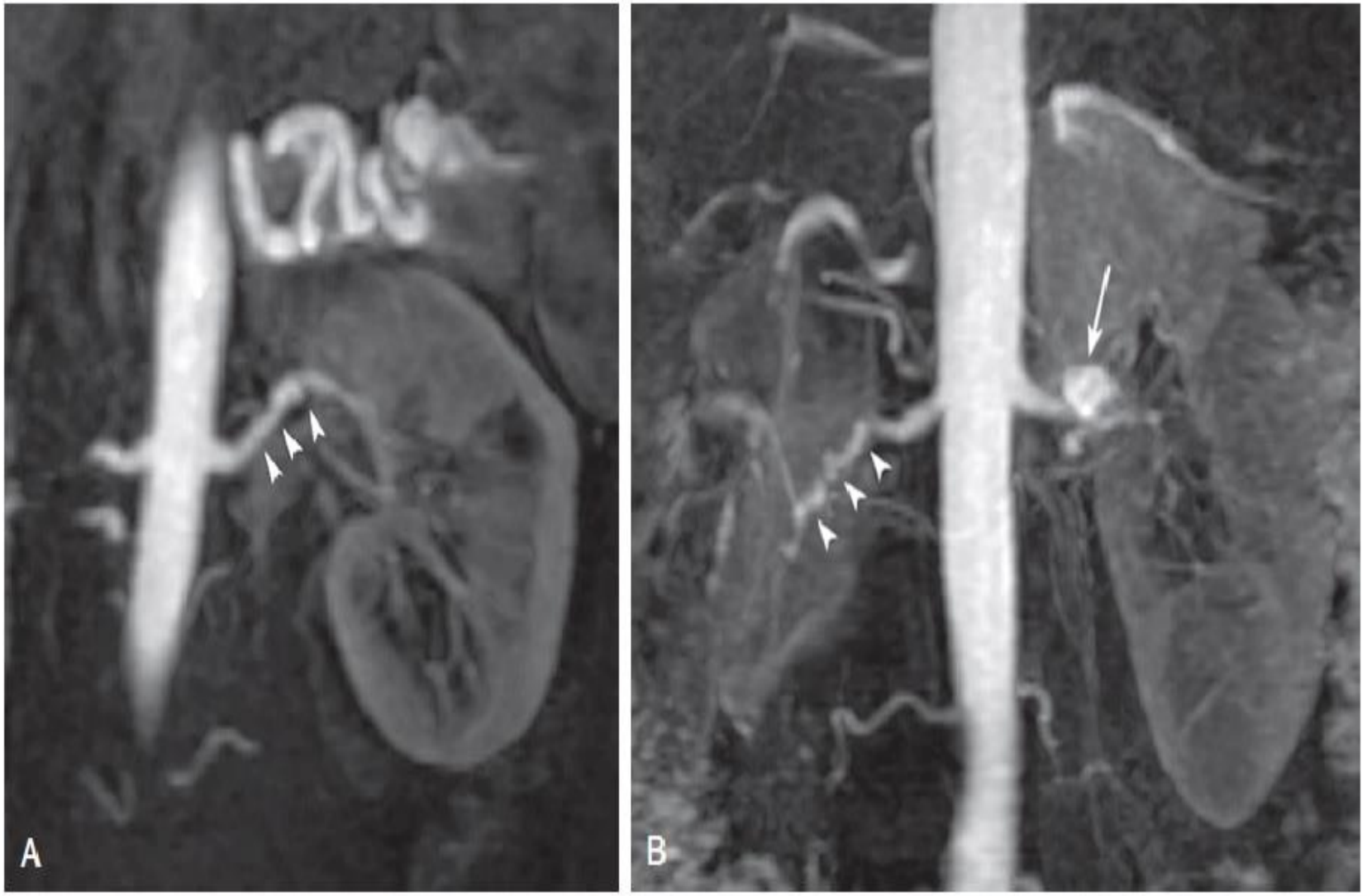
- Most common is atherosclerotic renal artery stenosis.

- MRA evaluating more subtle renal vascular conditions, Such fibromuscular dysplasia, renal artery aneurysms, and accessory renal arteries.

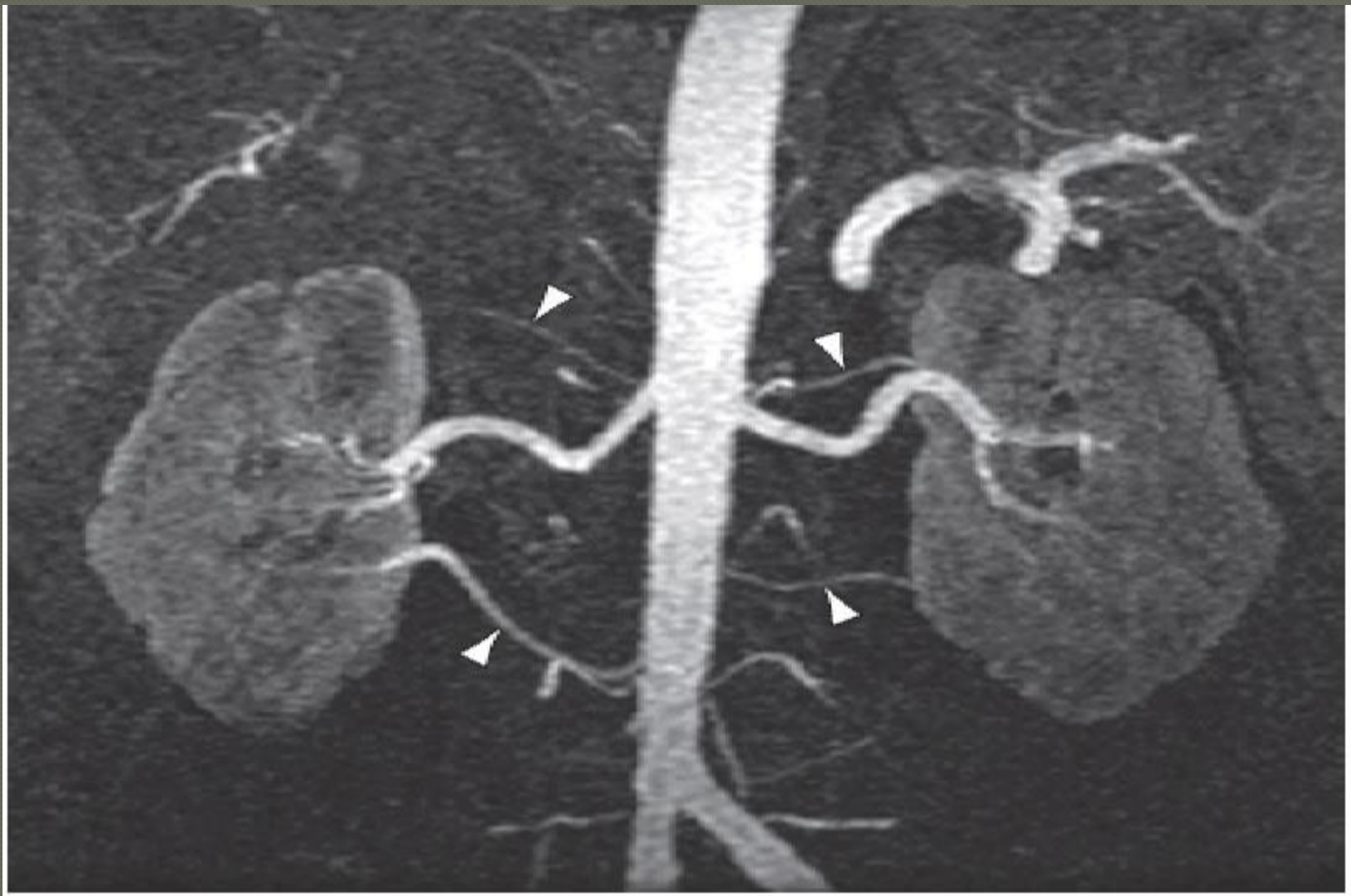
- Detection of accessory arteries is particularly important for assessment of potential living renal donors



Coronal 3D MR angiogram showing an ostial renal artery plaque *(arrow)*.



A, Coronal 3D MR angiogram showing subtle fibromuscular dysplasia *(arrowheads)*. Note that the disease is isolated to the dist portion of the main renal artery. **B,** Coronal 3D MR angiogram showing right-sided fibromuscular dysplasia *(arrowheads)* and a left-sided ren artery aneurysm *(arrow)*. Renal artery aneurysms may occur in patients with fibromuscular dysplasia.



Coronal 3D MR angiogram showing two main renal arteries and four accessory arteries *(arrowheads)*. Note that the accessory arteries may enter the renal hilum or perforate the cortex.

Peripheral Vascular Disease

✓ MRA is a method for evaluation of PAD.

✓ Improvement in step-table examination have increased speed and resolution of the examination.

✓ This allow improve in visualization of smaller distal vessels and permitted arterial-phase dedicated imaging of the feet.

✓ MRA may be superior to DSA for the evaluation of distal vessels in some cases.

