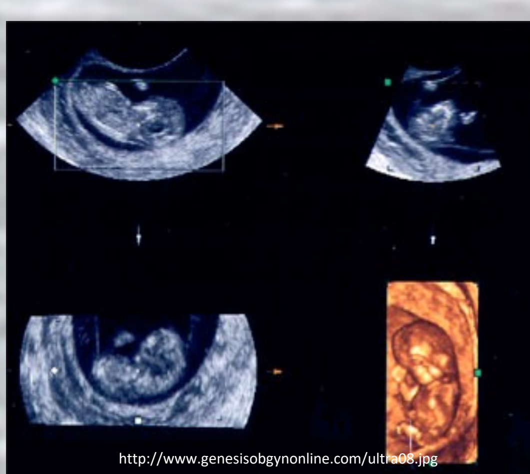
Seeing with Sound II:

- *Doppler Ultrasound with applications to Renal, Cardiac and Obstetrical Ultrasound*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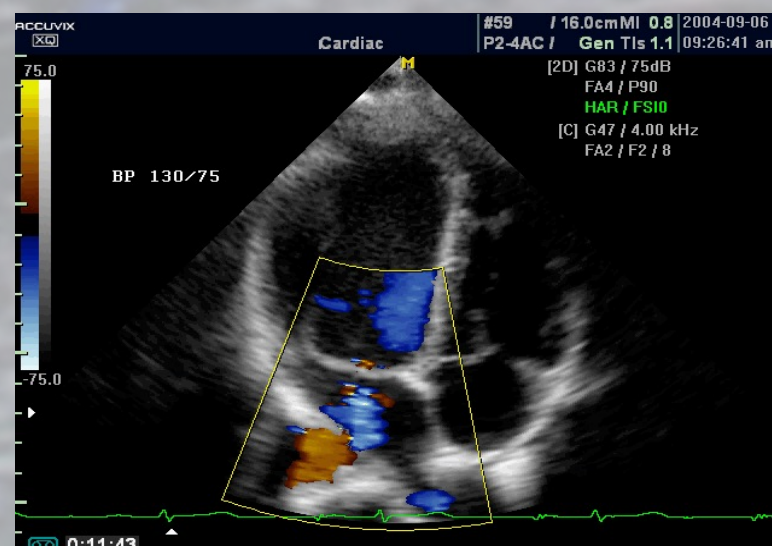

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http://www.medison.ru/uzi/eho365.htm

Diagnostic Doppler Ultrasound

- The basis of Doppler ultrasound is the fact that reflected/scattered ultrasound waves from a moving interface will undergo a frequency shift.

- The reflections from a stationary object undergo no frequency shift.

- In general, the magnitude and the direction of this frequency shift will provide information regarding the motion of this interface off of which the sound is reflecting.

- In medicine, Doppler US is used to detect and measure blood flow, and the major reflector is the red blood cell.

- The red blood cells act like a moving receiver "hearing" an altered frequency, say f_1, which is Doppler shifted from the US beam intensity, f_0 resulting in $\Delta f_1 = f_1 - f_0$.

- The red blood cells also act like a moving source when they reflect the US pulse. The reflected frequency f_1 is Doppler shifted when it returns to the US transducer and the transducer "hears" a frequency f_2 and the result is $\Delta f_2 = f_2 - f_1$.

- The total Doppler shift is the sum of these two frequencies $\Delta f = \Delta f_2 + \Delta f_1 = f_2 - f_0$.

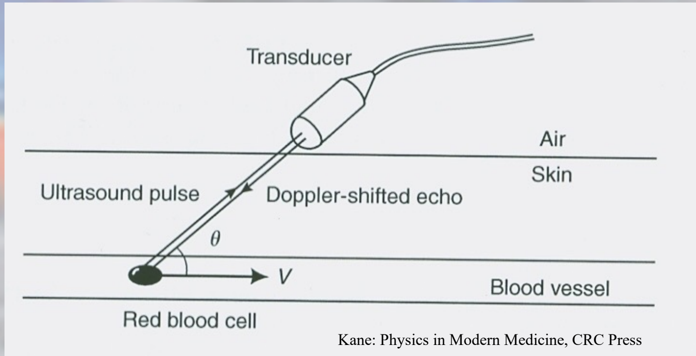
- These frequency shifts, coincidentally, are usually in the audible range.

Diagnostic Doppler Ultrasound

- The Doppler shift is dependent on the sound frequency, the velocity of moving blood, and the angle between the sound beam and direction of moving blood, as expressed in the Doppler equation

$$\Delta f = \frac{2 f v \cos\theta}{v_s}$$

- where Δf is the Doppler shift, or the change in frequency between the source and receiver, v is the velocity of the scatters (red blood cells) parallel to the US beam, v_s is the speed of sound in the medium, and θ is the angle between the incident beam and the velocity of the blood cells.



Kane: Physics in Modern Medicine, CRC Press

- Measuring the Doppler shift in frequency allows for the calculation of blood flow speed.

- Doppler US can be performed with US imaging of say the heart, so the physician can orient the transducer to an artery to determine the flow rate with minimal uncertainty.

Diagnostic Doppler Ultrasound

- We can solve the Doppler formula for the velocity of the blood.

$$v = \frac{v_s}{2f\cos\theta}\Delta f$$

- θ is determined by the sonographer by aligning the transducer to the artery or vein.

- The maximum Doppler shift is when the transducer points parallel to the flow or antiparallel to the flow.

- For $\theta = 90^0$, meaning the meaning that the ultrasound beam is perpendicular to the blood flow, it follows that $\Delta f = 0$ and there is no Doppler shift, which might lead one to believe that there is no flow.

- Also, it is evident that appropriate estimation of the angle θ, also called the angle correction, is essential for the accurate determination of Doppler shift and blood flow velocity.

- θ should also be less than 60^0 at all times, since the cosine function has a steeper curve above this angle, and errors in angle correction are therefore magnified.

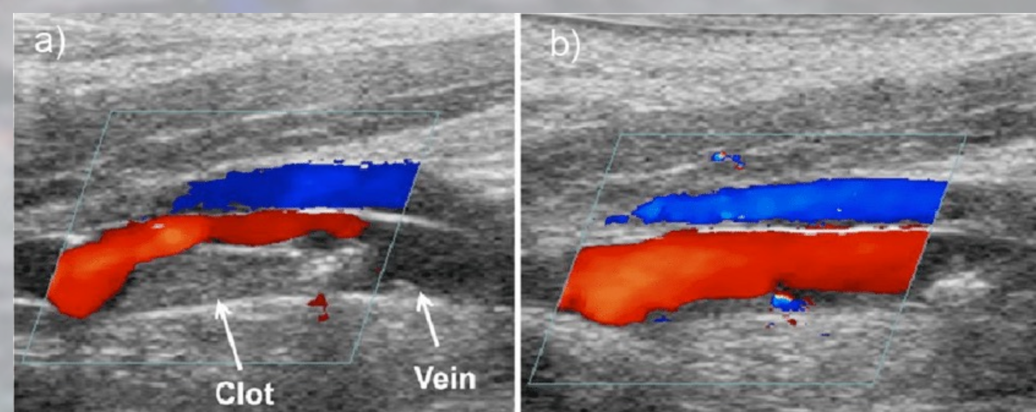
Diagnostic Doppler Ultrasound

- There are several forms for the depiction of blood flow in medical Doppler imaging: color, pulsed Doppler, and power Doppler. We'll look at color Doppler Imaging.

