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 1 Quiz under the Quizzes icon on the Course Home Page.
I would like to thank Dr. Donal B. Downey, Interventional Radiologist at London Health Sciences Centre, London, Ontario, who provided most of the content for this Module.

Jackie Williams also wrote some content and organized the module in its present format for WebCT.

Other material was used from the following sources:


Objectives

After studying this module the student will:

1. Be able to discuss the roles that vascular imaging has in managing patients.

2. Be able to list the common indications for vascular imaging.

3. Be competent in describing the commonest clinical manifestations of atheromatous arterial disease.

4. Be able to describe the commonly used imaging techniques and discuss the strengths and weaknesses of each imaging method.

5. Know some indications and contraindications for each imaging method.

6. Know some of the risks associated with each imaging method.

7. Be able to describe how each of the tests is performed.
Introduction

- Vascular imaging is playing an increasingly important role in modern medicine.

- Vascular atheromatous disease is now the number one killer in developed countries, and vascular imaging has a crucial role in diagnosing these diseases. It is used to guide interventional procedures such as angioplasties, in monitoring patient response to therapies, and in the detection of malignancies and other pathologies.

- Between all the different vascular imaging modalities there is a trade-off between quality of image, the degree of invasiveness, and/or cost. For example, the best detailed imaging of the coronary arteries is obtained with angiography. The procedure, however, is invasive, uncomfortable, has a definite morbidity risk, is expensive, and carries a slight mortality risk. In contrast, carotid ultrasound and Doppler imaging are less expensive and safer, but they are somewhat less accurate.

Angioplasty through a plaque:
Diagram of an angioplasty balloon that was guided across an atheromatous plaque. The balloon was inflated. The vessel narrowing was cured and the surface of the plaque developed tiny surface fractures (arrows).

The goal of this course is to familiarize students with the commonly used imaging techniques that are used for the more frequently encountered pathologies.
Pathologies Where Vascular Imaging is Necessary

- **Arterial Damage**
  An example of this would be when the thoracic aorta is transected (torn across) following a deceleration injury in a motor vehicle accident.

- **Ischemia**
  This is a condition in which the flow of oxygen rich blood to a particular part of the body is restricted. This can be due to heart disease, **arterial** or **venous** disease.

- **Arterial Ischemia Due to Vessel Narrowing**
  Examples include kidney damage downstream from an area of renal artery stenosis or brain injury in the area supplied by a severely narrowed internal carotid artery.

- **Arterial Ischemia Due to Emboli**
  An embolus is usually a blood clot, but may be fat, a gas bubble, or a fragment of plaque or other tissue that travels in the blood. If material such as a portion of atherosclerotic plaque breaks off in a large central vessel such as the aorta, it may lodge in a peripheral vessel such as an artery in the foot, and than local gangrene can result with tissue death.

- **Venous Ischemia**
  For example, the kidney may be irreversibly damaged if the draining of the renal vein is completely blocked, causing the kidney to swell, which will eventually impede all arterial flow.

- **Hemorrhage**
  During a hemorrhagic stroke the sheer pressure of blood exiting from a damaged blood vessel destroys adjacent brain tissue. The aim is to quickly identify the bleeding site and stop the bleeding.
What is Ischemia?

All tissues in the body require oxygen and nutrients for them to function properly. The blood circulatory system is the major system that fulfills this need. If it fails – ischemia or lack of oxygen occurs. If the blood flow is completely cut off the tissue that it supplies dies. e.g. if a coronary artery is blocked the cardiac or heart muscle may die. If a major artery to the brain (e.g. an internal carotid artery) gets blocked a variable portion of the brain will die.

If the blood flow to an areas is diminished but not completely blocked, then the tissue may not die but will not function properly, e.g if the leg arteries are narrowed, patients may be able to walk for a short distance before lactic acidosis builds up in their calves causing cramp like pain to occur. If they rest for a while, the pain will pass as more blood enters the legs, clears the lactic acidosis and allows the patient to walk for another short distance. This is called intermittent claudication.