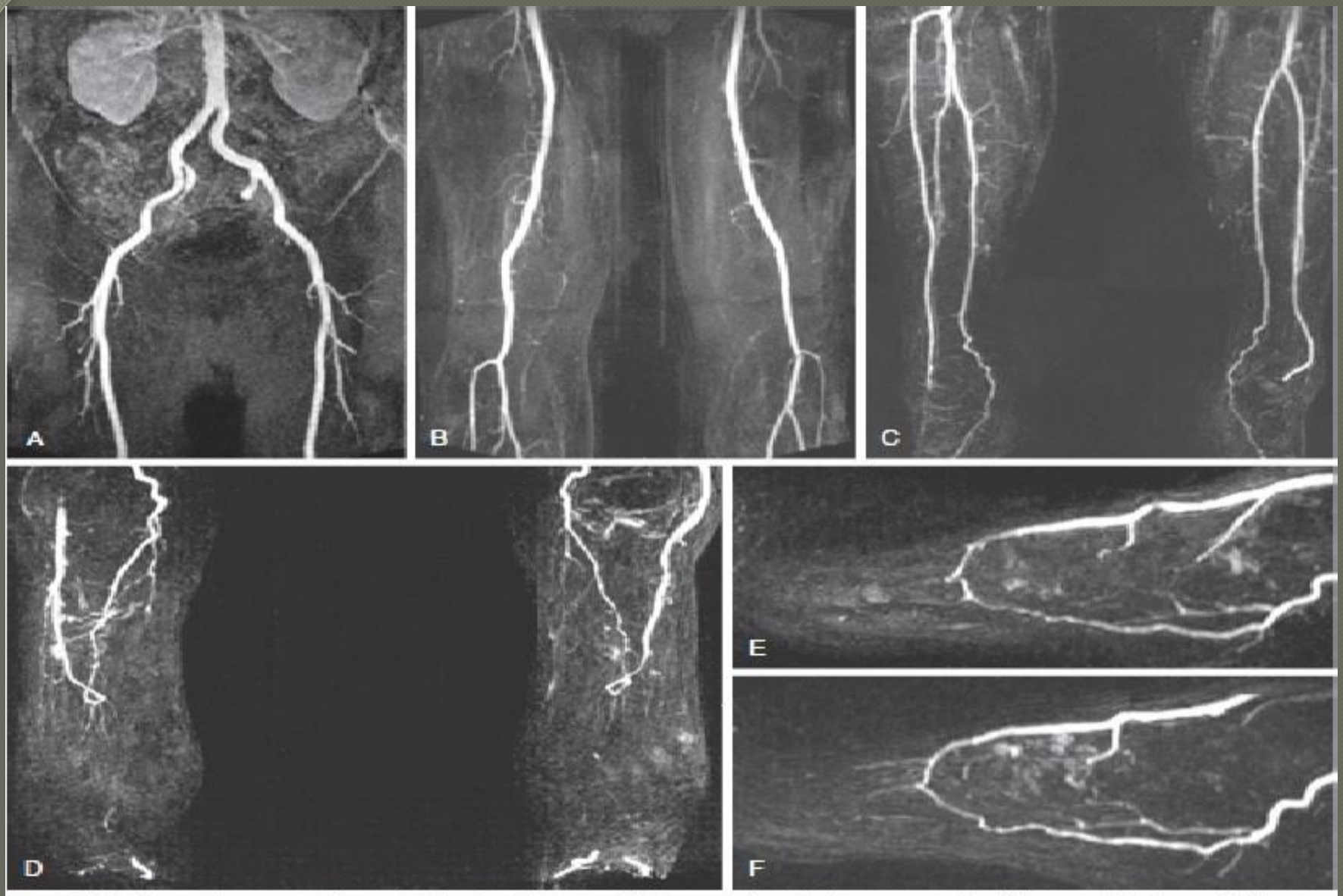


Figure 23-7 Five-station step-table examination showing normal inflow vessels to the lower extremities **(A)**, normal thigh vessels **(B)**, norma calf vessels **(C)**, and normal vessels in both feet **(D)**. The high-resolution 3D data allow reconstruction of each foot in the sagittal plane **(E** and **F)**, which shows a patent plantar arch in each.

Carotid Vascular Disease

- MRA used for evaluating carotid artery atherosclrosis.
- It is sensitive method to detect significant stenoses.
- For stenosis of between 70% and 99% narrowing, MRA has a reported sensitivity of 95%.
- For all stenoses, MRA has reported sensitivity of 98%.
- MRA used as a tool to plan operative or interventional revascularization.

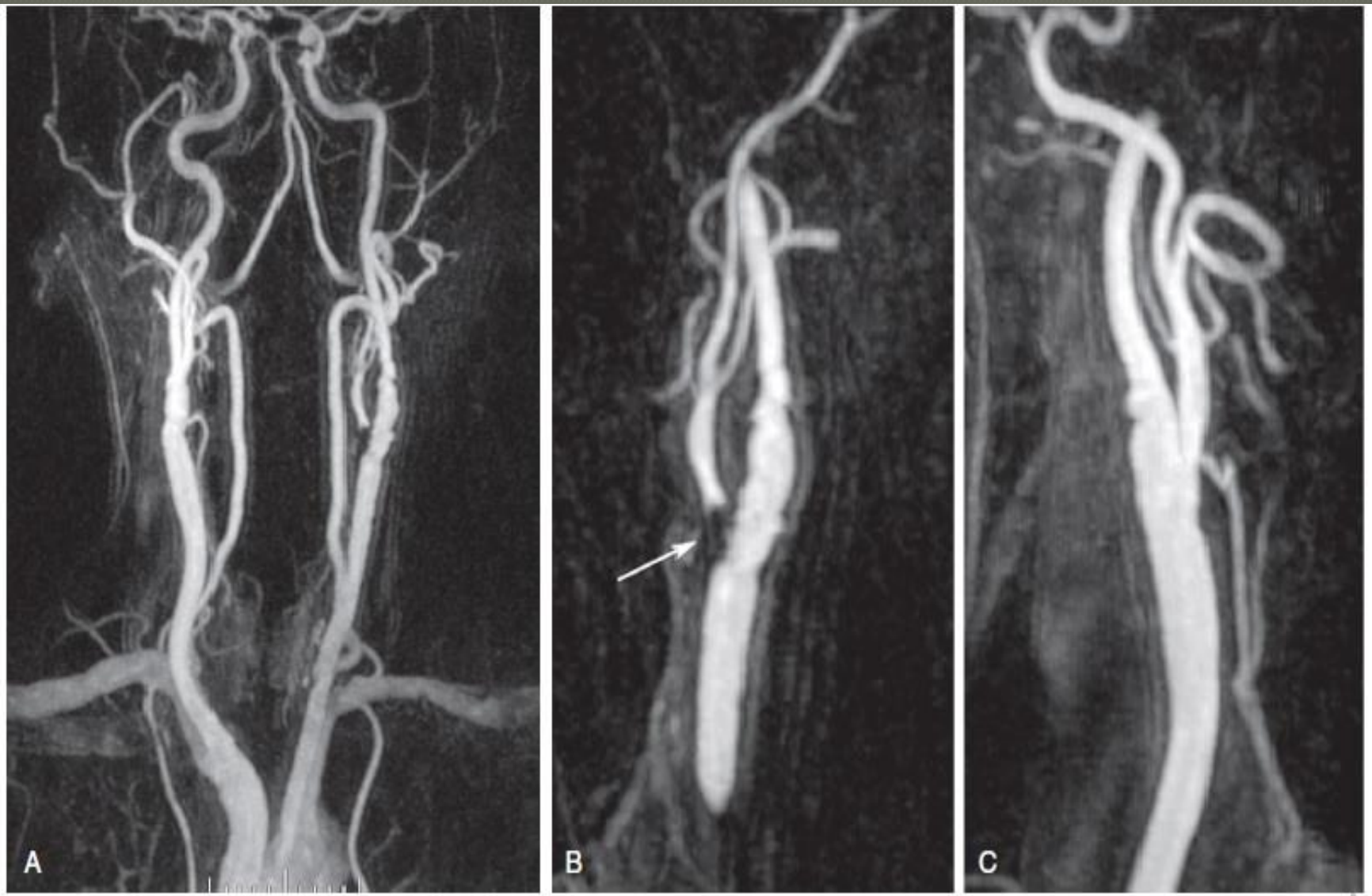


Figure 23-10 **A,** Coronal 3D MR angiogram of the carotid and vertebral arteries. **B,** Oblique sagittal reformatted MR angiogram showing high-grade narrowing at the origin of the left external carotid artery *(arrow)* and mild disease of the left internal carotid artery. **C,** Oblique sagittal reformatted MR angiogram showing the right carotid bifurcation with only mild disease in the proximal right internal carotid.

Aortic Vascular Disease

- Assessment of the **aortic arch** by contrast-enhanced MRA may be superior to any other technique.

- Other diseases evaluated by MRA include aortic **dissection and aneurysms.**

- MRA is also used to evaluate patients with **connective tissue disorders**

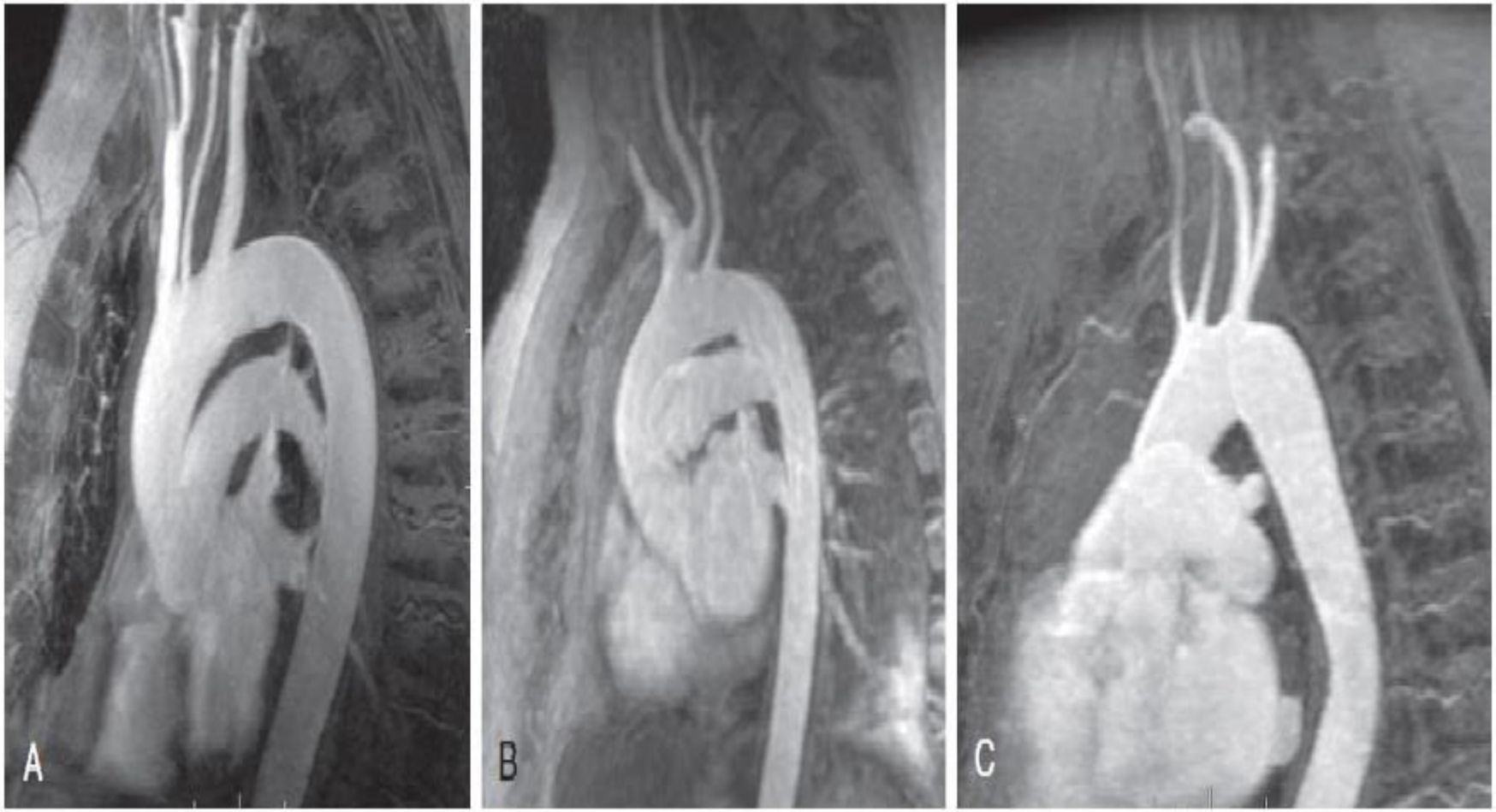


Figure 23-11 **A,** Sagittal oblique reformatted MR angiogram of a normal aortic arch. **B,** Sagittal oblique reformatted MR angiogram of a bovine arch. **C,** Sagittal oblique reformatted image of a rare arch anomaly, bicarotid truncus. All four vessels arise separately from the arch. The carotids arise anteriorly and the subclavians posteriorly.