Color Flow Images

- The average Doppler frequency shift of blood flow is depicted in color, and flow direction is assigned a color.
- By *convention*, blue-coded flow is away the transducer ($\Delta f < 0$), and red-coded flow is towards the transducer ($\Delta f > 0$).
- $\Delta f > 0$ is associated with a positive value for the flow speed (fluid is moving toward the transducer) and $\Delta f < 0$ corresponds to a negative flow speed (fluid is receding from the transducer.)

http://www.ucdmc.ucdavis.edu/vascular/images/body/renal.jpg



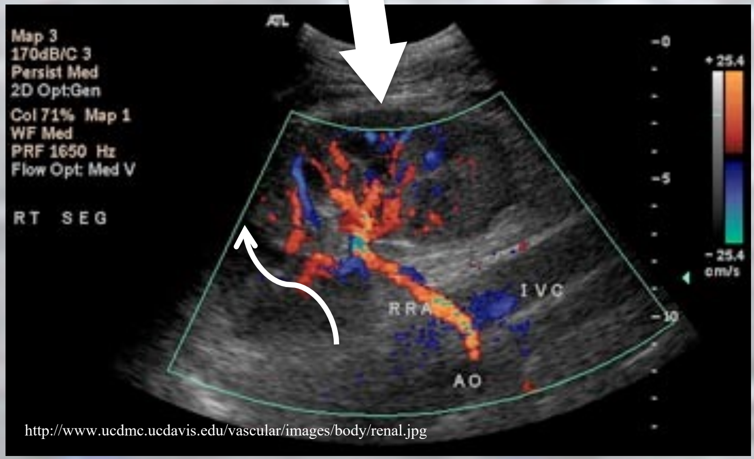
https://www.researchgate.net/figure/Example-image-of-the-Doppler-ultrasound-procedure-a-The-blood-vessel-is-blocked-by-a_fig1_317577803

Diagnostic Doppler Ultrasound

Color Flow Images

- Bright reds usually mean high velocity approaching flows toward the transducer and dim reds are weaker lower velocity flows toward the transducer.
- Bright blues usually mean high velocity flows away from the transducer and dimer blues are weaker lower velocity flows away from the transducer.
- Yellow and green colors usually represent turbulent flow or no well-defined flow direction

A possible transducer orientation and flow indicated.



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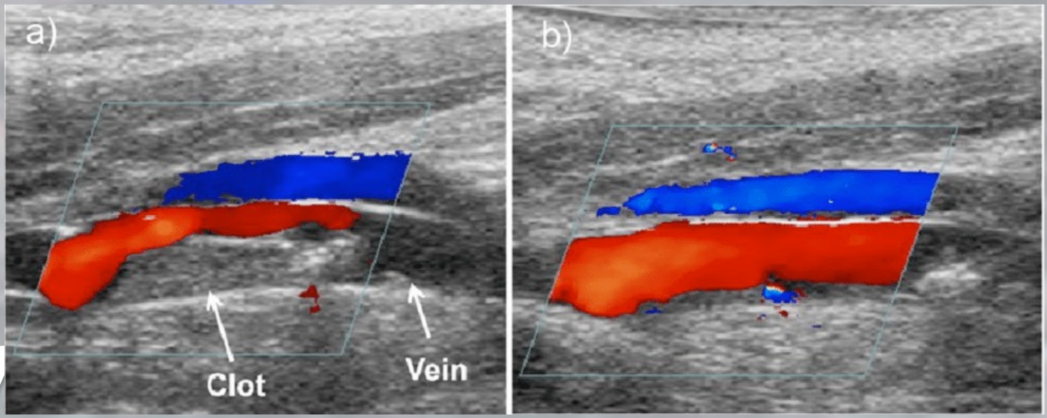

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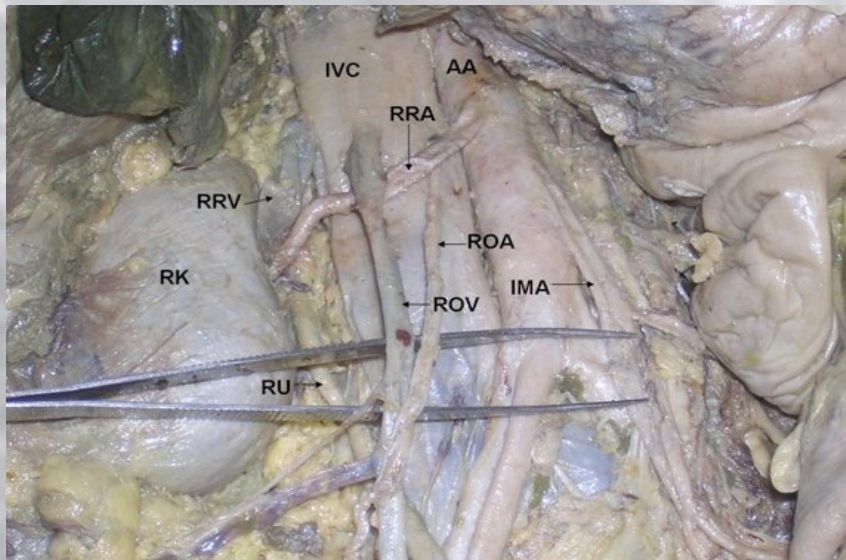
A possible transducer orientation and flow indicated

Kidney Disease & Doppler Ultrasound



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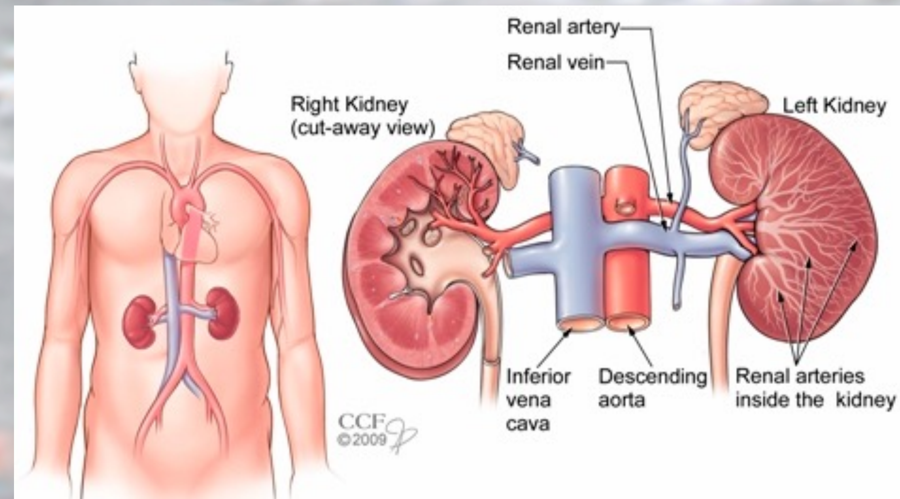
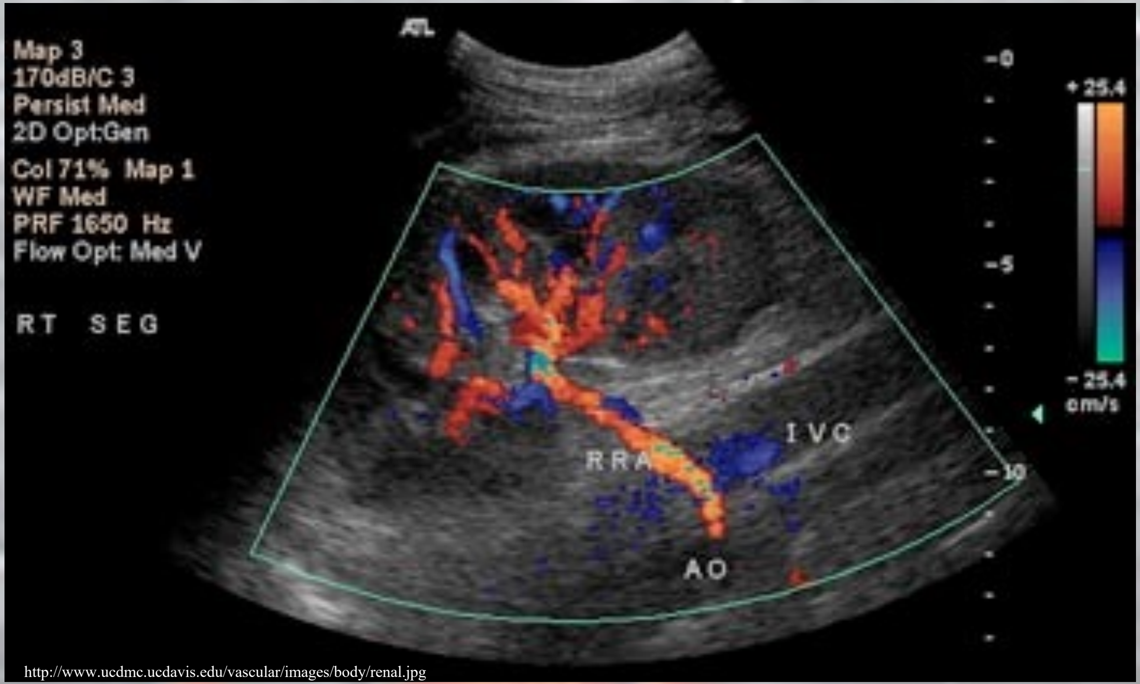


http://my.clevelandclinic.org/PublishingImages/heart/Renal-blood-supply.jpg

- Left anterior postmortem view of a 60-year-old human female's right kidney showing the renal artery, inferior vena cava, the aorta (and associated aortic artery) and common iliac artery (the aortic branches that go down each leg.)
- The renal arteries provide blood flow to the kidneys. Renal artery disease, including narrowing (*stenosis*) due to atherosclerosis, can result in reduced blood-flow to the kidney. This can cause hypertension (high blood pressure).
- Renal artery *stenosis* is the most common correctable cause of hypertension. Long-standing, untreated renal artery disease is also an important cause of kidney failure. This could lead to the kidneys needing an external source to filter the blood.

