Navigation through this Module

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Instead of a course textbook, all the modules contain links to excellent information that can be found on the internet. It is important that you visit these links to get more background on the topics. These also may be printed out to read in more detail later, or to be saved for future reference.

If you have any difficulty in accessing any of the links within these modules please send an email to jwilliams@robarts.ca. Sometimes the sources of the links change and adjustments will be made to correct this.

When you have finished the module, please go to the Module 8 Quiz under the Quizzes icon on the Course Home Page.
Information in this module comes from several sources, including lecture notes given by Robarts Scientists as part of the coursework in the Department of Biomedical Engineering at the University of Western Ontario, and the Radiology Residents’ Course entitled “Physics of Diagnostic Imaging”, given in partnership with the Department of Diagnostic Radiology and Nuclear Medicine, London Health Sciences Centre, Imaging Research Laboratories, Robarts Research Institute, St. Joseph’s Health Centre, and The Lawson Research Institute, all in London, Ontario.

Other sources of information were:


Jackie Williams wrote some of the content and organized the module in its present format for WebCT.
Introduction - What is Angiography?

Angiography techniques specifically image and diagnose diseases of the blood vessels, including those in the brain and heart. The most common angiography techniques is x-ray angiography.

In the past, angiography was typically used to diagnose pathology of the vessels, such as plaque formation, but now radiologists, cardiologists and vascular surgeons also are using x-ray angiography procedures to guide minimally invasive surgery of the vascular system, and particularly of the cardiac arteries.

To distinguish the type of vessel, the term arteriography is used for the study that visualizes arteries, and venography for the veins. For examinations of the arteries of the heart, the carotid artery, or the major arteries branching off the aorta, the catheter is usually inserted into the artery in the groin, but the artery in the arm can also be used.

The basic principles for x-ray angiography are the same as for a conventional x-ray. The differences in x-ray attenuation are measured by an image intensifier and the resulting image is picked up by a TV camera. In modern angiography systems, each frame of the analog TV signal is then converted to a digital frame and stored by a computer in memory or on a hard magnetic disk.

In recent times, MR, CT and/or ultrasound diagnostic vascular imaging techniques have been developed for diagnostic purposes, which can be less invasive than x-ray angiography, which requires the insertion of a catheter into the vessel to inject a contrast material.

These x-ray "movies" can be viewed in real time as the angiography is being performed, or they can be reviewed later using recall from digital memory.
The figure below shows a typical x-ray angiographic suite. X rays that are transmitted through the patient (originating below the patient in this example) are detected by an x-ray image intensifier and an image is produced on a television monitor.

Angiography is performed for a variety of reasons, including:

1. The detection of occlusions of blood vessels, possibly in patients with chest pain and suspected as having heart disease.

2. To look for the presence of an aneurysm, possibly in the cerebral vasculature or aorta.

3. To look for a possible tear in a blood vessel and bleeding.

4. For use in vascular surgery or percutaneous vascular intervention, arteriography is the central modality in planning therapy.

5. Many solid organ tumours can be diagnosed and surgical therapy planned based on arteriography.

6. In internal medicine patients, arteriography is important in evaluating hypertension, gastrointestinal bleeding, and pulmonary embolus.
Contrast Agents in X-Ray Angiography

- Blood vessels are not normally seen in an x-ray image, because they do not contrast sufficiently with the surrounding tissues.

- To increase image contrast, contrast agents, which are dense fluids with elements of high atomic numbers, such as iodine, are injected into a blood vessel during angiography. Because of its higher density and high atomic number, iodine absorbs photons more than blood and tissue.

- This creates detailed images of the blood vessels in real time.

- The first contrast media used for intravascular injection were called high-osmolar contrast media (HOCM). (Osmolality is the measure of the particle concentration in a solution.)

- HOCM had osmolalities seven to eight times higher than plasma. This high osmolality caused adverse effects such as pain, endothelial damage, thrombosis, and increased pressure in the pulmonary circulation.