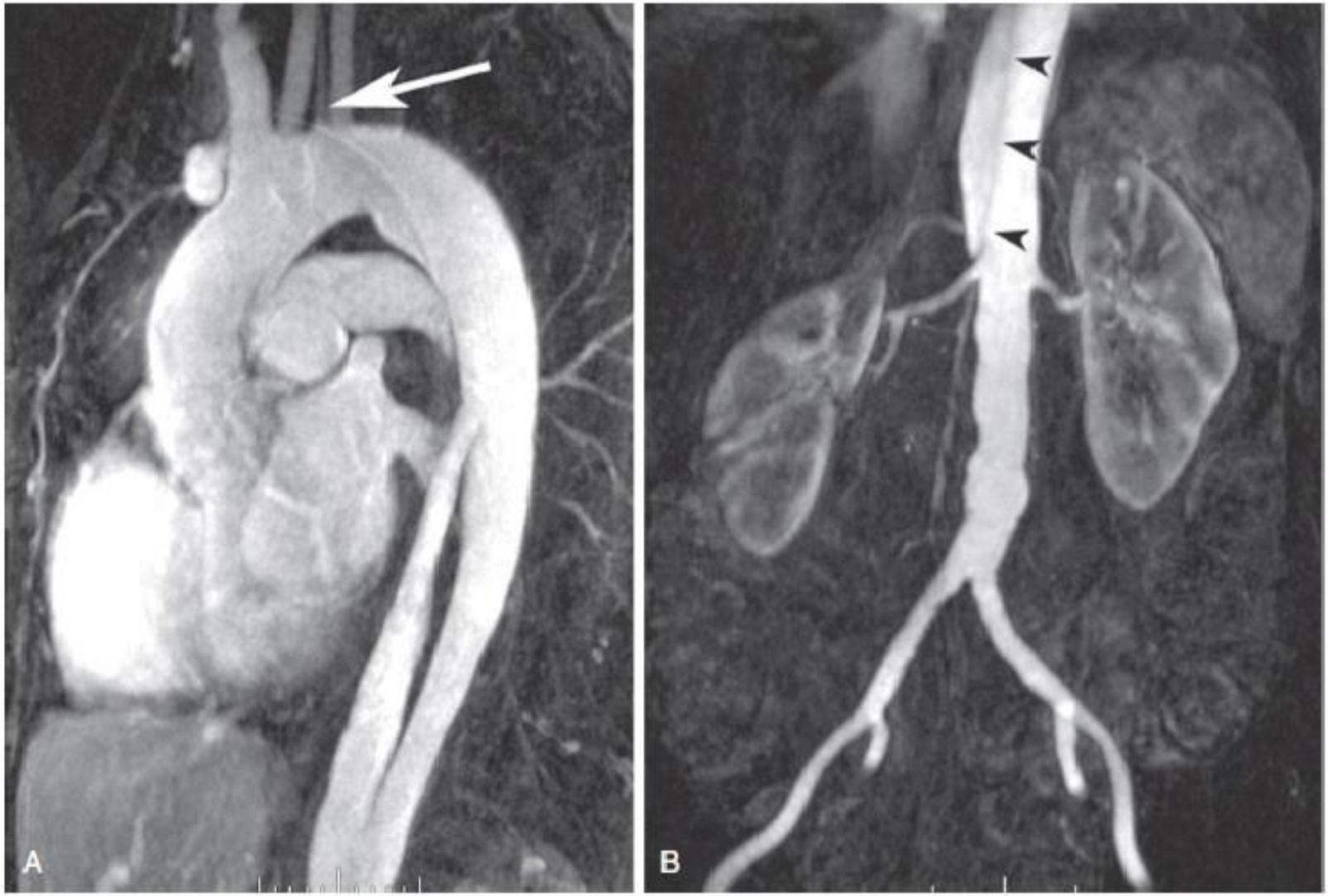


Figure 23-12 **A,** Sagittal oblique reformatted MR angiogram showing a type B dissection. The origin of the flap and filling of the proximal fal lumen are seen. A separate origin of the left vertebral artery is seen from the aortic arch *(arrow)*. **B,** Coronal 3D MR angiogram obtained durir the same examination as the chest-station image by using the step-table technique. The dissection flap *(arrowheads)* terminates just above th origin of the right renal artery.

LIMITATIONS AND RISKS

Scan Artifacts

Artifact of Concentrated Gadolinium MRA contrast material:

At high concentrations, MR contrast material behaves like a small piece of metal and produces a artifact on the surrounding tissues. These concentrations occur only during the injection of a pure contrast agent and are typically seen in the area of the origin of the great vessels.

High Intravascular Signal from Thrombus Methemoglobin:

- This occurs in subacute phase (1 to 14 days) of a blood clot.
- When clot contains large amounts of methemoglobin, signal may be high on T1-weighted images used in MRA.
- This signal can be mimic intravascular contrast.
- The use of precontrast T1-weighted imaging can identify the thrombus.

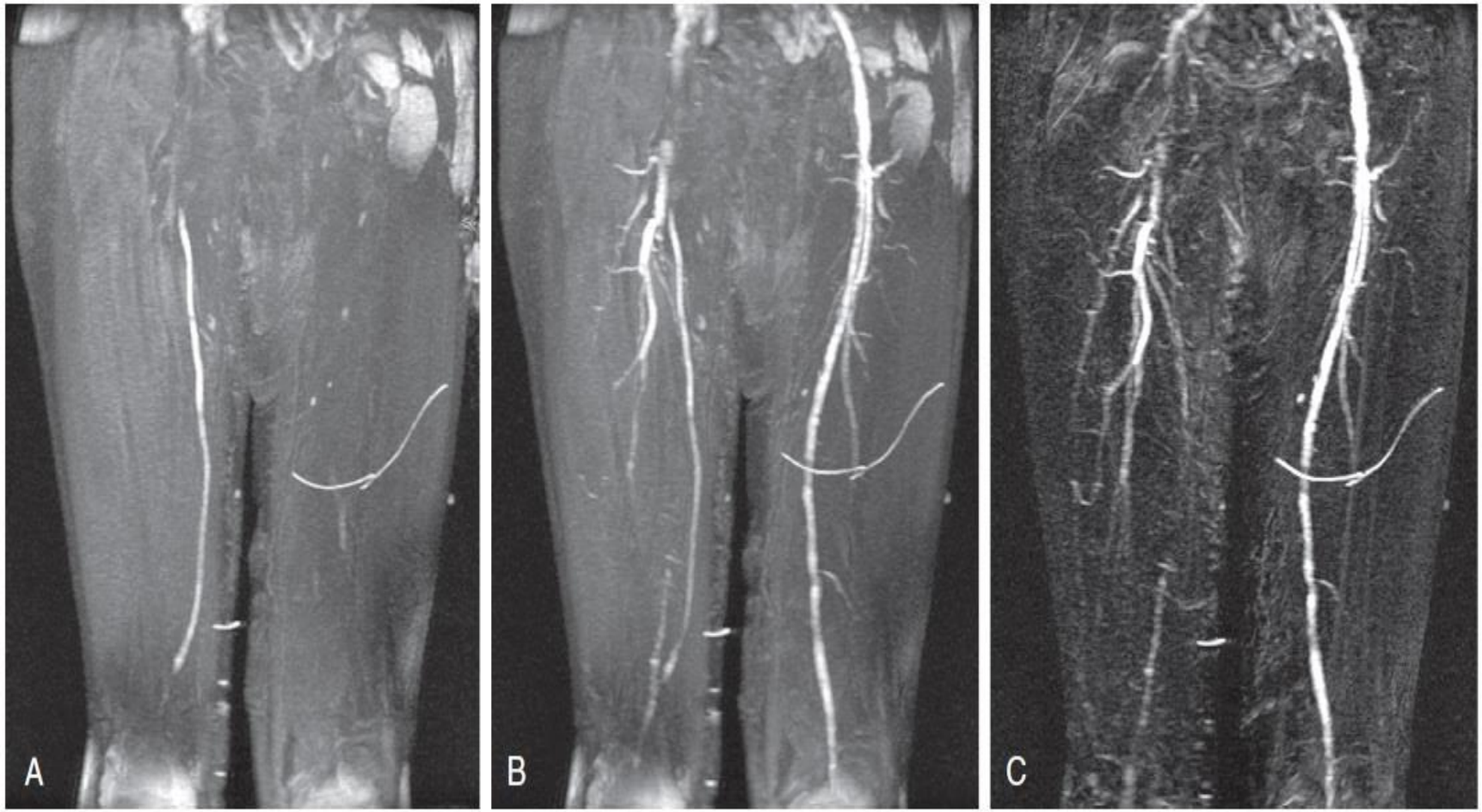


Figure 23-23 **A,** Precontrast coronal T1-weighted image showing high intravascular signal from a thrombosed femoral bypass graft. The high signal is from methemoglobin in the thrombus. **B,** Coronal 3D MR angiogram showing that the signal from the thrombus is as high as signal in the contralateral superficial femoral artery. There are signal voids at the origin and touchdown of the graft, suggesting stenosis, when in fact the entire graft is occluded. **C,** Subtraction image of the arterial-phase image minus the precontrast image showing only the contrast-enhancing arteries.

IVUS

•IVUS provide histologic detail of vessel wall and demonstrates blood flow within the lumen.

•Can distinguish between soft plaque and calcification.

•Intimal flaps, thrombus and ulceration are visible with IVUS.

•Luminal diameter and cross-sectional areas can be measured.

• Guide PTA, stenting, atherectomy, laser, thrombolysis, and endoluminal grafting.

•Assistance in OR environment has become easier to use with the developments of 3D, color-flow, and virtual histology IVUS (VH IVUS).