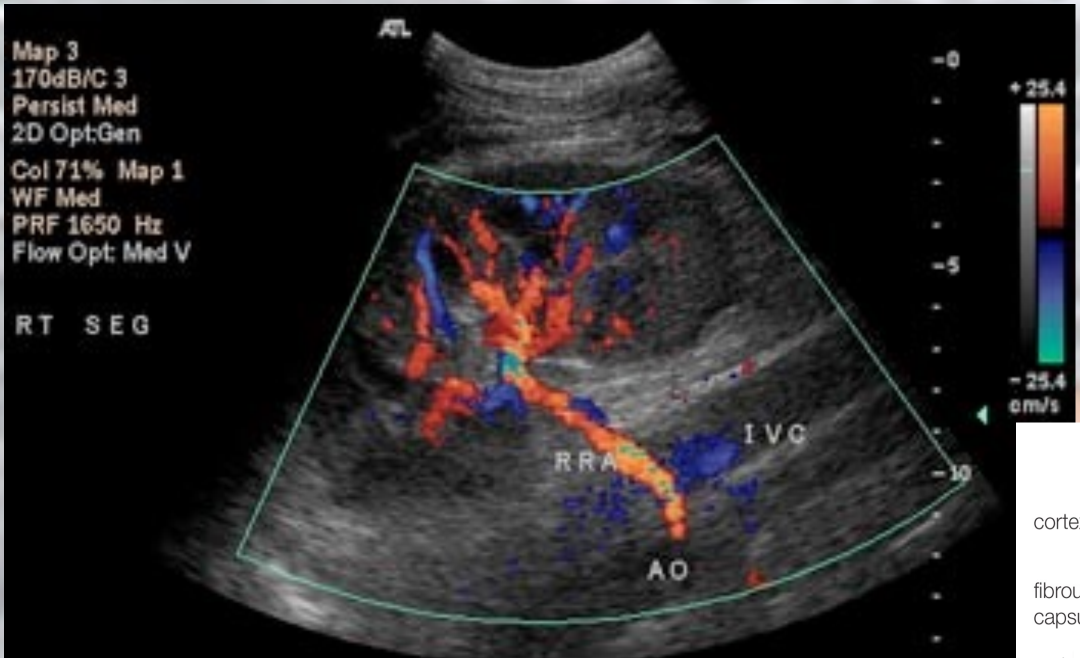
Kidney Disease & Doppler Ultrasound



- Doppler US can also be used to treat renal disorders such as renal artery disease.
- $\Delta f > 0$ corresponds to a flow towards from the transducer (or positive flow velocities colored red), and $\Delta f < 0$ is flow away from the transducer (or negative flow velocities colored blue).

- Blood-flow velocities and flow patterns in the aorta and renal arteries are evaluated with Doppler ultrasound. Imaging of the kidneys can provide information about secondary damage to the kidneys from chronic poor blood-flow.
- Flow patterns (resistance indices) in the small vessels within the kidneys can provide additional information about kidney damage and the potential for recovery of kidney function with therapy.

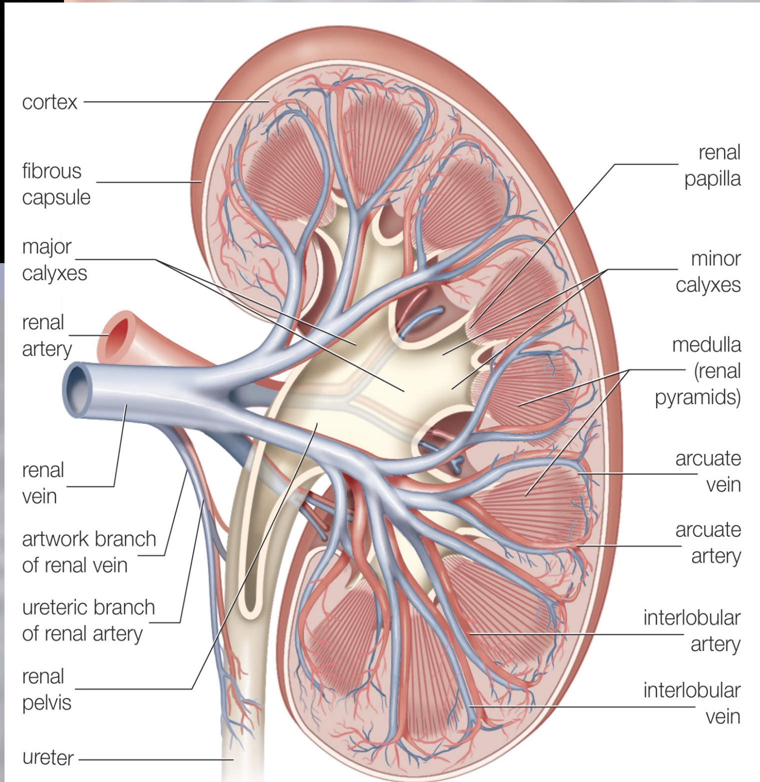
Kidney Disease & Doppler Ultrasound



http://www.ucdmc.ucdavis.edu/vascular/images/body/renal.jpg

- Doppler ultrasound image of the right kidney showing the flow into and out of the main arteries and veins and diagram of the arteries/veins in the kidney.

- The complete US set of images is used to determine the flow in the renal artery and diagnostic tool for diagnosing renal artery disease.



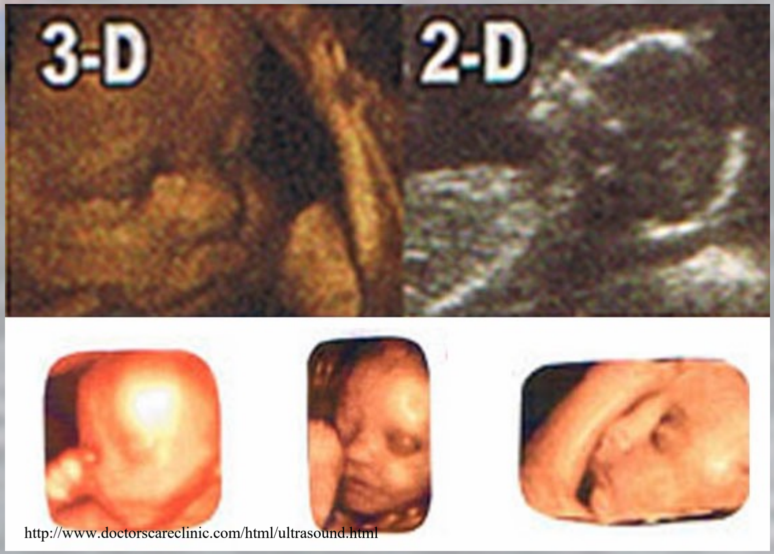
http://www.britannica.com/EBchecked/topic-art/275485/99762/Cross-section-of-the-right-kidney-showing-the-major-blood

Obstetrical Ultrasound

- 3D Ultrasound Imaging

- 3D ultrasound is a data set that contains many 2D planes (B-mode images).
- This is analogous to assuming that a page of a book is one 2D plane, and the book itself is the entire data set.
- Once the Volume is acquired using a dedicated 3D probe you can “Walk” through the volume in a manner like leafing through the pages of a book, meaning you can walk through the various 2D planes that make up the entire volume.
- This is also known as *translation* and the planes are reconstructed using a computer.