Angiography shows the right common iliac artery (L1) is normal. The left artery is severely narrowed and is being measured (L2) prior to insertion of a stent.

In German, this is called “shop window disease”, as patients will stop when the pain occurs and look at a shop window. They rest at the shop window until the lactic acidosis clears and then walk on. By adopting this policy they can pretend they don’t have leg ischemia problems.
Pathologies Where Vascular Imaging is Necessary

CT of the abdomen:
The hyperdense region at the pancreatic head (arrow) is a large pseudoaneurysm of an artery that if not treated could cause this patient to bleed to death.

Screening patient with high risk of vascular disease
For example, patients with autosomal dominant polycystic kidneys are at high risk for having Berry aneurysms in the brain and are screened with MRI or CT to rule out these aneurysms.
Atheromatous disease is the biggest killer of people in the western world. The process starts in teenagers with the deposit of fatty streaks in the inner layer of the artery - the intima. These will progressively get bigger and the fatty streak may develop inflammation and may bleed. As it gets bigger, its surface may ulcerate (red arrow). This ulceration may cause blood flowing in the lumen to clot and further narrow the vessel. The fatty lesion with possible inflammation, hemorrhage, surface ulceration and calcification is called a plaque (P).
How Does Atheroma Cause Disease & Death? (1)

With early atheroma the blood vessels compensate for the narrowing caused by the plaque by expanding above and below the narrowing as seen in figures A and B adjacent.

However, when the atheromatous plaques grow large, the vessels cannot compensate, and so the volume of blood flowing through them decreases too much leaving the tissues supplied by these arteries deficient in their blood supply. These deficit changes are called ischemia.
If the surface of the plaque becomes fissured (cracked) then the blood in the lumen is exposed to tissue in the plaque that promotes blood clotting. This can cause a new clot to form in the area (white arrow). This can narrow the vessel further, or the clot can break off and block another smaller branch vessel downstream.
Peripheral vascular disease affects about 4% of the population, and is commonest in smokers and older people. It causes leg pain, limitation in mobility, skin ulcers, gangrene and limb loss. Most sufferers are never diagnosed, let alone treated. It has a 25% mortality over 5 years.
Heart Attacks

- Heart attacks or myocardial infarcts are the commonest cause of death in the western world.

- Patients usually present with chest pain and shortness of breath.

- Death occurs either due to muscle death (the heart muscle is not able to circulate the blood around the body once its own blood supply is cut off) or arrhythmias (temporary electrical disturbances).

- If you know basic CPR (cardiopulmonary resuscitation techniques), you can save people’s lives by keeping their brain supplied with oxygen during this temporary arrhythmia

- Coronary angiography usually shows narrowing (see arrow) or blockage of a coronary artery in the heart.

- If the patient is treated early enough it may be possible to revascularize the heart with blood thinning drugs and/or angioplasty.
Strokes

- Strokes result in irreversible brain damage.

- Symptoms include motor symptoms such as unilateral or bilateral paresis (weakness) or paralysis. Sensory symptoms such as a loss of sensation from one area of the body may occur as can balance problems. Difficulty speaking or performing fine motor skills may occur. Higher cerebral functions such as reasoning and articulation may also be affected.

- They can be ischemic (a) or hemorrhagic (b)

- Recovery is variable. Sometimes considerable functional recovery may occur with new brain pathways being recruited to replace the damaged ones.

- Recently, clinicians are becoming more aggressive in trying to re-establish circulation to the brain as soon as possible after symptoms occur. This strategy is showing encouraging results.

(a) Ischemic stroke. An embolus from a complex internal carotid plaque blocked blood to a portion of the right cerebral hemisphere (white arrow)

(b) Hemorrhagic stroke. A bleed occurred into the tissue in the right cerebral hemisphere (arrow).
**Heart Imaging**

**Heart** - The cardiac chambers (atria and ventricles) are imaged to assess the function of the heart valves, that the muscular chambers pump appropriately, and that the coronary arteries (the arteries that supply the heart muscle itself) are patent (have normal, unblocked flow). If they block, a “heart attack” or coronary thrombosis occurs, resulting in the death of the portion of the heart muscle they supplied with blood.