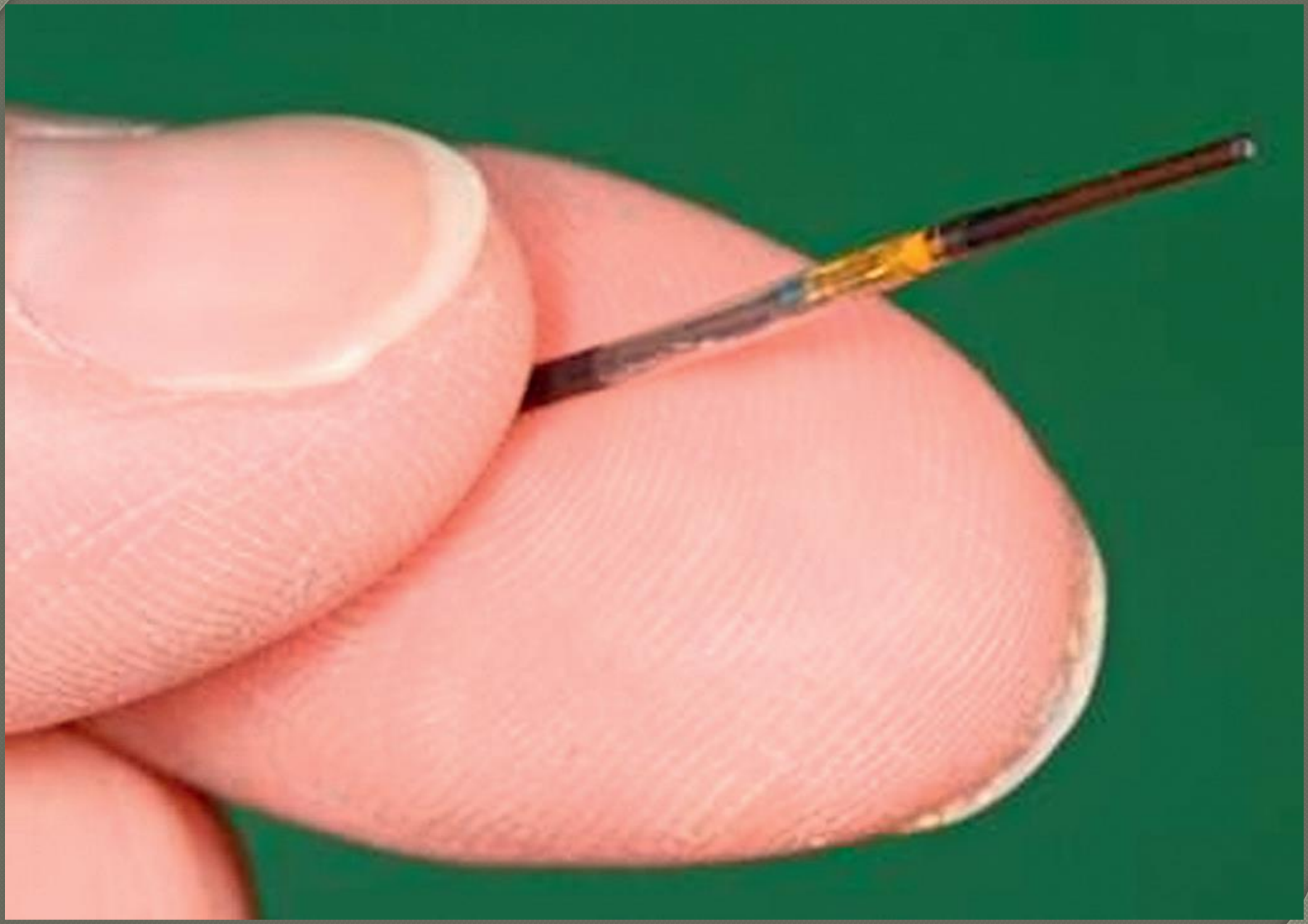
Intravascular Ultrasound Systems

There are two commercially available types of IVUS:

A> First is mechanical with U/S transducer located at tip of flexible high-torque catheter with fast rotation of transducer.
® Boston Scientific Corporation (Natick, Mass).

B> Second electronic sweeps U/S signal around circumference of probe electronically by transducer positioned circumferentially around tip of the catheter to produce an array of images in plane perpendicular to long axis of catheter.
® Volcano Corporation (Rancho Cordova, Calif).

✓Both types transmit sound waves covering 360° of vessel wall and create axial image of lumen and vessel wall and have a dual-purpose channel that allows catheter access over GW.



Catheters and Probes

Appropriate catheter for particular vessel depends on choosing **appropriate frequency** for its **size** and **depth**.

✓**0.014-inch** and **0.018-inch** catheters are **20 MHz** for small Vs as iliac arteries and carotid, SFA, popliteal, and tibial vessels.

✓**0.035-inch** catheters are **10 MHz** for aorta, (IVC), and iliac aneurysms.

- **Lower frequency** catheters require a larger **9F** sheath.
- **Higher frequency** catheters delivered through **7F** and smaller.

- All catheters are delivered over a guide wire.

Intravascular Ultrasound Images

- 2D gray-scale image allows visualization of 3 layers of wall. Intima is bright and echogenic, media is darker and more echolucent, adventitia is brighter than the intima.

- Demarcation of the blood-filled lumen and the vessel wall which show free luminal area and evaluation of degree of stenosis and distribution of plaque.

- Calcified lesions are bright and cause posterior shadowing due to the lack of penetration of the US through calcification.

- Fibrotic plaque are brighter but without posterior shadowing

- Soft plaque containing lipids appears darker.

Color-Flow Intravascular Ultrasound

- **ChromaFlo is computer software that detect blood flow and colors it red.**
- **Software detects differences between frames where there has been movement of blood and colors this red.**
- **Flow velocities cannot be measured.**
- **It shows clearly where the lumen meets vessel wall.**

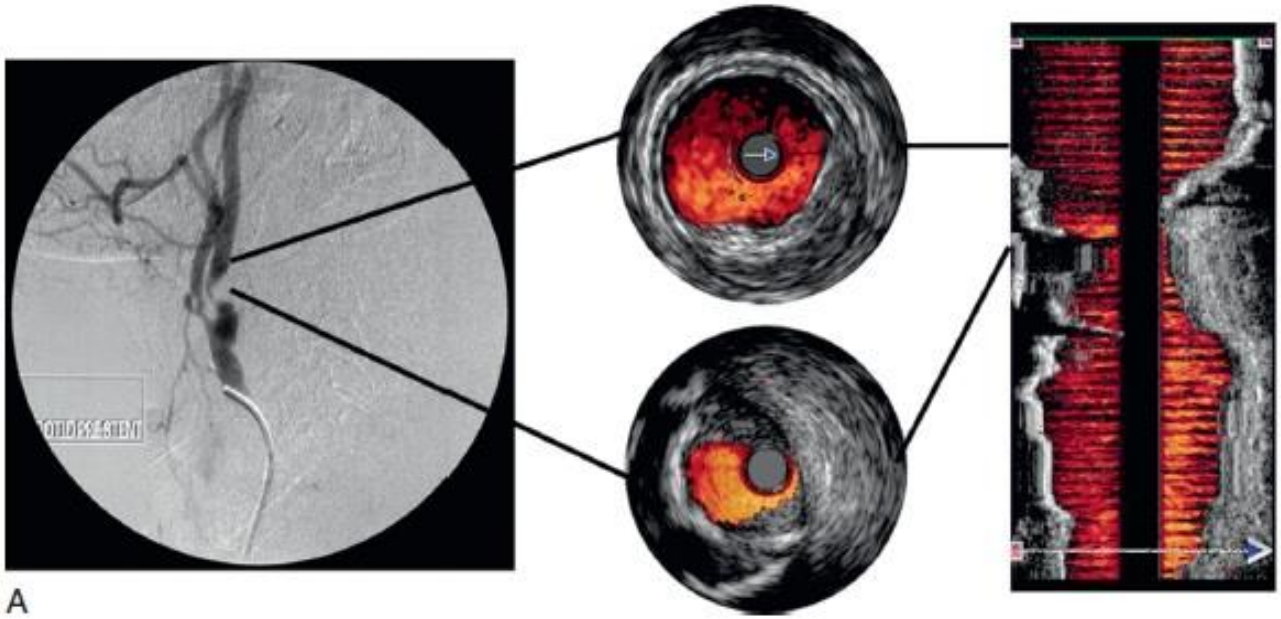
Three-Dimensional Intravascular Ultrasound

A longitudinal reconstruction provides an image similar to an angiogram.

Longitudinal image is created by performing a "pullback" of the IVUS probe through the vessel.

Computer software automatically detects borders of layers of artery (intima/lumen and intima/media) facilitates imaging.

Axial images allow accurate diameter measurements but length measurements with the longitudinal reconstruction are not accurate.



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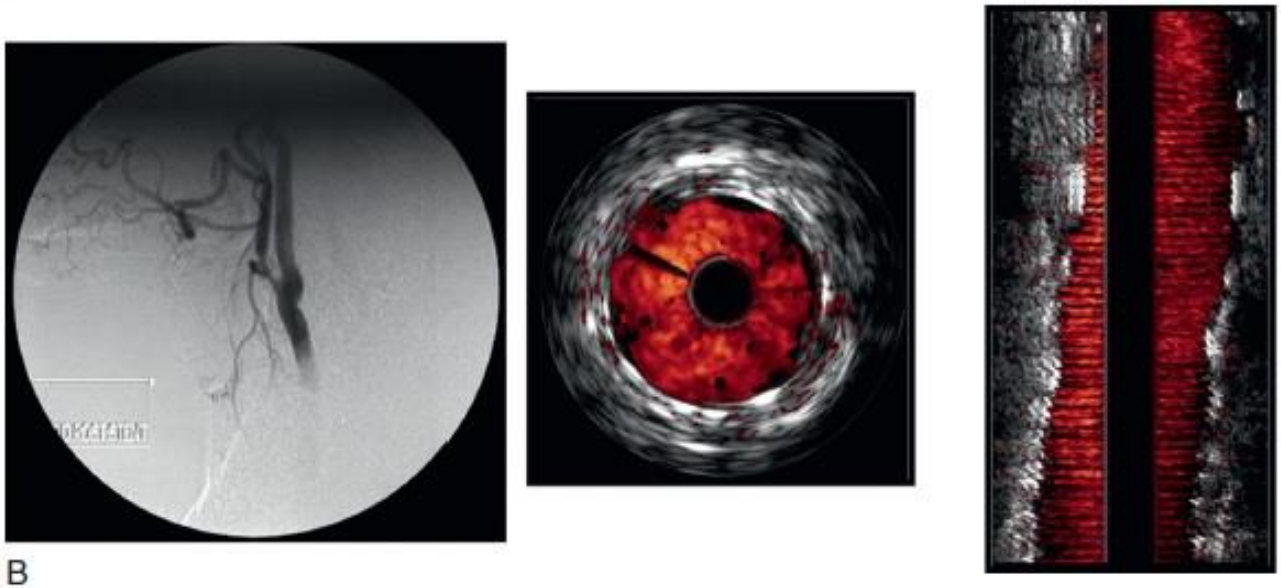


B

Figure 24-2 **A,** Color-flow IVUS demonstrates an eccentric plaque and tight stenosis in the internal carotid artery. **B,** Color-flow IVUS confirms the completeness of treatment with a carotid stent.

Virtual Histology Intravascular Ultrasound

- VH IVUS creates an image using the frequency as well as the amplitude of the returning signal.

Different tissues reflect US at different frequencies.

Correlation of IVUS frequency data with subsequent tissue histopathologic sections of vessels enable classification into four histologic components:
fibrous, fibrofatty, calcified, and necrotic lipid core.