http://www.3d-4d-ultrasounds.com/images/gallery/before-after.jpg



http://www.doctorscareclinic.com/html/ultrasound.html

Obstetrical Ultrasound

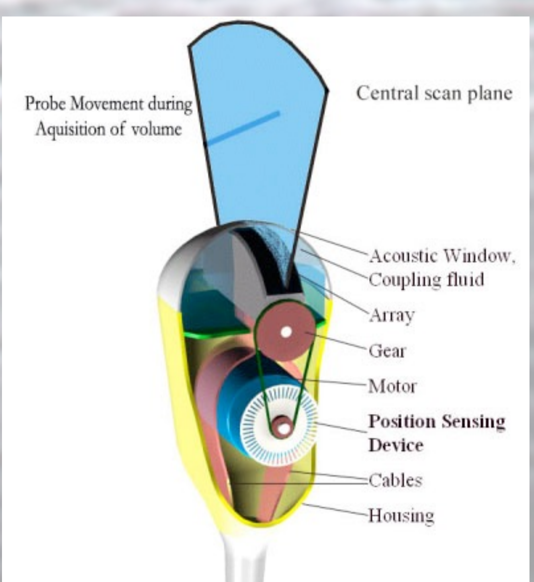
- 3D Ultrasound Imaging

- Each US image represents one slice of the body and by taking therefore multiple cross-sectional scans and putting them "side-by-side" you can render a 3D image, or you could view any one of the 2D slices.

- The transducer must "fan out" across a section of body and sweep out a volume of space to be sliced and the physician/ultra sonographer can select the intensity echoes to display. You can "select out" the heart say the heart of the fetus.

- 4D ultrasound is also known as "Real-time 3D Ultrasound" – The basic concept being that the processing powers of the computers has increased so much that today we can get our ultrasound equipment to acquire and display the 3D datasets with their multi-planar renderings in real time, as we scan the patient.

- This has many benefits in obstetrical scanning where it is critical to analyze anatomy as it continues its physiological developments.



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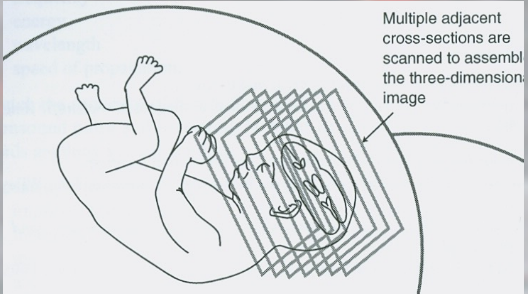


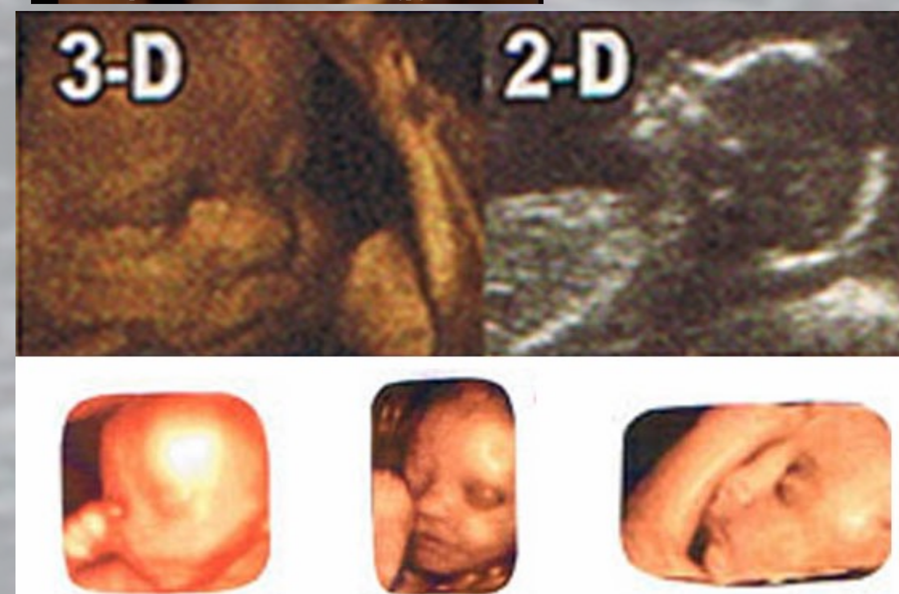
Kane, Physics in Modern Medicine, CRC Press

Obstetrical Ultrasound

- 3D Ultrasound Imaging – Fetal Ultrasound

http://www.medison.ru/uzi/eng/ugeo-hm70/

http://modernultrasoundtechnician.com/wp-content/uploads/2012/06/3D-Ultrasound.jpg



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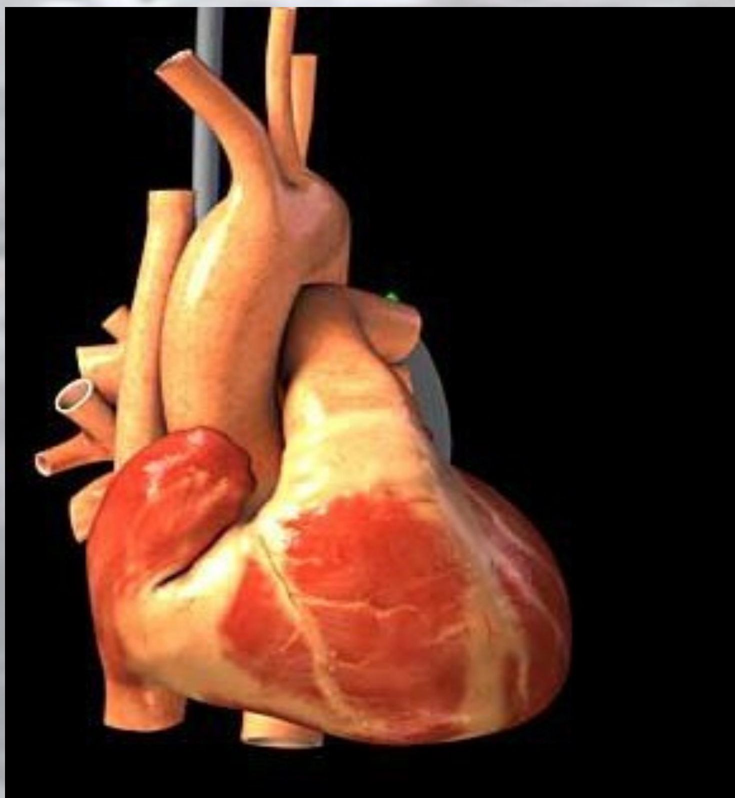
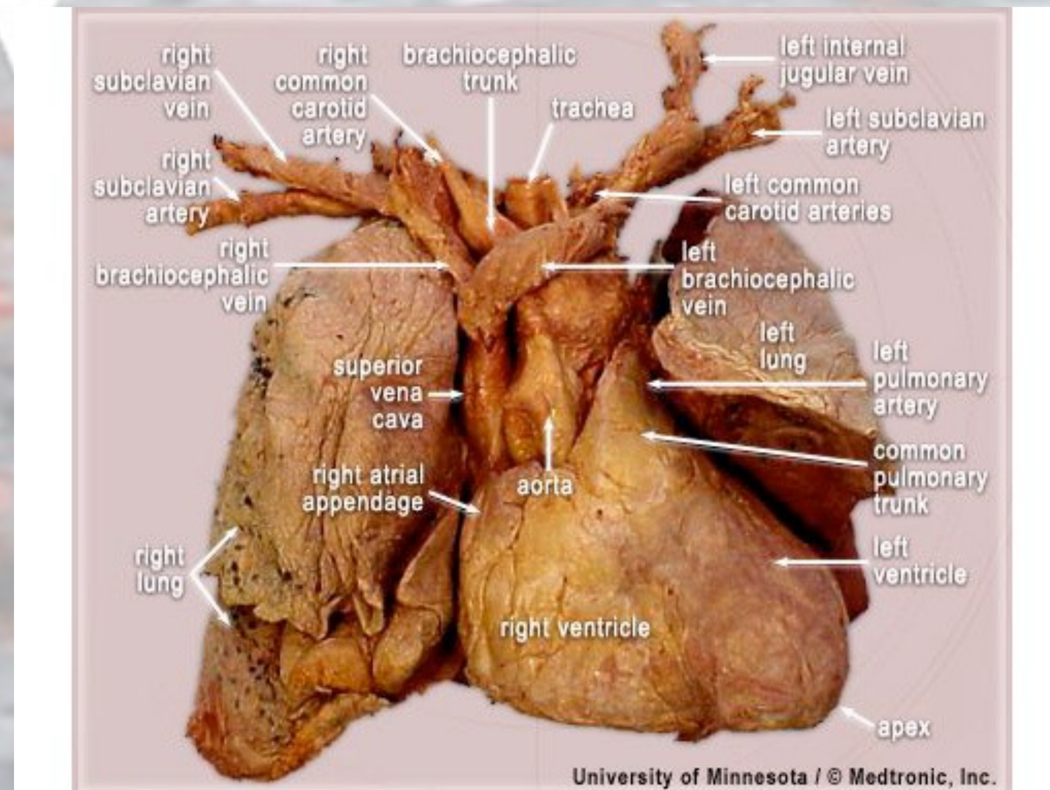
Transesophageal Ultrasound Imaging