- Low-osmolar contrast media (LOCM) were first developed in the 1970’s and these helped to reduce these side effects.

- One of the major risks of modern iodine contrast media is an allergic reaction to iodine.

- Different types of contrast agents are used for other imaging modalities as will be described later in this module.
How is X-Ray Angiography Performed?

During x-ray angiography, patients may be sedated to reduce anxiety. Their heart rate and rhythm, breathing, and oxygen saturation are monitored throughout the procedure. A local anesthetic is usually used in the area where the catheter is to be inserted, most commonly the femoral artery.

First, a short, thin wire with a rounded tip is carefully inserted into the artery using a needle. Fluoroscopy is used to guide the needle to the proper position for injection.

The needle is then removed and a vascular sheath is inserted around the wire. The catheter is then inserted along the guide wire.

When the catheter is in the correct position, the wire is pulled out and dye is inserted through the catheter. The patient often experiences a slight burning sensation in the area, but this disappears after a few seconds.

Images are acquired during contrast injection. Injections can be made directly into the artery of interest (selective arteriography), or intravenously. The intravenous method is safer, but the images have less contrast.

The normal injection site for selective cerebral arteriography is in the left and right carotid arteries, which are the main blood supply to the brain.

Complications from an arteriogram are very rare, but there is some risk. Most problems that occur can be detected at the time of the procedure or in the immediate post-procedure. The artery may be injured at the puncture site or along the artery where the catheter is passed.

Besides allergic reactions to the iodine, the contrast can also cause injury to the kidneys, most commonly in patients that already have renal insufficiency.
Why Perform X-Ray Angiography?

Stenosis of the carotid arteries is one of the most common causes of cerebrovascular accidents. Severe narrowing by an atherosclerotic plaque diminishes the blood supply to the brain. This can lead the artery to be blocked by a clot, or allow small bits of blood clots or other debris to float from the plaque to the brain. Any of these events can lead to a stroke or a transient ischemic attack (TIA).

When a patient's symptoms or examination raises the possibility of narrowed carotid arteries, the first test usually performed is a Doppler ultrasound scan. If a significant narrowing is detected, confirmation using x-ray angiography is usually required. Carotid arteriography is the most definitive test to confirm the presence of arterial narrowings. The figure opposite shows a typical intravenous angiogram.

Typical x-ray angiogram showing:

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<tr>
<td>A.</td>
<td>Aorta</td>
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<tr>
<td>B.</td>
<td>Left and Right Common Carotid Arteries</td>
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<tr>
<td>C.</td>
<td>Vertebral Arteries</td>
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In the above figure, (A) shows a normal arteriogram of the carotid artery in the neck. There are two main branches of the common carotid artery (CCA), the external carotid artery (ECA) and the internal carotid artery (ICA). Narrowing most commonly occurs at the bifurcation, called the carotid bulb. Notice that the artery at the level of the base of the brain is also seen. This level cannot be seen with ultrasound and is one reason that arteriograms provide additional information. Note also the subtraction artifacts in the top half of the image. (B) shows a severe stenosis (S) of the internal carotid artery. This is the severity of narrowing that usually would require surgery. (C) shows a similar narrowing with an ulcer (U), or crater within it. The ulcer allows debris that collects within the plaque to float to the brain. Ulcerated plaques are more likely to cause strokes than smooth plaques like that in (B).
Digital Subtraction Angiography (DSA)

In standard x-ray angiography, the images of the vessels are often obscured by bone, particularly when the vessels within the skull are being imaged.

Digital subtraction angiography (DSA) was developed to improve vessel contrast. This is a technique that uses a computer to subtract two images, obtained before and after contrast media is injected into the vessels of interest. The anatomical structures that are the same in the two images can be removed and the resulting image shows the vessels only.

The idea of subtraction images was first proposed by the Dutch radiologist Ziedses des Plantes in the 1930’s, when he was able to produce subtraction images using plain film.

Modern DSA systems are based on digital fluoroscopy/fluorography systems, which are equipped with special software and display facilities.