A color-coded map of atherosclerotic plaque VH IVUS of:
Green, fibrous
Yellow, fibrofatty
White, calcified
Red, necrotic lipid core plaque

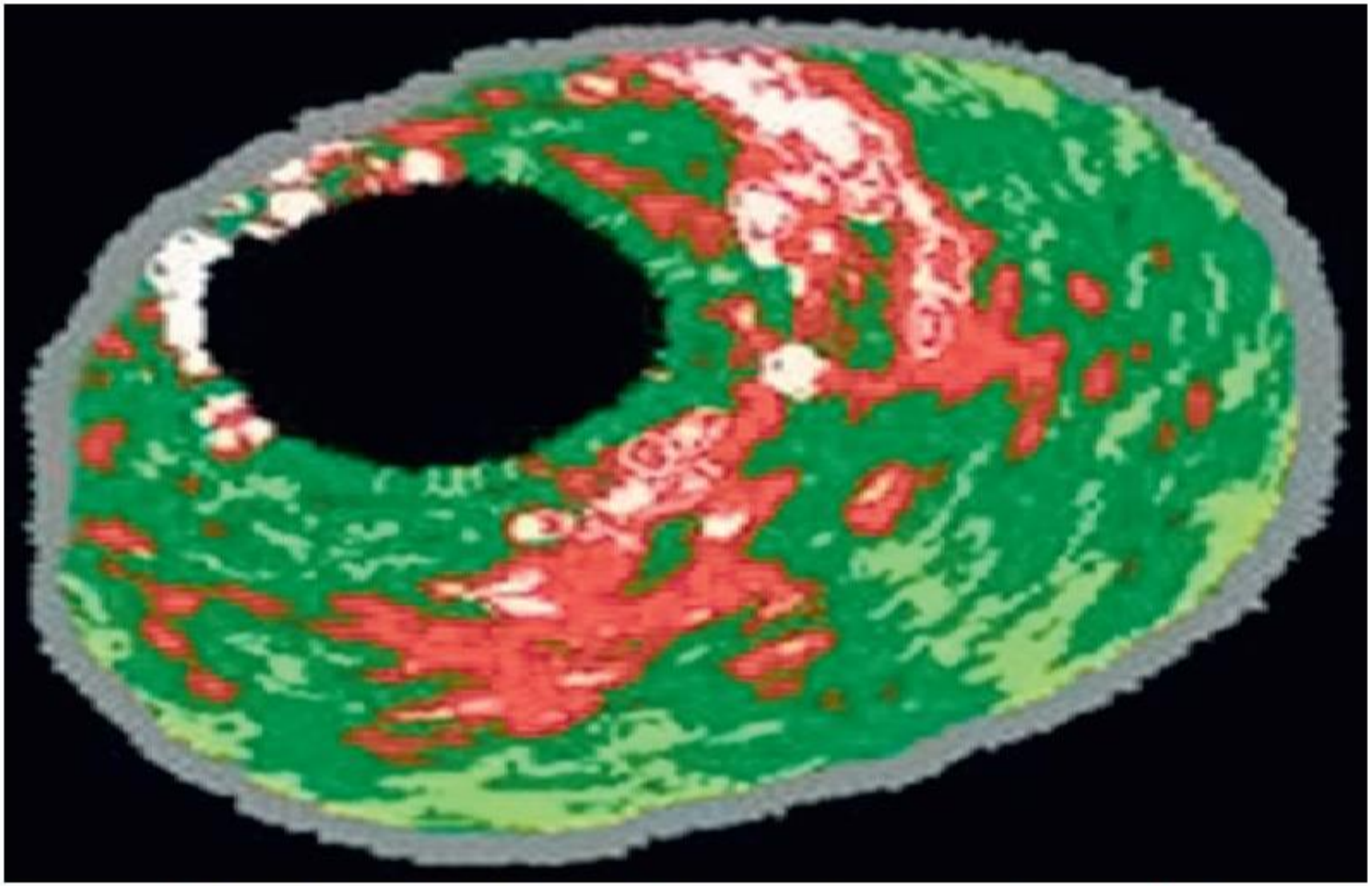
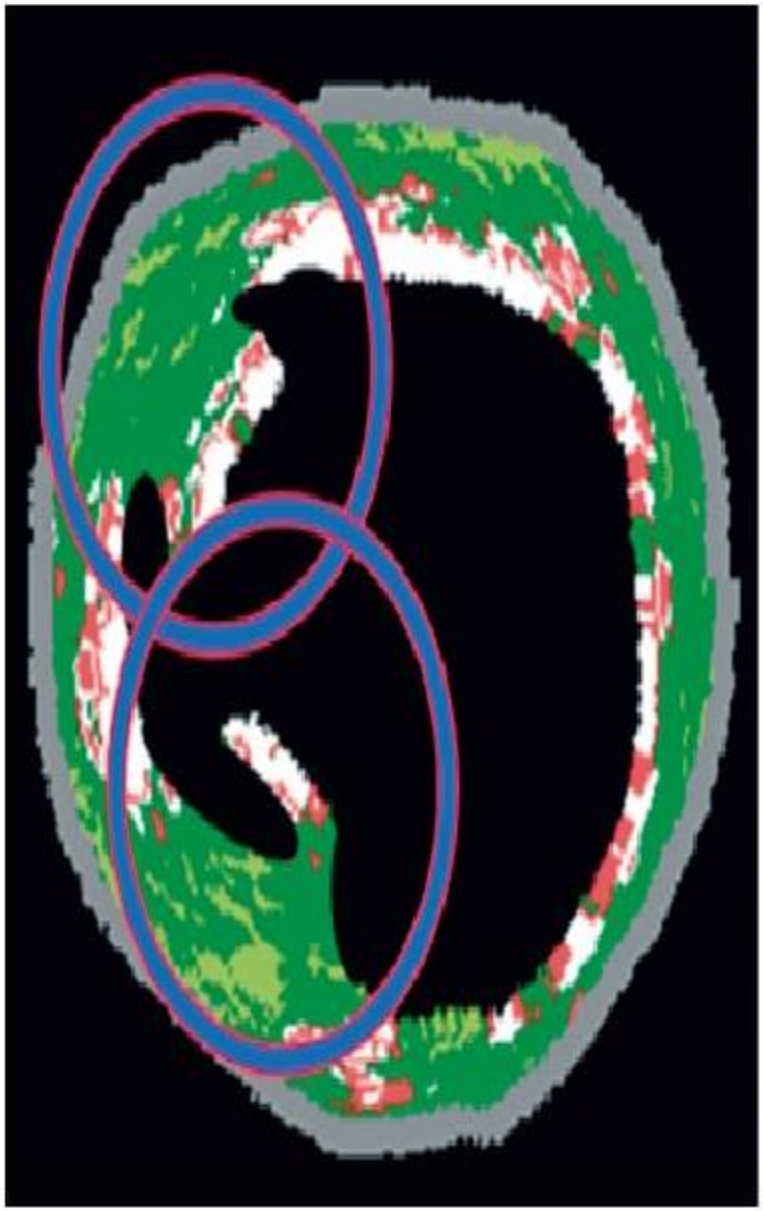
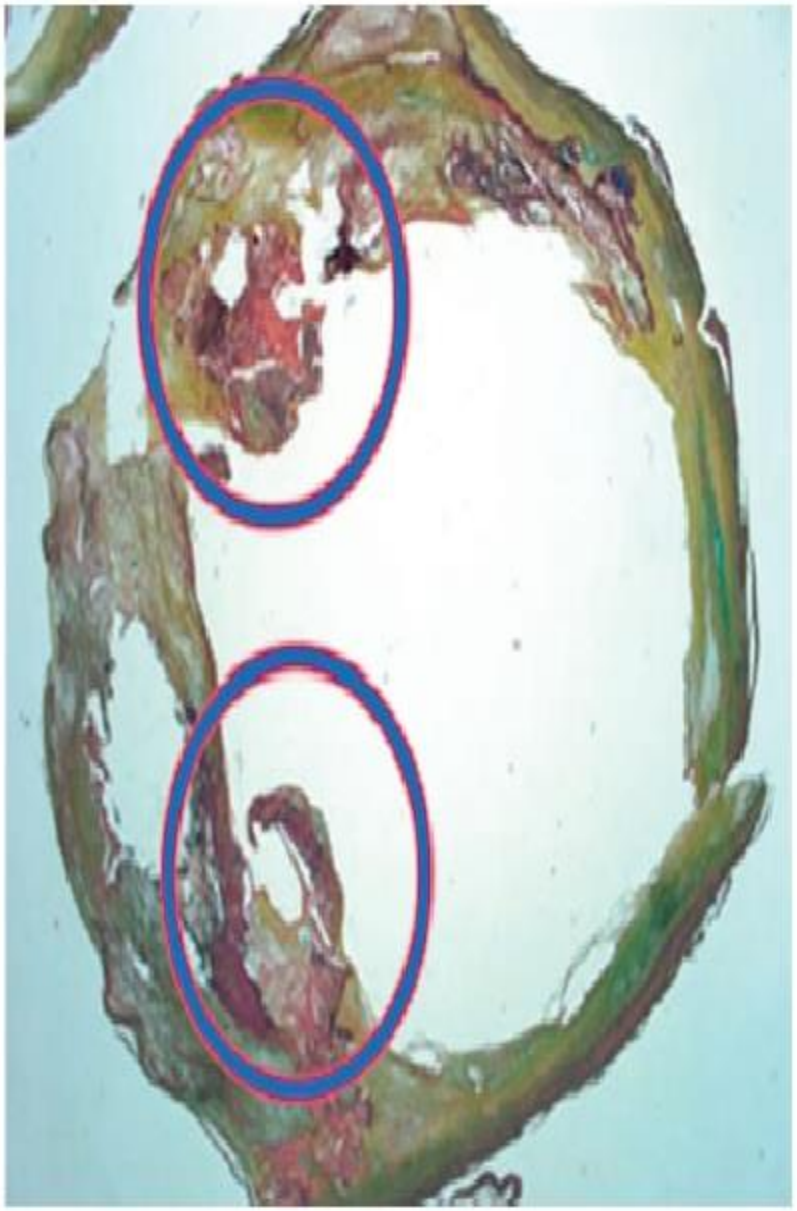


Figure 24-3 Virtual histology IVUS produces a color-coded map of the histologic components of the plaque. *Dark green,* fibrous; *yellow/green,* fibrofatty; *white,* calcified; *red,* necrotic.





CLINICAL APPLICATIONS

1. Balloon Angioplasty and Stenting
2. Endovascular Stent-Grafts for Abdominal Aortic Aneurysms
3. Thoracic Aortic Disease
4. Venous Imaging

Balloon Angioplasty and Stenting

- IVUS acts as a guidance system during balloon angioplasty and stenting.

- Determine diameter of vessel to be dilated, composition of plaque and calculate the degree of stenosis allows sizing of balloon & stent to be implanted.

- Can assess results of intervention and determine dissection.

- Predict any residual stenosis to predict patency; residual stenosis of >60% is associated with unfavorable patency rates.

- Can identify stent strut as echogenic structure and determine degree of stent expansion and apposition to vessel wall.