**MR Heart**
The pulmonary arteries are highlighted as they are projected over the heart.

**CT Heart**
CT and coronary angiogram showing area of stenosis in the left anterior descending artery (yellow circles).
Aortic Arch Imaging

**Aorta and IVC** (Inferior Vena Cava)
These large blood vessels may be congenitally malformed, damaged by traumatic injuries, or be affected by degenerative changes such as atheromatous disease.

**Angiogram of the Aortic Arch:**
This patient just had a blockage (Image A - lower left - red arrow) in one of his main vessels in his upper chest (left subclavian artery) cleared by angioplasty (Image B – lower right). Note the intravascular catheter (yellow arrows) is still in position. A=aorta
The pulmonary arteries and pulmonary veins
Arteriovenous malformations may occur in the lungs but pulmonary thromboembolic disease is a much more frequent clinical situation for which these blood vessels are imaged – most commonly with CT.

CT pulmonary angiogram showing a pulmonary embolus in the right main pulmonary artery (white arrow)

Metal filter (red arrow) deployed in the IVC to prevent emboli from the legs reaching the lungs and causing death.
Mesenteric vascular imaging – The mesenteric vessels supplying the large and small bowel can have atheromatous stenoses and embolic phenomena that lead to abdominal pain and possible infarction of the bowel. In patients with profuse rectal bleeding mesenteric angiography may localize the bleeding site.

Inferior mesenteric angiogram showing colonic bleeding site (arrow). This was successfully embolized.
Liver and Pancreas – Vascular imaging is important in detecting cancers in these organs, in characterizing them and in staging them adequately. Staging refers to the classification of the disease stage and is important for assigning a prognosis to a particular patient and to help patients and physician choose the best treatment.

MR and the angiographic appearance of this lesion proved it was a benign lesion without biopsy or surgery. It is a “focal nodular hyperplasia” (FNH)
Kidneys

The kidneys also require forward blood flow throughout the cardiac cycle. These can be damaged by trauma, narrowing or blockage of the renal arteries or narrowing or blockage of the renal veins.

Renal artery stenoses (yellow arrows). Note there are also stenoses in the left common iliac artery (purple arrows). Normal angiogram from another patient.
Portal Venous Imaging

Imaging the portal venous system involves blood vessels that drain blood from the large and small bowel to the liver. This blood system is quite different from the rest of the vascular system as it typically contains a higher concentration of toxins and nitrogen containing molecules than the rest of the vascular system.

The rest of the body needs to be shielded from these toxins and nitrogen rich molecules, as they impair proper function of the rest of the cells in the body. This portal venous blood is effectively filtered by the liver before it can circulate safely through the rest of the body. The portal venous system frequently becomes dysfunctional when severe liver disease occurs such as cirrhosis. If the liver’s filtering ability decreases, blood pressure typically increases in the portal system. This can cause the vessel walls to develop life-threatening bleeds from a variety of areas within the abdomen.

Pseudoaneurysm in the liver in a post liver transplant patient. Colour Doppler shows the hepatic vein (H) the portal vein branch (P) and the pseudoaneurysm (arrows).
Peripheral arteries can be directly injured following trauma, or the vessels can become narrowed either by localized atheroma or by the presence of emboli. These patients frequently present with symptoms of limb pain and possible skin damage. The disease process is more common in the lower limbs compared with the upper limbs.

Translumbar aortogram in a 43 year old smoker with no palpable groin pulses. A needle (white arrows) is inserted into the back and the aorta canulated (upper image shows where needle was inserted). Contrast is injected and a tight stenosis (red arrow) is seen just above the aortic bifurcation.
Imaging the Veins

Venules are the small venous channels that collect the blood from the capillaries.

The other veins vary in size but typically correspond in size and in location to the adjacent artery. They typically carry deoxygenated blood at a low velocity.

They are affected by a different set of diseases than the arteries. Blood clots are probably their biggest problem and they are not affected by atheroma.