- Anatomy of the heart

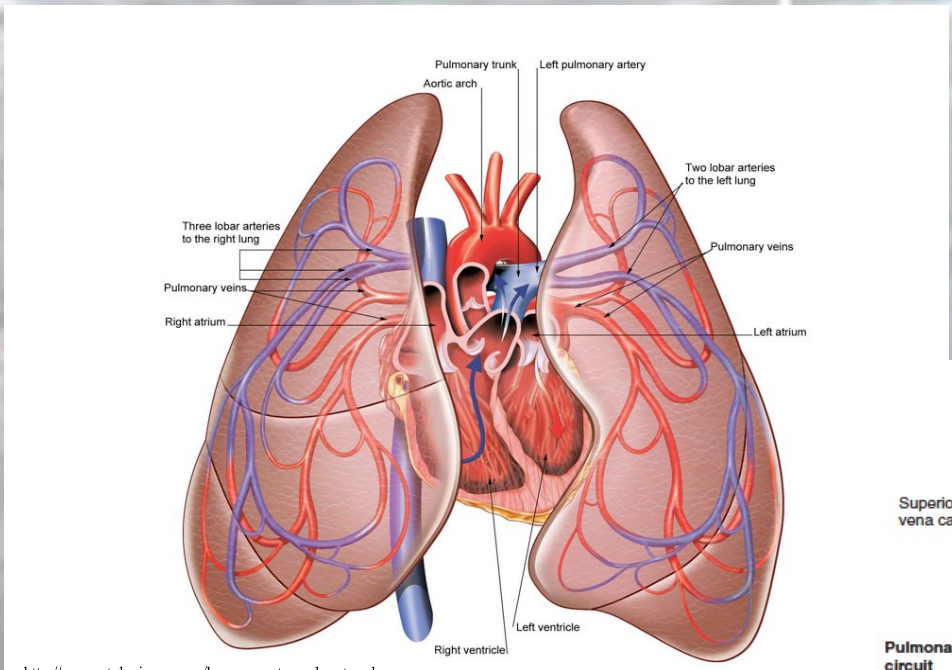




The function of the heart is to pump blood through the network of arteries and veins called the cardiovascular system. Arteries carry oxygenated blood from the heart to the major systems of the body and veins carry oxygen poor blood back to the heart.

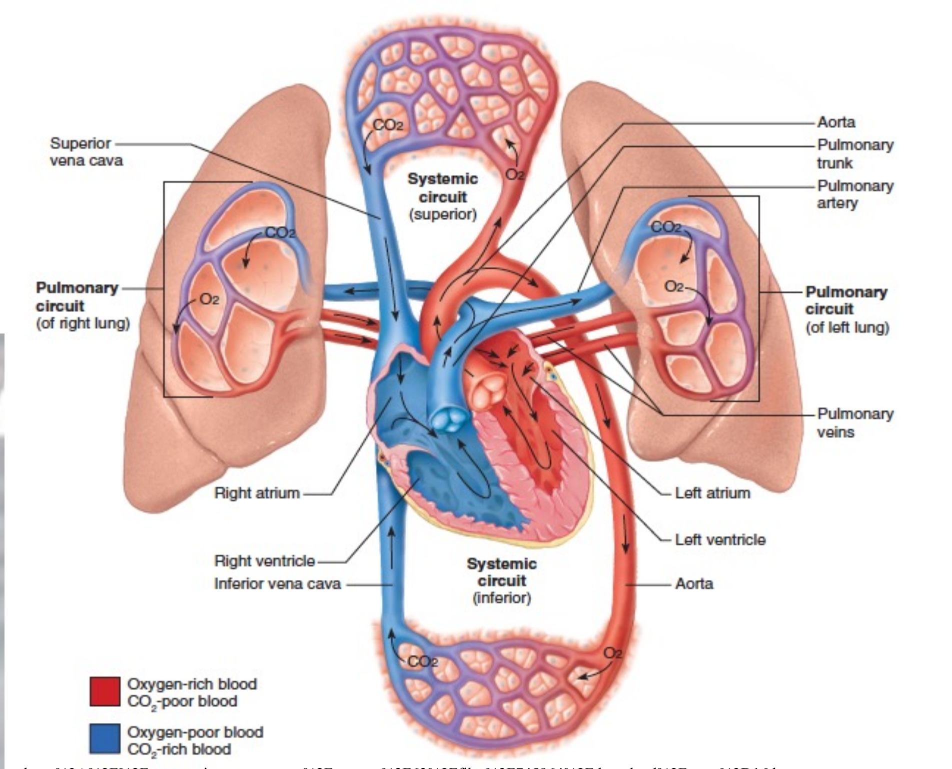
Transesophageal Ultrasound Imaging

- Anatomy of the heart



http://www.stylepinner.com/human-anatomy-heart-and-lungs/aHVtYW4tYW5hdG9teS1oZWFydC1hbmQtbHVuZ3M/

Anatomical locations of the heart and lungs showing the major arteries/veins.