The image before the contrast agent is administered is called the mask image. Once the contrast is administered, a sequence of images are taken by a television camera in analog form, which is then digitised by computer.

The DSA processor has two separate image memories, one for the mask and the other for the images with contrast medium. These two image memories are subtracted from one another arithmetically, and the result goes to an image processing and display unit.
DSA systems can perform considerable post-processing of images. The processing options include windowing (a technique for enhancing contrast in the image), filtering, and quantitative measurements. They can also correct for any motion shift that has occurred in the mask image. For perfect subtraction the mask can be moved a few pixels or perhaps just a fraction of a pixel (this is called pixel shift).

A website that shows the process of motion correction in DSA images can be found at:

http://www.isi.uu.nl/Research/Gallery/DSA/

On the right the mask image with dye is subtracted from the mask image (prior to contrast injection) to reveal just the vessels uncontaminated by overlying bone structure. (From Bushberg et al. 2003)
This is a mask image showing the background bone which obscures many of the smaller vessels.

Subtracted image with the background details removed.

Both images from Bushberg et al. 2003
CT Angiography (CTA)

- CT (computed tomography) angiography (CTA) uses CT to visualize blood flow in arterial vessels throughout the body.

- CT combines the use of x rays with computerized analysis of the images. One of the most important advantages of CT angiography over conventional angiography is that CT angiography is inherently 3-dimensional, whereas conventional angiography produces only 2D projection images.

- Beams of x rays are passed from a rotating device through the area of interest in the patient's body from several different angles so as to create cross-sectional images, which then are assembled by computer into a three-dimensional picture of the area being studied.

- Conventional catheter-based angiography involves injecting contrast material into an artery, but CTA is much less invasive procedure. The contrast material is injected into a vein rather than an artery.

**Typical CT angiograms of the head (top) and leg (bottom)**
CT Angiography

CTA is commonly used to:

- Examine the pulmonary arteries in the lungs to rule out pulmonary embolism, a serious but treatable condition.
- Visualize blood flow in the renal arteries, those supplying the kidneys, in patients with hypertension and those suspected of having kidney disorders. Narrowing (stenosis) of a renal artery is a cause of high blood pressure in some patients, and can be corrected surgically. A special computerized method of viewing the images makes CT renal angiography a very accurate examination. It is also done in prospective kidney donors.
- Detect atherosclerotic disease that has narrowed the arteries to the legs.
- CTA also is used to detect narrowing or obstruction of arteries in the pelvis and in the carotid arteries bringing blood from the heart to the brain.
- When a stent has been placed to restore blood flow in a diseased artery, CT angiography will show whether it is serving its purpose.
- Examining arteries in the brain may help reach a correct diagnosis in patients who complain of headaches, dizziness, ringing in the ears, or fainting.
- Identify atherosclerotic disease, aneurysm, or dissection in the body's main artery, the aorta and its major branches, the iliac arteries. Dissection means that the layers of the artery wall peel away from each other—like the layers of an onion.
- Injured patients may benefit from CTA if there is a possibility that one or more arteries have been damaged.
- In patients with cancer it can show the details of arteries supplying the tumour.
CT Angiography – Advantages and Disadvantages

**Advantages**

- CT Angiography is considerably faster than conventional x-ray angiography, taking approximately 15 minutes.
- It is less expensive than conventional angiography.
- CT images provide 3D information, which can give important views of plaque morphology, or the structure of an aneurysm.
- As compared to MRA, CTA is more widely available and can be more robust, at least as compared to MR techniques that do not use contrast agents.

**Disadvantages**

- CTA does not have the same degree of spatial resolution as conventional angiography.
- CTA is more invasive than MRA due to its reliance on iodinated contrast media.

If you would like more information on CTA there is an excellent article giving details of how it performs on different vessels at:

[CT Angiography of the Systemic Arterial System](#)
MR angiography (MRA) is just an MRI study of the blood vessels and can be used to detect and diagnose heart disorders, stroke and blood vessel diseases, and for interventional treatments.