Veins can develop thrombi within them, which can impair the vein’s ability to return blood to the heart. This can result in local skin damage - varicose edema and leg swelling. The clots can also migrate centrally in the venous system to the lungs where they are blocked by the capillary beds in the lungs. If this occurs the resulting impairment of lung function can be so severe that it results in death.

Typical venogram showing the deep veins of the calf (a) and the knee region (b) filled with contrast that was injected into the foot. The veins all appear normal.
These are the imaging modalities most commonly used in imaging vascular disorders.
Angiography is a generic term that refers to diagnostic studies of both arteries and veins. X-ray angiography remains the primary means of evaluating vascular disease in the body. The figure opposite 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.

The vasculature generally does not normally show up in an x-ray image. To acquire an angiogram, it is necessary to inject the patient with a radio-opaque "contrast" liquid containing iodine. Arteriography is the study that visualizes arteries using a radio-opaque contrast agent, and venography is the study of veins.
Patients may be sedated to reduce anxiety while monitoring heart rate and rhythm, breathing, and oxygen saturation. A catheter is usually inserted into the femoral artery and fluoroscopy (x rays operate continuously while a moving picture is viewed on a video display) is used to guide the catheter to the proper position for injection. Images are acquired during contrast injection.

Injections can be made intraarterially directly into the artery of interest (selective arteriography), or intravenously which is safer but produces images in which the arteries have less contrast (harder to see). The left and right carotid arteries are the main blood supply to the brain and the normal injection site for selective cerebral arteriography.
Most angiograms are performed by injecting contrast through a catheter. This is usually introduced percutaneously via the common femoral artery.
The needle is inserted into the artery at an oblique angle (A).

When the needle tip is in the lumen the centre stylet of the needle is removed.

A guide wire is then gently introduced through the needle into the common femoral artery (B).

Gentle pressure is applied to the artery with the index and middle fingers and the needle is withdrawn, leaving the guide wire in the artery (C).

A catheter is then guided over the guide wire (D). When the catheter is safely inserted, the catheter is guided to the appropriate location under imaging guidance.
## X-Ray Angiography

Angiography is performed for a variety of reasons, including:

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<td>1.</td>
<td>The detection of occlusions of blood vessels, possibly in patients with chest pain and suspected as having heart disease.</td>
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<td>2.</td>
<td>To look for the presence of an aneurysm, possibly in the cerebral vasculature or aorta.</td>
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<td>3.</td>
<td>To look for a possible tear in a blood vessel and bleeding.</td>
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<td>4.</td>
<td>For use in vascular surgery or percutaneous vascular intervention, arteriography is the central modality in planning therapy.</td>
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<td>5.</td>
<td>Many solid organ tumors can be diagnosed and surgical therapy planned based on arteriography.</td>
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<td>6.</td>
<td>In internal medicine patients, arteriography is important in evaluating hypertension, gastrointestinal bleeding, and pulmonary embolism.</td>
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![Normal Digital subtraction flush aortogram showing the abdominal aorta (A), the common iliac arteries (I), and multiple renal arteries coming off either side of the aorta.](image)
Renal Angiography

Renal angiography is the best way of demonstrating the arterial anatomy in the kidney. As there are frequent normal variants it is an important tool in planning renal surgeries, especially for patient donating their kidneys to a renal failure patient.

**Normal Digital subtraction flush aortogram** showing the aorta (a), the common iliac arteries (I), the renal arteries (arrows), the hepatic artery (h) and the splenic artery (s).

**Selective right Digital subtraction right renal angiogram** shows much better detail of the intra-renal vessels but is more risky than the flush aortogram.
To perform a digital subtraction angiogram a baseline radiograph of the area is performed (A). Intravascular contrast is then administered and a second image is obtained (B). The first image is then digitally subtracted from the second and there remains only the contrast enhanced vessels (C).
For **Angioplasty** procedures a catheter is introduced across the stenosis (A) and the balloon is inflated (B). This widens the narrowed vessel.