Aortic Intervention

- IVUS identify nature of aortic disease, including dissections, penetrating ulcers, intramural hematoma, aneurysms.

- Used instead of CTA in patient with CKD &allergy to contrast.

- Determine length and diameter of landing zones in choosing endograft size, identify side branches, to deploy the stent-graft by visualizing lowest renal while using fluroscopy for showing stentgraft open.

- Check contralateral gate has been accurately cannulated.

- After repair, demonstrate good apposition of stent-graft & access inspected for luminal patency and if there are any irregularities, such as dissection to the vessels.

- In cases of aortic dissection, it can clearly identify true and false lumen and accurate assessment of size of graft.

- Identify location of entry tear and determine whether the left subclavian artery needs to be covered.

- Thickness, movement of dissection flap, and number of fenestrations between true and false lumen.

- Visceral vessel can be seen and assessed as to whether it is perfused by the true or false lumen.

- After deployment, thoracic aorta can again be visualized. Ensure that innominate and left carotid arteries are patent.

- Stent-graft expansion and apposition .

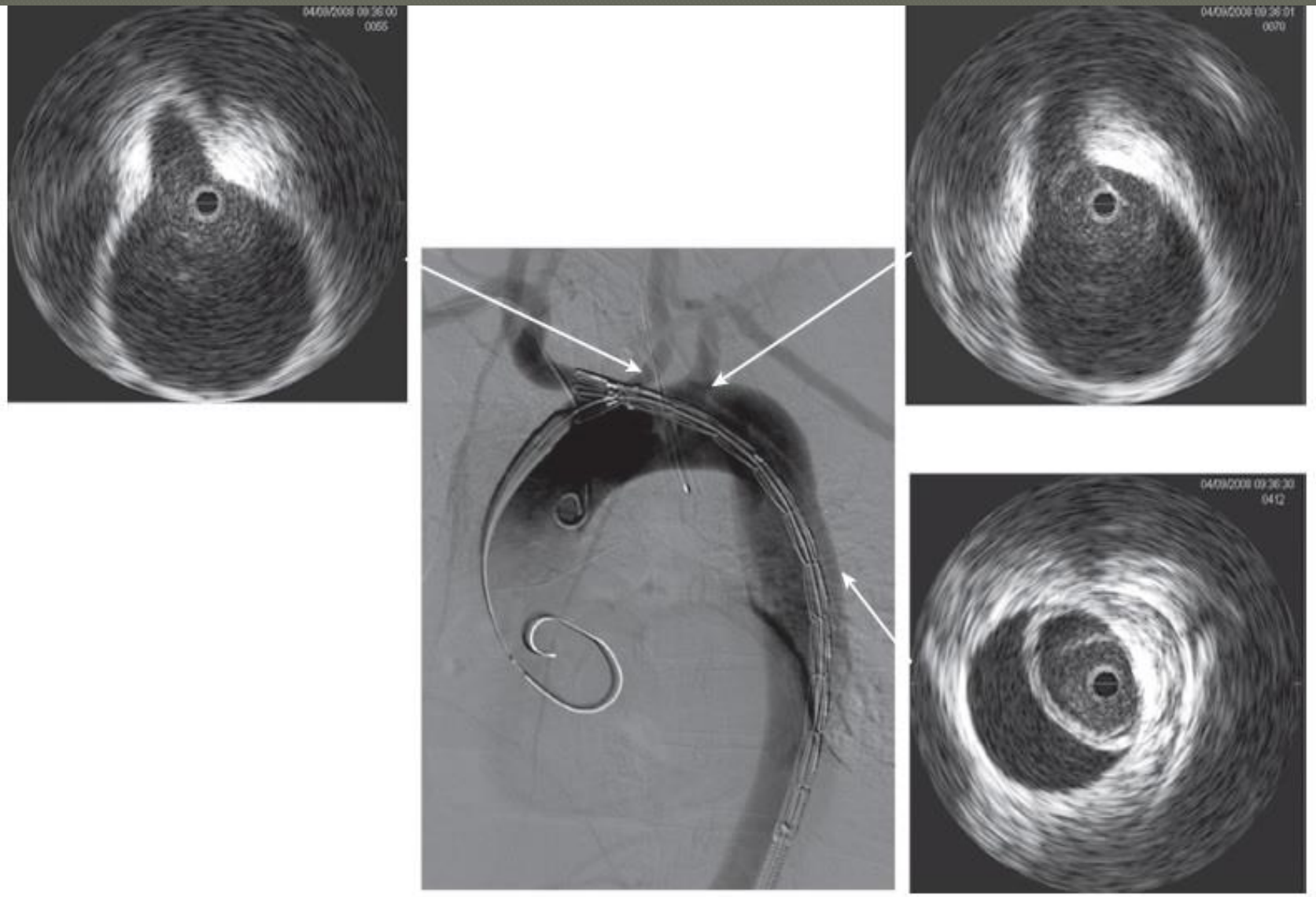


Figure 24-7 Digital subtraction aortography shows a dissection of the aorta being treated by endoluminal grafting. The corresponding IVUS images accurately locate the origins of the left carotid and left subclavian arteries, which are healthy. The IVUS probe is in the true lumen surrounded by the circle of intima that has separated, causing a false lumen.

LIMITATIONS

- Large (8F-9F) sheath size.
- Calcified vessel & metallic stent struts produce bright echoe with posterior shadow, which limits visualization.
- Emboliztion by dislodge of disease from vessel wall.
- Mechanical systems, unlike electronic systems, require flushing of the transducer chamber to avoid air bubbles that can distort the image.

Arteriography

EQUIPMENT

System, imaging hardware, catheters, contrast agents, devices for delivery of contrast agents, and digital software used to assist in processing of arteriographic images.

Operating Room versus Imaging Suite

Hybrid suite are preferred.
Complications that arise during any endovascular procedure, can be managed immediate no need for emergency transport from an angiography suite to the operating room.

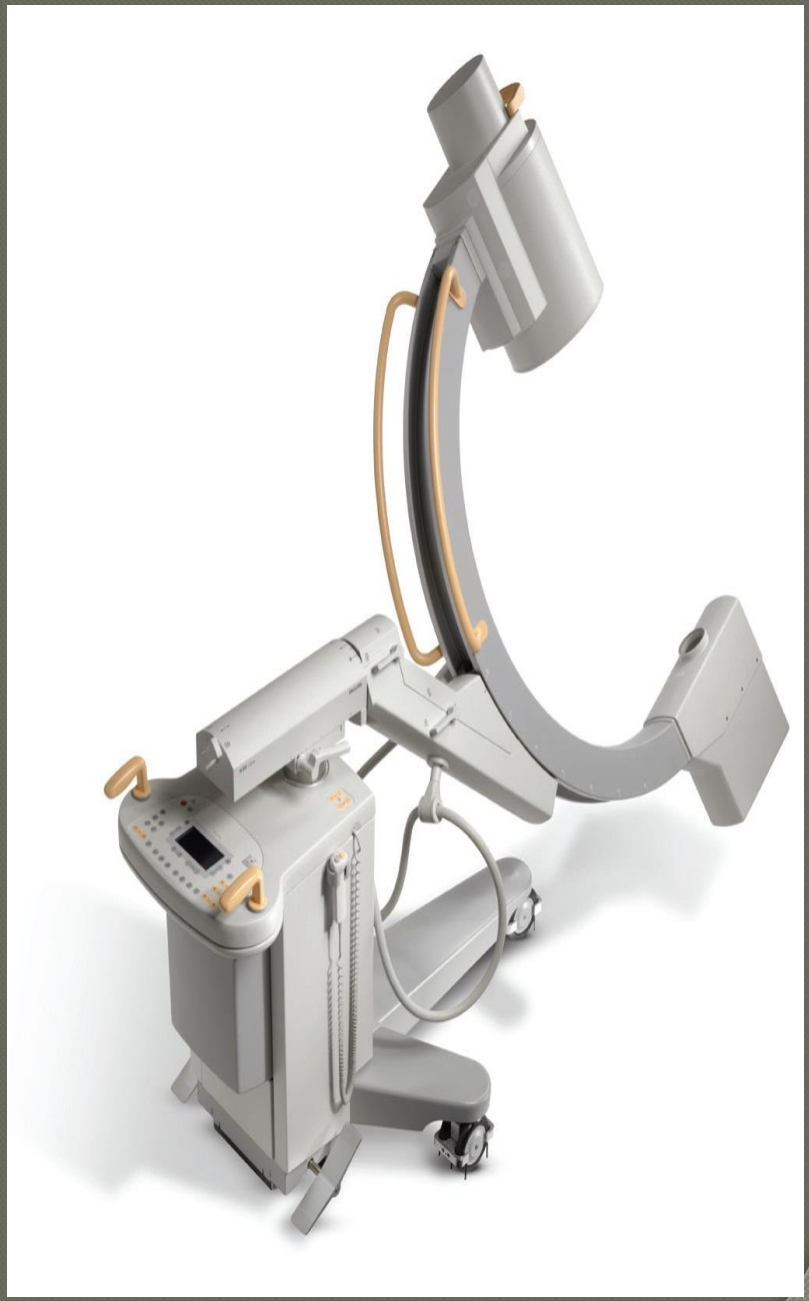
Fixed-Mount versus Portable Equipment

1. More powerful generators for more detailed imaging.
2. Cover more imaging area with less radiation exposure
3. Less contrast material.
4. Manipulations in C-arm angulation improve arterial visualization.

- Ability to move the from room to room.

- Bringing the imaging equipment to patient can be easier, safer, and more practical than a suite with a fixed-mount unit.

- Much less costly



Catheters

Type of catheter plays a role in **optimizing image** and **avoiding injury** to the vessel.

Catheters come in all shapes, sizes, and lengths.

Multiple side holes in addition to the end hole is designed for safe, quick, dispersion of contrast material at high injection pressures to image large arteries with high flow.

End-hole catheters, are used after remote arterial access is achieved for guiding procedure.

Contrast Agents

- This agent needs to have a radiodensity differ from that of tissue being imaged.
- Typical agents have greater radiodensity than surrounding and appear darker .

Iodinated Contrast Agents:

- Conventional agents containing iodine & can be categorized ionic or nonionic.