MRA can provide good images of blood vessels without using any contrast material, although contrast agents may be used to improve the quality of the MRI images. The contrast agent usually used for MR is a compound called gadolinium. Gadolinium has proved to be safe and the risk of an allergic reaction is low.

As there is no need to insert a catheter into an artery, the procedure itself and the time needed to recover are much shorter, and the costs are less.

Advanced 3-Dimensional techniques can also be used, and recent studies have shown that high-resolution 3D MR angiography is comparable to conventional catheter-based angiography in differentiating between patent (unblocked) and occluded vein grafts after coronary artery bypass surgery. It also can be used in the assessment of vein graft disease.
There are two main types of MR angiographic techniques that do not use contrast media, which are:

**Time of flight (TOF) MR angiography**

1. **Phase contrast (PC) MR angiography**

These techniques are very different, each having its own advantages and disadvantages, but both can be used with 2D or 3D volume acquisitions. All angiographic techniques use methods that enhance the MR signal from the vessels.

There is a third technique that uses contrast media:

3. **Contrast medium enhanced (CM) MR angiography**

   This method needs a fast gradient system and so has only been used clinically for the past few years. It uses a rapid bolus infusion of high dose contrast media, and then the image acquisition is carefully timed during the passage of the bolus through the vasculature.

If you need more detailed information on this subject, there is an excellent paper by Frank R. Korosec, PhD at the University of Wisconsin at Madison at the following link:

[Basic Principles of Phase Contrast, Time-of-Flight, and Contrast Enhanced MR Angiography](#)
MR Angiography (MRA)

Some of the most frequent vessels studied in MRA include the Circle of Willis (and its main branches) in the brain and the carotid bifurcation in the neck.

The basic principle is that special pulse sequences are used by the MR scanner which causes flowing blood to appear very bright, and all stationary tissue to appear very dark.

If arterial structures are being studied, additional pulses are applied to erase the signal in veins. Multiple slices are obtained at adjacent levels through the region of interest. A computer then stacks these images on top of each other and creates a 3D image similar in appearance to a contrast angiogram, although no contrast agent is used. The constructed images can be rotated 360 degrees so that the vessels can be studied in all projections.

The figure opposite is an example of the raw images created by the scanner.

Raw MRI images where flowing blood appears white

Note that the vessels are bright and all of the surrounding tissues are dark.
MR Angiography (MRA)

Three views of an MR angiogram
This figure demonstrates the appearance of the MRA. The same data can be used to create sagittal, transverse and coronal images.
Intravascular Ultrasound (IVUS)

Intravascular ultrasound (IVUS) is used in cardiology as an adjunct to coronary angiography and coronary angioplasty. Before IVUS, the only way to view the coronary arteries was by using angiography or catheterization. IVUS is performed during cardiac catheterization. A tiny ultrasound transducer is threaded into the coronary arteries to give a cross-sectional view from the inside-out. The images are able to differentiate where the normal artery wall ends and the plaque begins to evaluate the extent of blockage in the artery, and they can also distinguish any calcification.

The use of IVUS gives the cardiologist another tool to help to select the best treatment options, or, after a procedure, to evaluate the success of the treatment.

Recently, IVUS has been found to be effective in evaluating pulmonary hypertension by measuring the wall thickness of the pulmonary arteries.

Intravascular ultrasound is able to:

- Measure the velocity of blood flow within the artery. This helps to determine the extent of a blockage to ascertain the extent to which the heart muscle is compromised by lack of blood flow.

- Show not only the severity of the narrowing produced by a blockage, but also the composition of the underlying atherosclerotic plaque. This information is very important in choosing the optimal angioplasty procedure to treat the blockage.

- Give the surgeon an immediate assessment of the angioplasty procedure while the catheters are still place. If the procedure must be extended, it can be completed without the patient needing a return visit, with all the attendant stress, and the administration of more anesthesia.