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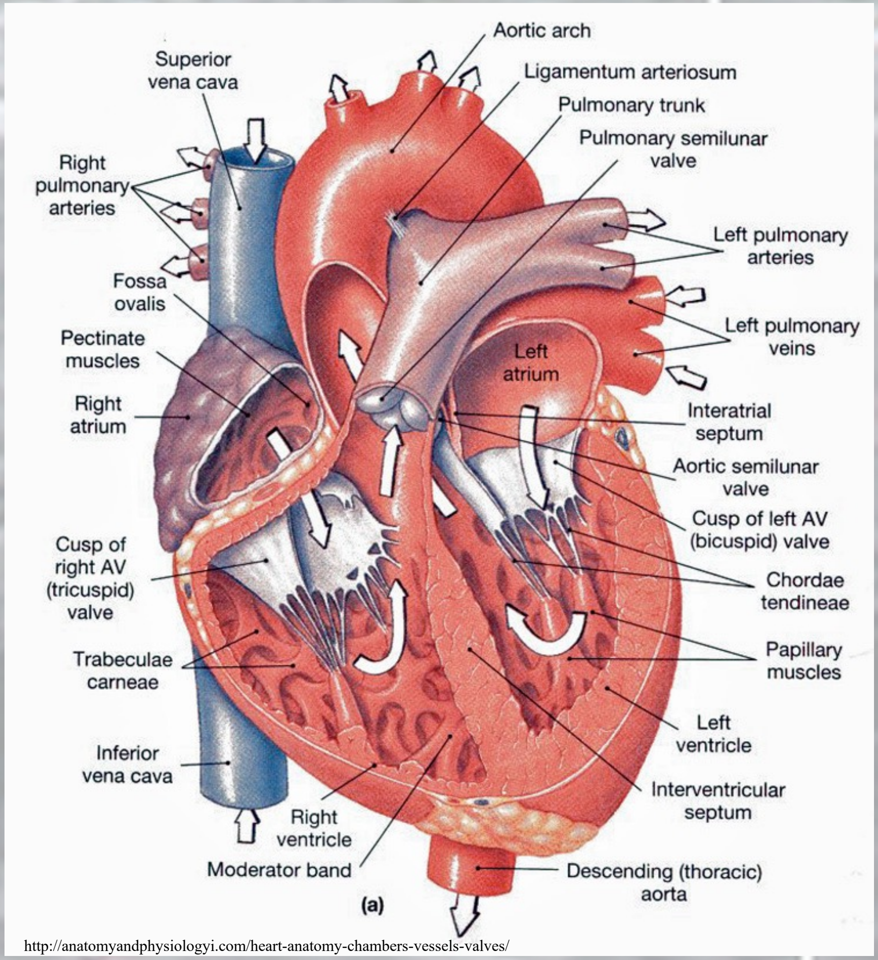
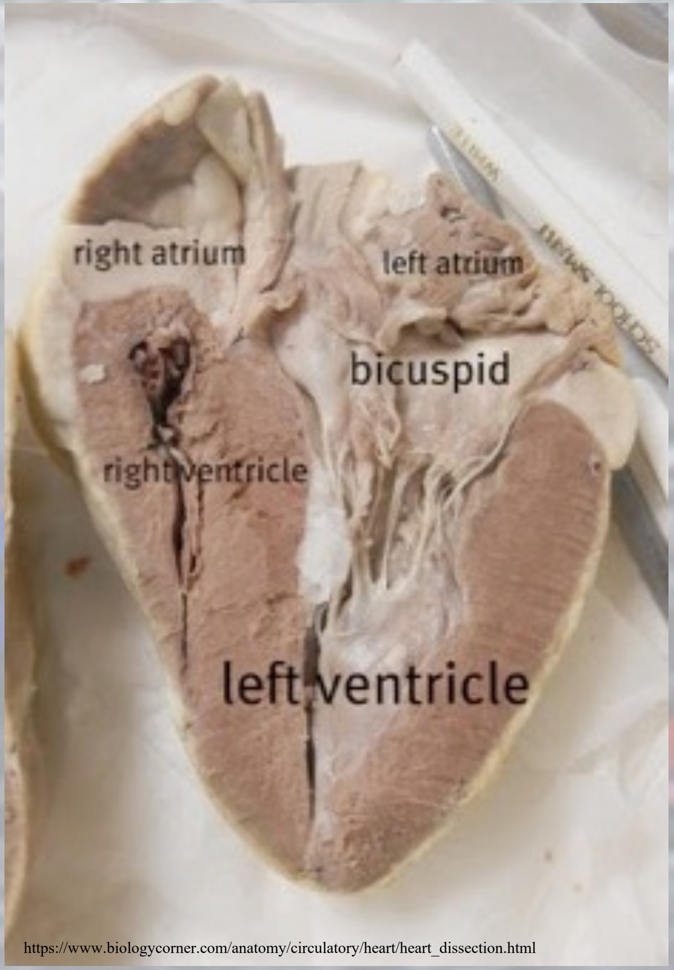
Heart and Lungs form a closed loop system which forms the basis for the circulatory system.

Transesophageal Ultrasound Imaging

- Anatomy of the heart



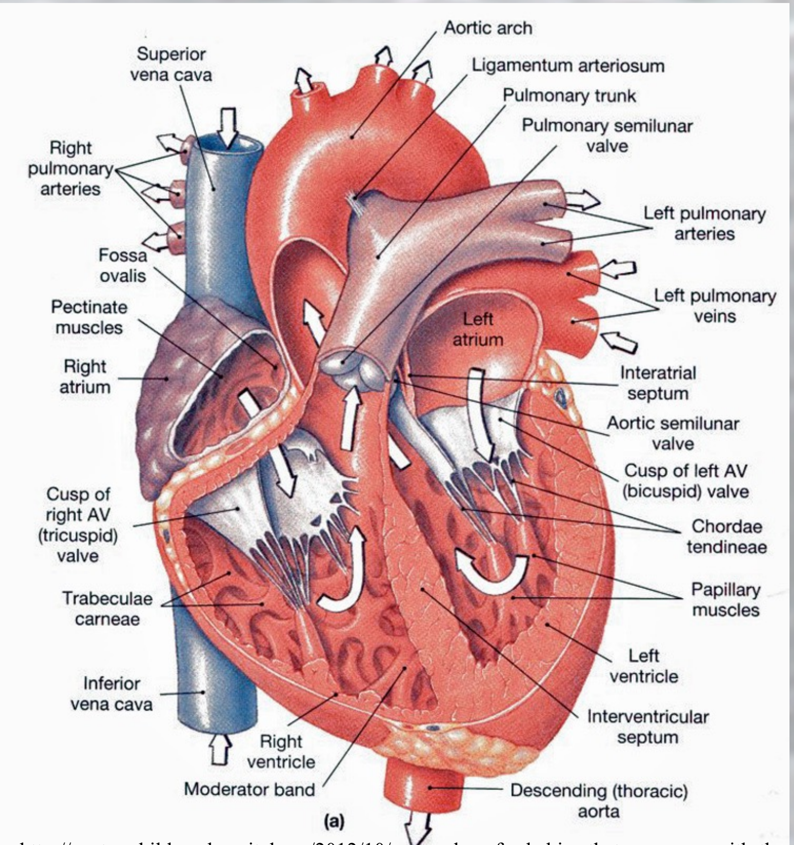


Cross-section of the human heart showing the major structures.

Transesophageal Ultrasound Imaging

- Anatomy of the heart

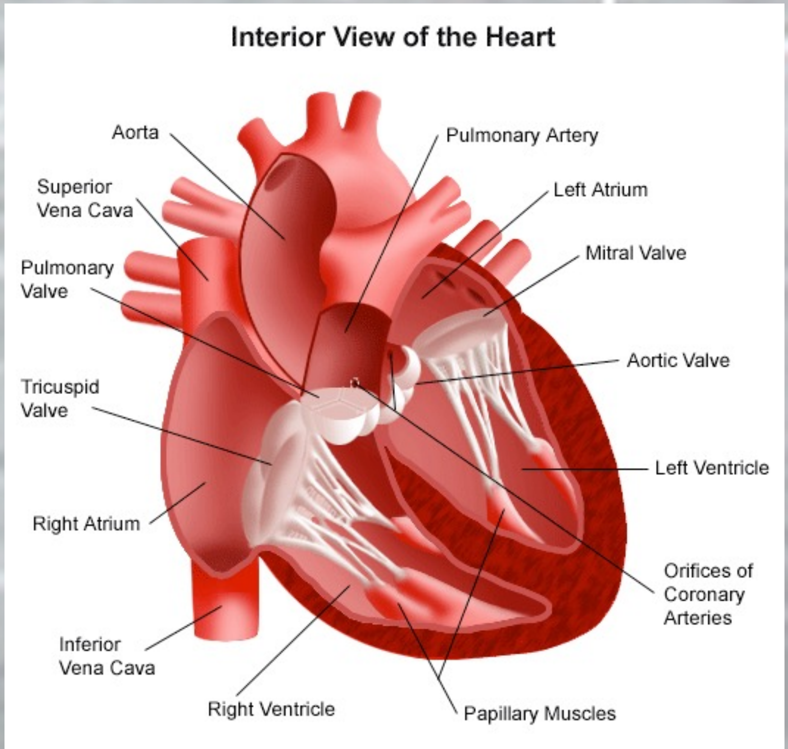
- The heart has four chambers:
- The *right atrium* receives blood from the veins through the *superior and inferior vena cava* and pumps it to the right ventricle.
- The *right ventricle* receives blood from the right atrium and pumps it to the lungs through the *pulmonary arteries*, where it is loaded with oxygen.
- The *left atrium* receives oxygenated blood from the lungs through the *pulmonary veins* and pumps it to the left ventricle.
- The *left ventricle* (the strongest chamber) pumps oxygen-rich blood to the rest of the body through the *aorta* which ascends out of the heart and leads to the head and descends to the lower body. The left ventricle's vigorous contractions create our blood pressure.



http://vector.childrenshospital.org/2012/10/new-valves-for-babies-that-can-grow-with-them/