For **stent insertion** procedure a wire is introduced across the stenosis (C) and the balloon within the stent is inflated (D). This widens the narrowed vessel and the stent keeps it open.
A. Aortogram shows stenoses of the distal aorta (red arrow) and the origin of both common iliac arteries (yellow arrows).
B. Angioplasty balloons have been inserted from below from both common femoral arteries to transverse the stenoses.
C. The angioplasty balloons are then inflated.
D. Post angioplasty angiogram shows the vessels have been recanalized.
Ultrasound uses high frequency sounds to construct an image based on the fact that different tissues reflect high frequency sounds differently. During an ultrasound examination, a transducer that both emits the sound and detects the returning echoes is placed on the body part being studied (see figure opposite).

When the emitted sound encounters a border between two tissues that conduct sound differently, some of the sound waves bounce back to the transducer creating an echo (This process will be explained in more detail in Module 4 – Ultrasound Imaging).

Typical duplex ultrasound system being used in an examination of the carotid arteries.
Ultrasound

There are different modes used in ultrasound, with B-mode (brightness mode) being probably the most familiar, as this is the mode used to image babies in utero. B-mode ultrasound imaging uses only the amplitude information in the backscattered signal to generate the image, with the differences in the strength of the different reflector interfaces (e.g. between the liver and diaphragm) being displayed in the image as varying shades of gray.

Although B-mode only uses the amplitude information, other information is used in additional ultrasound modes, such as M-Mode (motion mode), and Doppler ultrasound, including colour flow and continuous wave Doppler. Doppler techniques are described more fully in Module 5 – Doppler Ultrasound.

The figure opposite is from:

Some of the common uses of ultrasound are:

1. Echocardiography looking at the heart structure including heart valves and chambers of the heart as well as heart function.

2. Carotid arteries using Doppler ultrasound to measure blood flow.

3. Abdominal ultrasound looking at different organs such as gallbladder, liver, kidneys, pancreas, and biliary tree.

4. Pelvic ultrasound looking at structures such as the ovaries, uterus and developing babies.

Colour Doppler image showing a venous pseudoaneurysm (white arrow) and an arteriovenous fistula (yellow arrow).
The advantages of ultrasound include the lack of ionizing radiation, relatively low cost, and real-time (moving picture) display. Disadvantages are the need for a highly-skilled operator and the inability to get around bone and gas. In the last few years, methods have been developed for producing 3-D doppler ultrasound images.

Colour Doppler image details of the normal vessels in the patient’s kidney. These images can be obtained at the bedside without the patient having to come to the radiology department.
Doppler Ultrasound

Blood flow can be imaged using various Doppler techniques, such as Doppler frequency shift, Colour Flow and Power Mode Doppler, Continuous Wave and Pulsed Wave Doppler.

The figure above is a Doppler frequency spectrum showing changes in flow velocity and direction as vertical deflections of the waveform above and below the baseline.

This figure shows a colour flow Doppler image. Backscattered signals from red blood cells are displayed in colour as a function of their motion toward or away from the transducer.

Doppler echocardiography detects the direction and velocity of moving blood within the heart. The technique can be used for detecting cardiac valvular insufficiency and stenosis, as well as other abnormal flow patterns. Doppler echocardiography has reached a remarkable level in just the past few years. Doppler methods extend the use of cardiac ultrasound into the evaluation of flow states and provide quantitative data facilitate the clinical decisions for patients with heart disease.

Obstruction to flow usually results in an increase in velocity. Turbulent flow is characterized by disordered directions of flow in combination with many different red cell velocities. If the obstruction is significant, some of the red blood cells may be moving at higher velocities than normal and may reach speeds of 7 m/sec. Turbulent flow is usually an abnormal finding and is considered indicative of some underlying cardiovascular pathology.

All Doppler systems have audio outputs and listening to this is very helpful during a Doppler examination. The changing velocities (frequencies) are converted into audible sounds and, after some processing, are emitted from speakers placed within the machine.