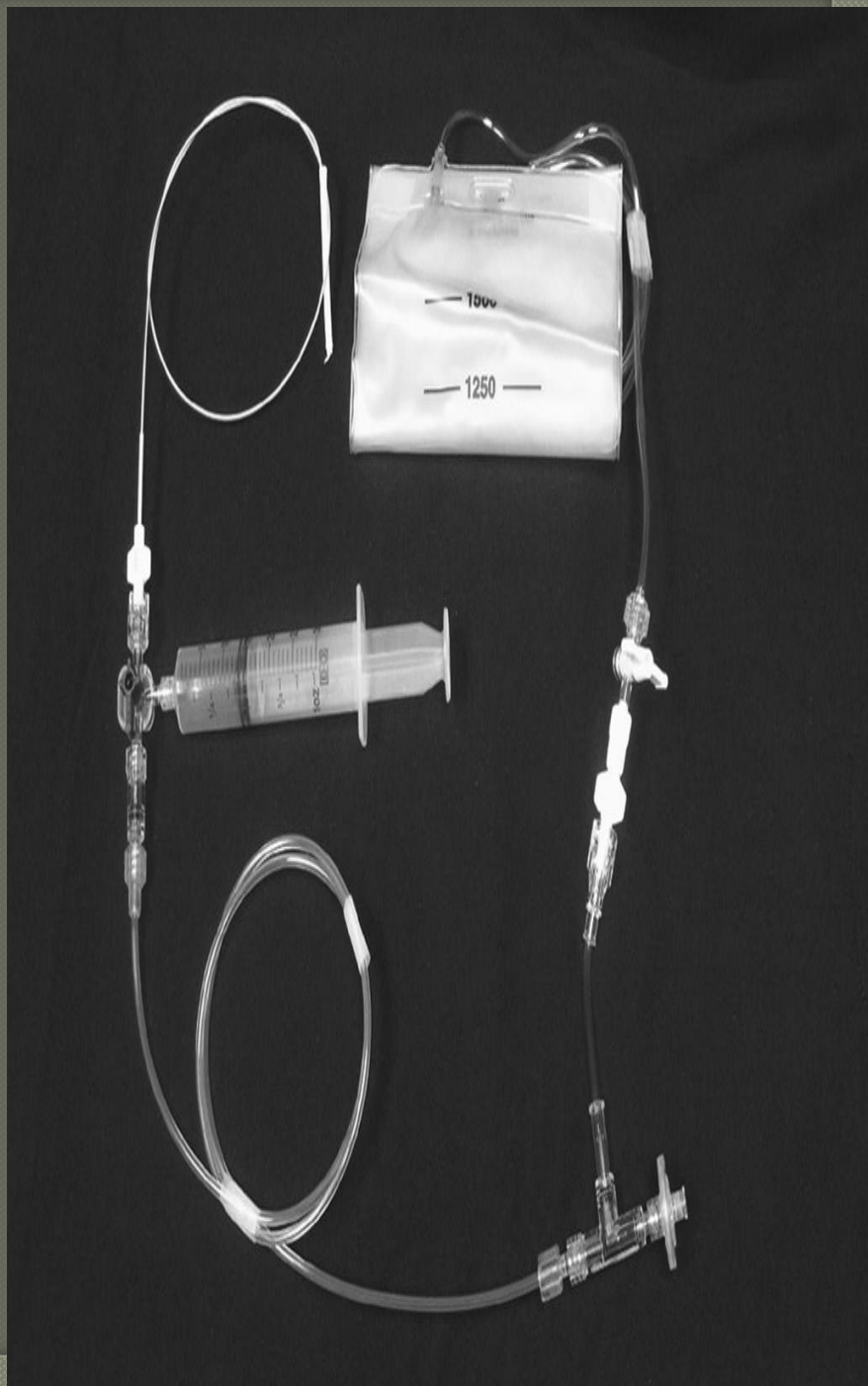
- Iodine atoms absorb the x-ray photons and responsible for contrast visualization, or radiopacity, of artery visualized.

- Nonionic contrast have twice number of iodine atoms are present in Ionic contrast.
- This leads to a greater amount of x-ray photon absorption, and thus arteriographic images are achieved with less volume of contrast material.

Carbon Dioxide Arteriography

Injection of this gas with its **decreased radiodensity** creates radiographic contrast by **transiently displacing blood from the artery** being imaged.

Used in vascular patients who have **compromised renal function.**



Devices for Injection of Contrast Agents

Power Injection:

- Allow rapid high-pressure injection of contrast into the catheter.

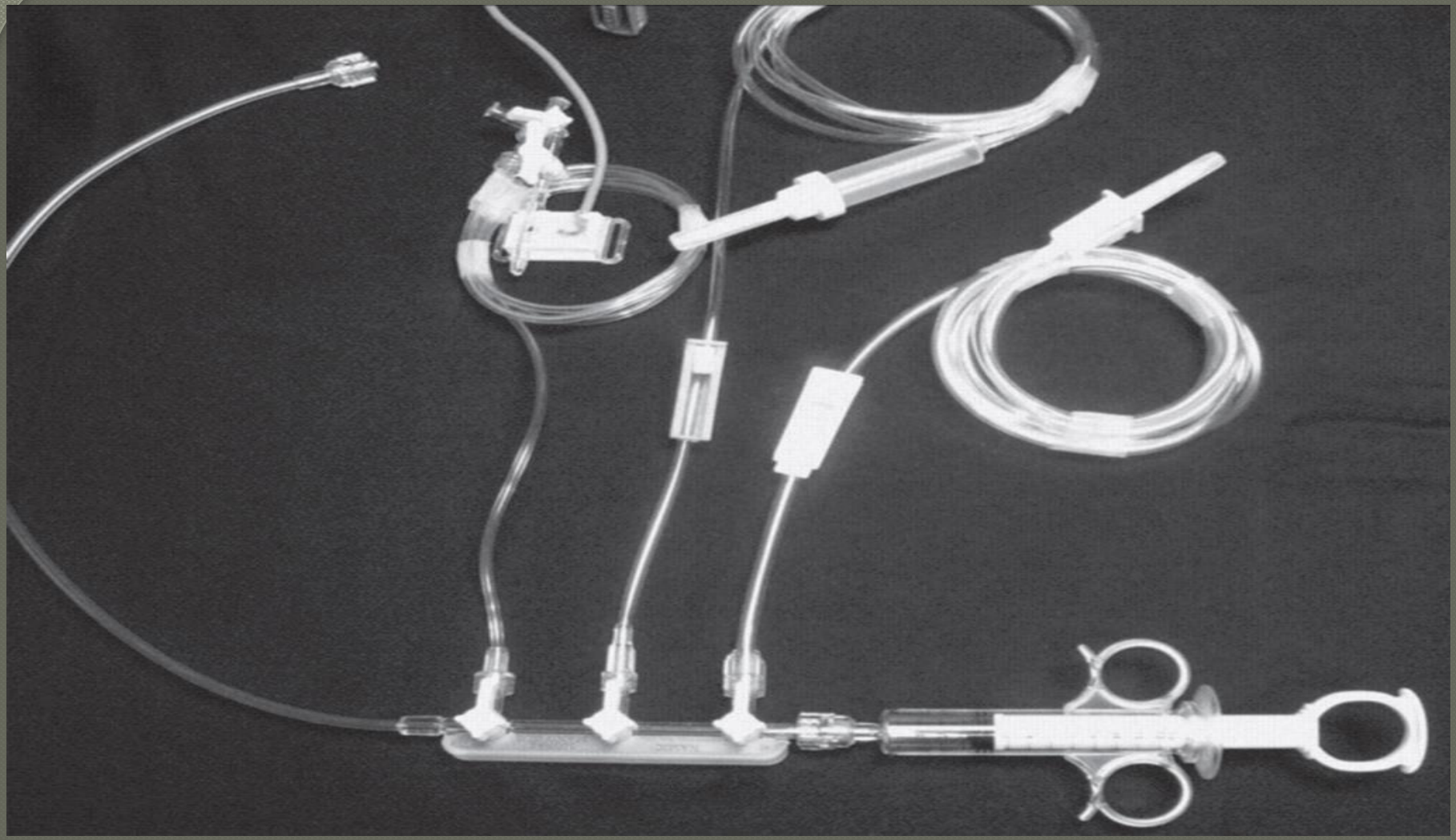
- Used for prolonged injections, ranging from 3 to 6 seconds.

- For every power injection, determine what volume of contrast in what time.

- For example, typical aortic arch arteriography may require 20 mL of contrast material per second for a total of 2 seconds.

Manual Injection:

Use of a simple syringe with full-strength contrast agent or a manifold device.



MANIFOLD DEVICE

Table 19-2 Typical Injection Method, Rate, and Volume of Contrast Agent for Various Vascular Regions

Location	Suggested Method	Injection Rate (mL/s)	Total Volume (mL)
Aortic arch	Power injection	20	40
Selective carotid	Hand or power injection	3-5	5-10
Selective vertebral	Hand injection	2-4	2-4
Selective subclavian or brachial	Hand or power injection	5-10	10
Abdominal aorta	Power injection	20	40
Renal or mesenteric	Hand injection	3-5	5-10
Iliac artery	Hand or power injection	10	10
Infrainguinal segments	Hand or power injection	5-10	10
Aorta to pedals, stepped run	Power injection	20	90*

Tips and Tricks For Proper Imaging

Subtraction Tool and Masking:

This technique subtracts all visible radiodensities on the current image to create a mask image, represented as a blank screen.

After subtraction is achieved and the mask image is created, contrast agent is injected and visualized as it is radiodense and moves with blood flow through vessels of concern.

By subtraction of the surrounding tissue and vessel wall from the contrast images, the quality of visualization of intraluminal contrast is greatly enhanced.

In an ideal image capture, there is no movement between creation of the mask and injection of contrast material.

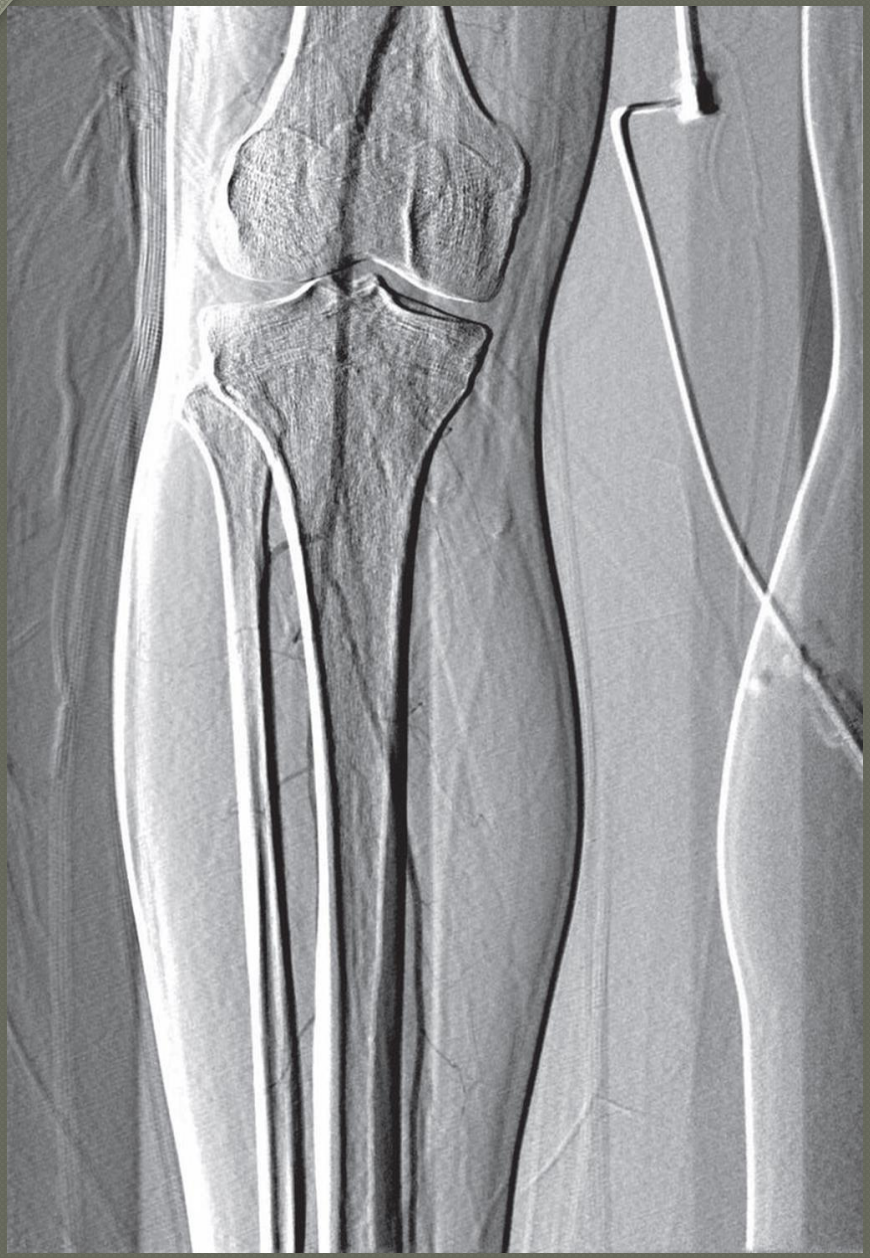
Pixel Shifting:

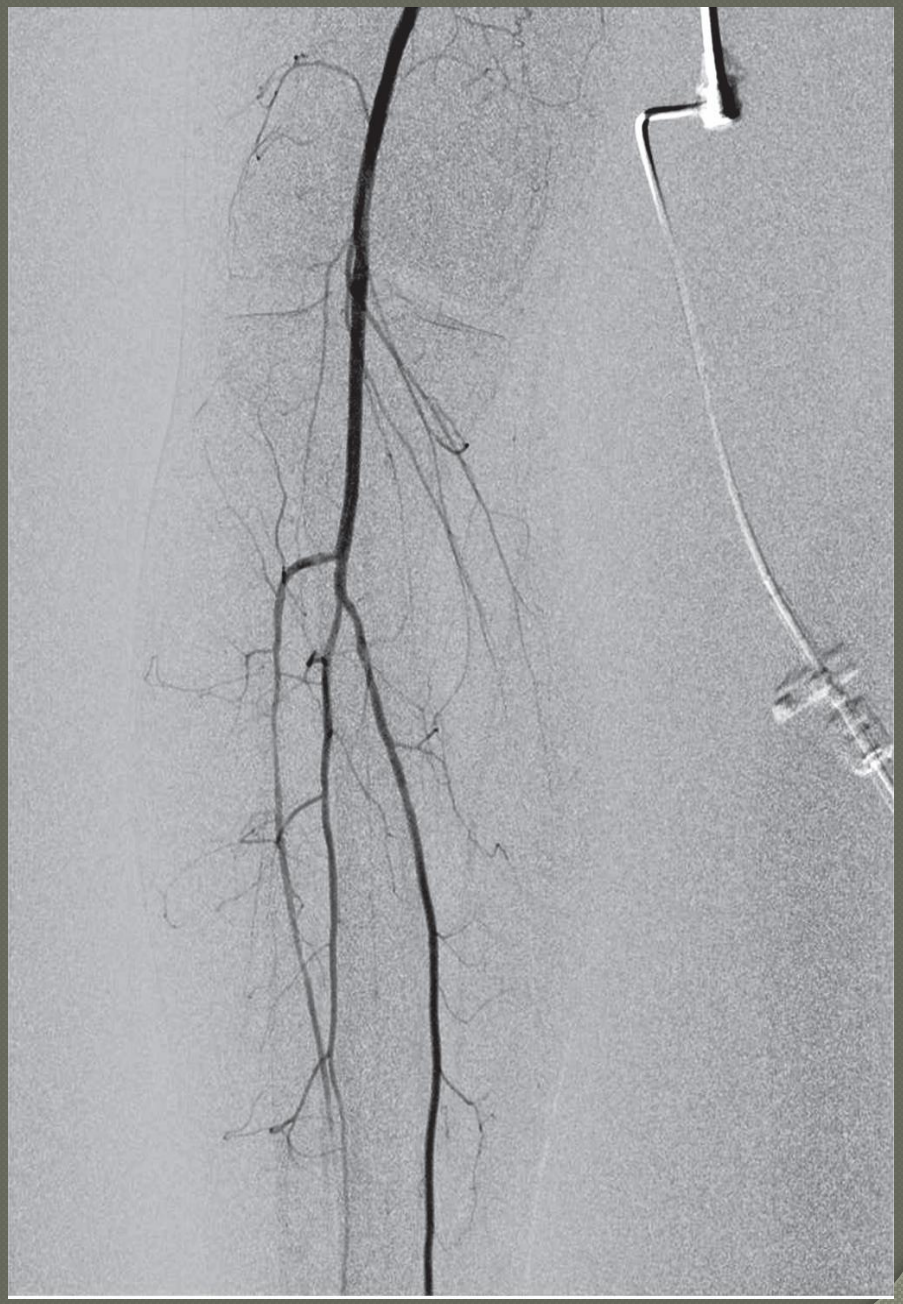
It is a valuable tool when artifactual movement occurs after contrast material has already entered the field of view.

Instead of creating new mask, one can take existing mask and slide it in a bidirectional plane (vertical,horizontal, or both) to realign the surrounding tissue.

This realignment of the existing mask to the patient's current position on the contrast image erases the discrepancy and minimizes the motion artifact.

Some software programs allow automatic or manual pixel shifting.





View Tracing

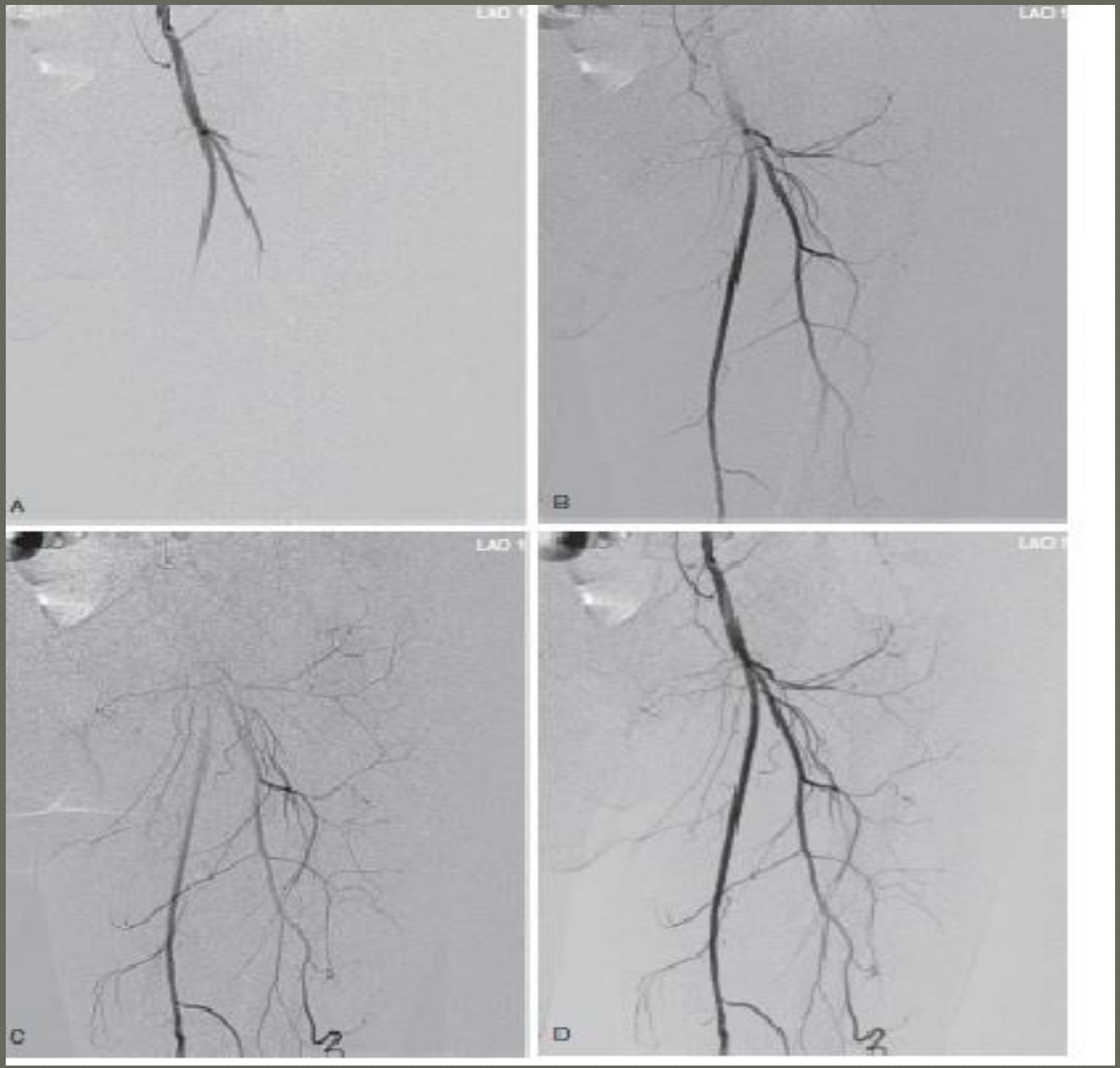
Allows consolidation or "stacking" by overlaying consecutive static images in a series to provide one cumulative image.

Roadmapping and Measuring

Allows a previously constructed image of a contrast-filled vessel to be displayed on the working monitor.

Real-time fluoroscopic imaging can then be superimposed on the monitor so that the contrast image can be used as a "roadmap" to direct guide wires and catheters.

This technique effective as long as table and patient positions do not change.


A
B
C
D

Single-Injection Multiple–Linear Field Arteriography

- Stage Technique
- Stepping Technique

Rotational Arteriography

Table 19-3 Recommended Radiographic Filming Projections for Optimal Branch Separation

Location	Recommended Filming Projection
Aortic arch	30-degree left anterior oblique
Cervical carotids	AP, lateral, and 45-degree ipsilateral anterior oblique
Intracranial carotids	AP and lateral
Vertebrobasilar system	AP and lateral
Right subclavian	Right anterior oblique
Renal artery origins	AP ± 10 degrees
Celiac artery and SMA origins	Lateral
Iliac bifurcation	20- to 30-degree contralateral anterior oblique
Femoral bifurcation	20- to 30-degree ipsilateral anterior oblique
Trifurcation and tibial arteries	Anatomic AP (or 20-degree ipsilateral anterior oblique with feet in the neutral supine position)


Thank you for listening..
Any questions?