Transesophageal Ultrasound Imaging

- Anatomy of the heart



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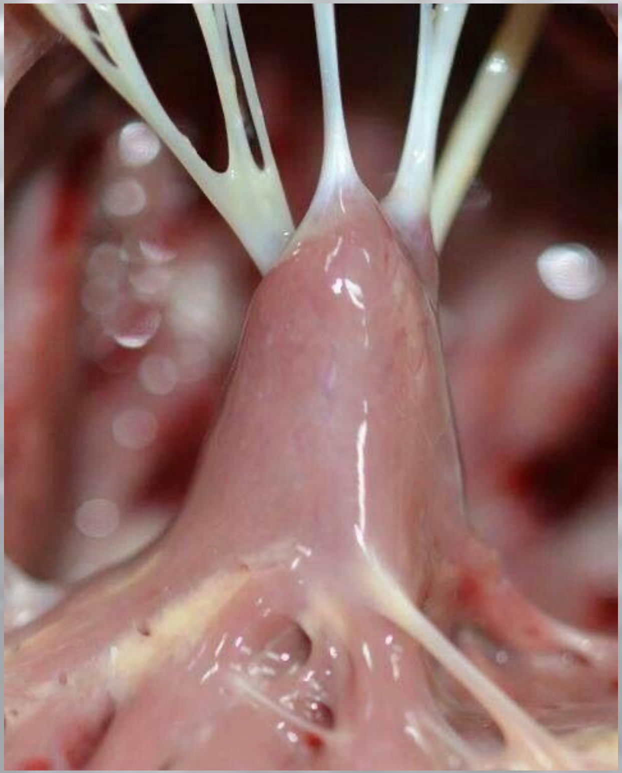
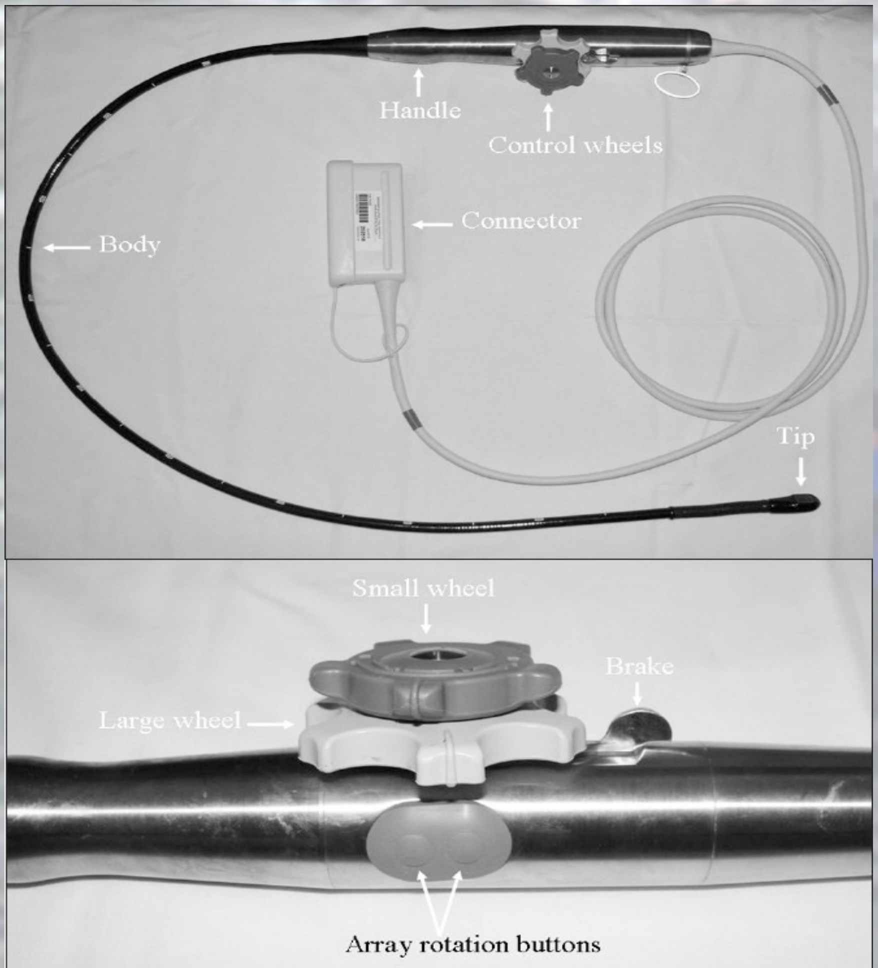


The *Chordae Tendineae* (or heartstrings) are strong, fibrous strings attached to the leaflets (or cusps) of the heart on the ventricular side; i.e., the lower chamber. These strings originate from small mounds of muscle tissue, the *papillary muscles*, which project inward from the walls of the ventricle. The heartstrings anchor the valves and aid in their opening/closing.

Transesophageal Ultrasound Imaging

- Instrumentation



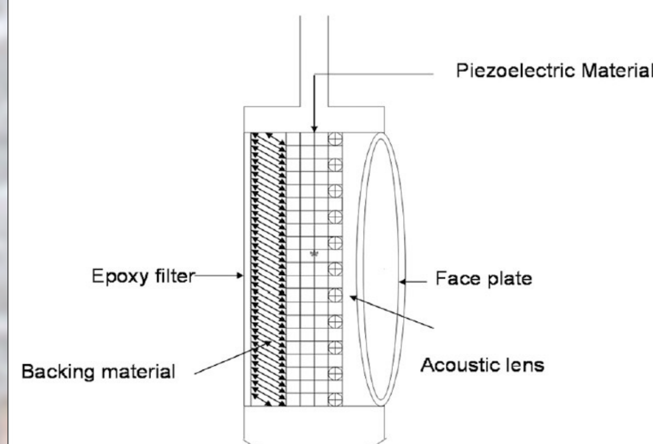
http://www.annals.in/viewimage.asp?img=AnnCardAnaesth_2012_15_2_144_95080_f2.jpg

- Modification of standard *gastroscope (or endoscope)*, with piezoelectric transducers in place of fiber optics
- Conventional rotary controls with inner and outer dials.
- A numbing agent is given to the the patient and the scope is snaked down the esophagus.

Transesophageal Ultrasound Imaging

- Instrumentation

- Inner dial guides *anteflexion* and *retroflexion*.
- Outer dial controls medial and lateral movement
- Multiplane probe has a lever control to guide rotation
- The main component consists of a phased array of piezoelectric crystals (up to 128 for a 2D probe and 2500 for a 3D probe), which function both as the transmitter and receiver of ultrasonic waves.
- The commonly used transducer material is ceramic lead zirconate titanate or a piezoelectric crystal.



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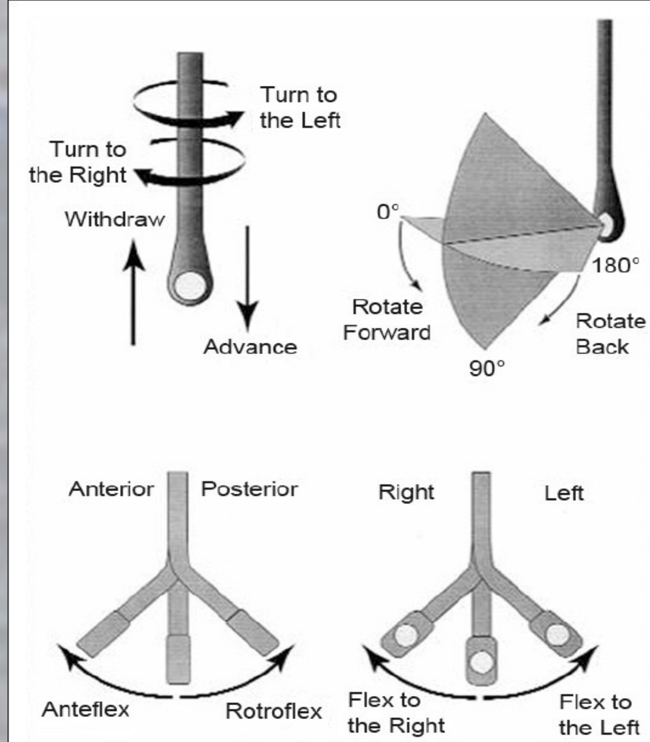

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Transesophageal Ultrasound Imaging

Advantages

- Transducer - 2- 3 mm from heart
- Closer to posterior structures…. Better visualization of LA, PV, MV, LV, Aorta
- High resolution images

Disadvantages

- Semi-invasive procedure which leads to chance of injury
- Needs special setup, technique, preparation, instrumentation
- Needs orientation and expertise

Complications

- Majority are minor.
- Major complications [death, laryngospasm, sustained VT
- Cardiac complications include SVT or AF, VT, bradycardia, transient hypotension or hypertension, angina , pulmonary edema.