High pitched sounds result from large Doppler shifts and indicate the presence of high velocities, while low pitched sounds result from lesser Doppler shifts. Flow direction information (relative to the transducer) is provided by a stereophonic audio output in which flow toward the transducer comes out of one speaker and flow away from the transducer.
Computed Tomography (CT)

CT is the process of using computers to generate three-dimensional images from two-dimensional x-ray pictures, slice by slice (from the Greek, tomos, meaning section). CT is sometimes referred to as CAT scanning (Computed Axial Tomography), which just refers to images created parallel to the longitudinal axis of the body. This term is not used much anymore, as images can also be acquired by transverse tomography, perpendicular to the long axis.

CT was the first widely used digital imaging modality and it is still the workhorse of most hospitals throughout the world, being cheaper, faster, and more available than magnetic resonance imaging (MRI). CT is used for the whole body, including the brain and internal organs.

A CT scanner looks like a large square doughnut. It has an opening measuring about two feet in diameter that surrounds a narrow table. Inside the frame of the scanner is a rotating device with an x-ray tube mounted on one side and a curved detector opposite it.

CT combines the use of x-rays with computerized analysis of the 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, creating cross-sectional images, which then are assembled by computer into a three-dimensional image. This 3-D image can be interrogated slice by slice on the computer display. CT is described in more detail in Module 3.
CT Angiography (CTA)

The vascular system can be imaged using CT angiography, which involves the intravenous injection of a contrast agent. Nearly all CTA studies use an advanced type of unit called a spiral CT machine that looks like any other type of CT unit, but is able to record a large number of pictures in a short time. This means that patients do not have to hold their breath for a prolonged period.

CT angiography (CTA) is an examination that uses x rays to visualize blood flow in arterial vessels throughout the body, from the arteries serving the brain to those bringing blood to the lungs, kidneys, and the arms and legs. Compared to catheter angiography, which involves placement of a catheter and injecting contrast material into an artery, CTA is a much less invasive and a more patient-friendly procedure; contrast material is injected into a peripheral vein rather than an artery.
Renal CTA

Roles for renal computed tomographic angiography (CTA)

- Evaluation of renal artery stenosis
- Renal artery disease related to aortic disease
- Preoperative evaluation of living related renal donors
- Preoperative evaluation of renal masses before nephron sparing surgery
- Evaluation of minimally invasive procedures such as stent placement, angioplasty, nephron sparing surgery or minimally invasive techniques such as cryosurgery.

Volume rendered image of a CTA study showing excellent detail of the aorta (A), renal arteries (arrows) and the kidneys (K).
Magnetic resonance imaging (MRI) scanning requires the use of a very strong magnetic field but does not use ionizing radiation. The magnet is contained in the housing of the scanner (Figure 10 below) and creates a magnetic field oriented down the bore of the magnet. The patient is placed within the magnetic field by lying on a table which is placed through the center of the opening of the magnet.

The strength of the magnetic field is measured in units called gauss or Tesla: 10,000 gauss equals 1 Tesla. The earth's magnetic field is approximately 0.6 gauss. Most MRI scanners contain superconducting magnets with a field strength of approximately 1.5 Tesla.

In superconducting magnets, the wire conducts the current without resistance because it is cooled to a temperature close to absolute zero (4 K) by being bathed in a jacket of liquid helium.

The electrical current flows continuously around many loops, creating the required magnetic field.

Typical MR Scanner

MRI images can be obtained in any imaging plane without moving the patient. The three standard views usually used are:

**Transverse (axial):** viewed as if standing at the patient's feet (similar to standard CT).
**Coronal:** Viewed from the front.
**Sagittal:** Viewed from the side.
Magnetic Resonance Imaging (MRI)

The physics of MRI are extremely complex, and will be explained in a little more depth in Module 6 – Magnetic Resonance Imaging. When a patient is placed within an MR scanner, the protons in the patient's tissues (primarily protons contained in water molecules) will tend to align themselves along the direction of the magnetic field. A radio-frequency electromagnetic pulse is then applied, which deflects the protons off their axis along the magnetic field. As the protons realign themselves with the magnetic field, a signal is produced. This signal is detected by an antenna, and with the help of computer analysis, is converted into an image.