Echocardiography & Doppler Ultrasound

- The heart is a dual suction and pressure pump that propels blood through the infinite double loop of the *pulmonary* and *systemic* circuits. The right side of the heart serves the pulmonary (low pressure) and the left side of heart the systemic (higher pressure) circuit. The *atrium* is a receiving chamber while the suction, compression, and expulsion chamber is the *ventricle*.

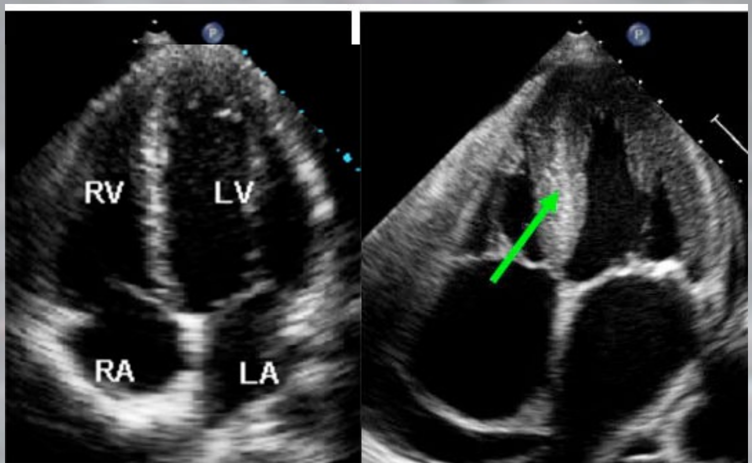
- *Echocardiogram*s are ultrasound images of the heart. The picture on the left shows an ultrasound image of a normal heart, while the image on the right shows the same structures but with amyloid deposits.

- *Amyloidosis* is a disease characterized by proteins abnormally depositing in various organs in the body. The hallmark of *amyloidosis* is the specific pattern of deposition – where the proteins deposit as tiny fibrils in a sheet-like fashion.

- Amyloid deposits originally impair the heart muscle's ability to relax, and ultimately impair the heart muscle's ability to squeeze.

- In addition, amyloid deposits can cause abnormalities in the heart's electrical system, causing the heart rate to be too fast or too slow.

- Common signs and symptoms of amyloid cardiac involvement include fluid retention, fatigue, shortness of breath, dizziness, low blood pressure, and fainting.

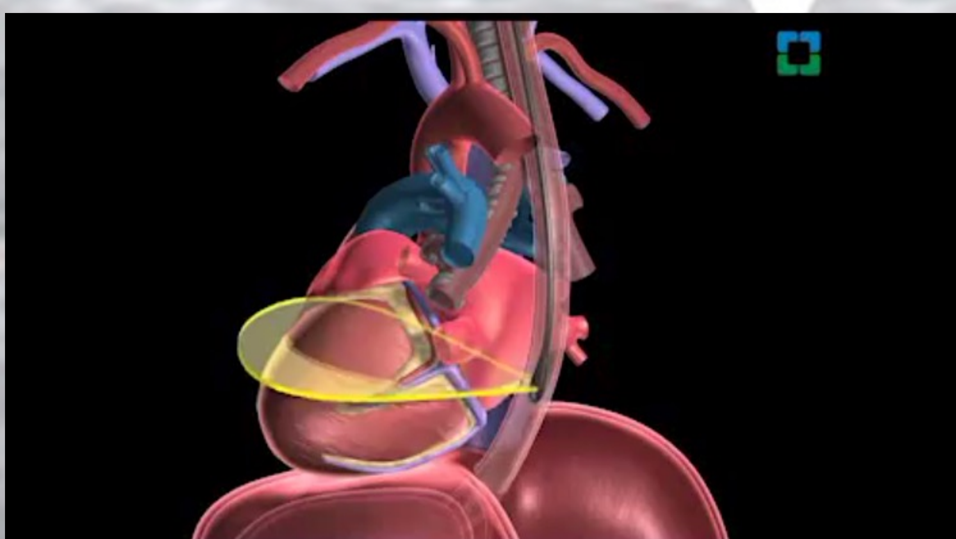


Normal Patient Patient with Amyloid Deposits in Heart

http://stanfordhospital.org/ImageGallery/images/COE/heart/amyloid/echocardiogram.jpg

Echocardiography & Doppler Ultrasound

• Cartoon animation of a transesophageal ultrasound



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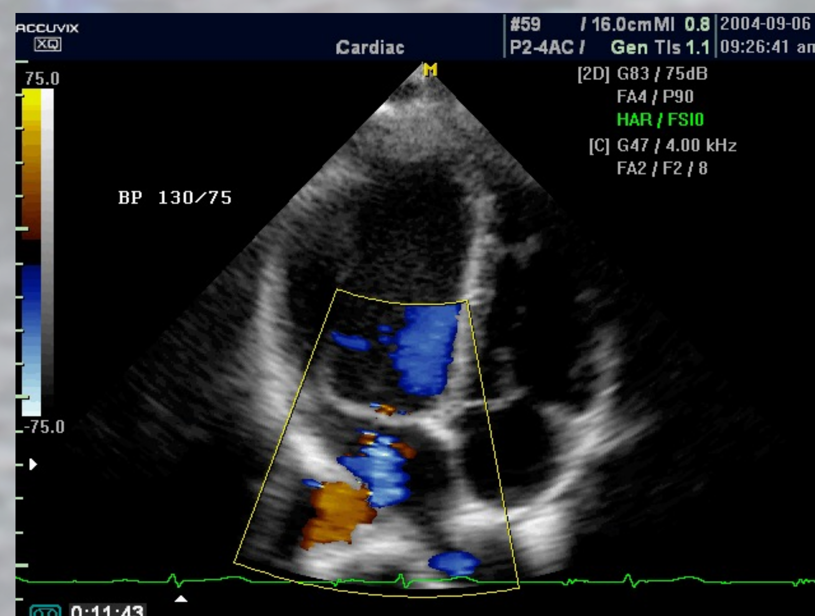
This technique coupled with *echocardiography* (which gives distance information) gives a complete picture of the heart and its function.



http://www.medison.ru/uzi/eho365.htm http://www.heartsite.com/assets/applets/echo_normal_mon.swf

Seeing With Sound

- The Physics of Ultrasound – Advantages of US

- Ultrasound examinations are non-invasive i.e., they do not require the body to be opened, or anything to be inserted into the body. This is a major advantage compared to fiber optic endoscopy, for example, which may involve much more patient discomfort as the probe is inserted.

- Ultrasound machines are relatively inexpensive (~$100k high-end, sometimes non-portable & include Doppler technology), quick and convenient, compared to techniques such as X-rays or MRI scans. The equipment can be made portable, and the images can be stored electronically.

- No harmful effects* have been detected, at the intensity levels used for examinations and imaging. This contrasts with methods based on X-rays or on radioactive isotopes, which have known risks associated with them, and ultrasound methods are preferred whenever possible. This is particularly relevant to examination of expectant mothers.

- Ultrasound is particularly suited to imaging soft tissues such as the eye, heart and other internal organs, and examining blood vessels.

Seeing With Sound

- The Physics of Ultrasound – Disadvantages of US

- The major disadvantage is that the resolution of images is often limited. This is being overcome as time passes, but there are still many situations where X-rays/MRI produce a much higher resolution.

- Ultrasound is reflected very strongly on passing from tissue to gas, or vice versa. This means that ultrasound cannot be used for examinations of areas of the body containing gas, such as the lung and the digestive system.

- Ultrasound also does not pass well through bone, so that the method is of limited use in diagnosing fractures. It is possible but difficult to obtain good ultrasound scans of the brain due to most of the sound being reflected by the skull. Much greater detail is obtained by an MRI scan.