The process by which the protons realign themselves with the magnetic field is referred to as relaxation. The protons undergo two types of relaxation: T1 (or longitudinal) relaxation and T2 (or transverse relaxation) relaxation.

Different tissues undergo different rates of relaxation, and these differences create the contrast between different tissues. T1-weighted images emphasize the difference in T1 relaxation times between different structures. In these images, water-containing structures are dark.

Since most pathologic processes (such as tumours, injuries, CVA's, etc.) involve edema (or water), T1-weighted images do not show good contrast between normal and abnormal tissues. They do, however, demonstrate excellent anatomic detail. T2-weighted images emphasize the difference in T2 relaxation times between different tissues. Since water is bright on these images, T2-weighted images provide excellent contrast between normal and abnormal tissues, although the anatomic detail is less than that of T1-weighted images.
Magnetic Resonance Imaging (MRI)

The figure below shows a typical T1-weighted image.

This figure shows the difference in appearance between T1 and T2-weighted images.

Intravenous contrast is often used to improve the sensitivity of MR imaging, especially in the brain and spine. MR contrast agents contain gadolinium, which increases T1 relaxation and causes certain abnormalities to "light up" on T1-weighted images. These agents contain no iodine, and allergic reactions are extremely rare.
MR angiography (MRA) permits imaging of the blood vessels in several parts of the body, including in the head, neck (carotids), body, arm and legs. The most frequent vessels studied include the Circle of Willis (and its main branches) in the brain and the carotid bifurcation in the neck.

MR Angiography is a noninvasive method to evaluate the patency of blood vessels. Conventional x-ray angiography requires the insertion of a catheter into an artery (usually in the groin) and carries a certain amount of risk, including infection, vessel rupture, hematoma, occlusion, embolism, and allergies to iodine dye.

Unlike x-ray angiogram, MR angiogram (MRA) is performed either with no dye or with intravenous (as opposed to intra-arterial) injection in an arm vein. The contrast or dye used in MRA has no iodine in it and is much safer than x-ray dye.

Advances in technology are bringing new, more patient-friendly MR designs. Some of these are open MR machines and others have a short-bore design. The new "open" or "C-shaped" MR systems (0.2 to 0.3 Tesla field strength) are typically open on all sides and improve a person's MR experience by lessening claustrophobia.
Safety of MR

Although multiple studies have been performed, no significant permanent biological hazards have been demonstrated as a result of exposure to patients from the magnetic fields or radio-frequency electromagnetic pulses used in magnetic resonance imaging. However, there can be adverse effects on various medical devices implanted into patients and therefore all patients must be carefully screened to determine if MR scanning can be safely performed.

Potential risks include the following:

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<td>1.</td>
<td>Cardiac pacemakers: Absolute contraindication. These patients cannot be scanned.</td>
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<td>2.</td>
<td>Cerebral aneurysm clip: Unless there is documented proof that a non-ferromagnetic clip was used, these patients cannot be scanned.</td>
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<tr>
<td>3.</td>
<td>Metal fragments in body (bullet, BB, shrapnel, etc.): Safe, unless in contact with vital organ, such as heart, spinal cord, eye.</td>
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There appears to be a relationship between the hemodynamics of blood flow and the progression of vascular disease. Unfortunately, only simple flow factors such as velocity can be measured in vivo (e.g. with MRA) while the important hemodynamic factors cannot. One way around this problem is to use MRI to determine the size and shape of an artery (or, for example, the carotid bifurcation which is a common location for vascular disease), MRA to determine the pulsatile velocity at the input and output of the vessel, and to use a computer to simulate the actual flow pattern through the vessel so as to match the input and output conditions. The image at the right is an example of the calculated flow pattern through the carotid artery of a healthy volunteer. The regions of high shear can be determined using this calculation. In the future, it may be possible to use this method to identify patients with an elevated risk of atherosclerotic plaque development.

Lines represent the calculated flow patterns through the carotid bifurcation using MRI to determine the arterial geometry, and MRA to determine the pulsatile flow through each segment.