The Hospital for Sick Children
Toronto, Ontario, Canada

Pediatric Echocardiography Fellows Training Program

A resource and educational tool to help trainees achieve the level of knowledge and technical skills required for competency

Expectations for Core Fellows

General information and expectations while on rotation in the echocardiography laboratory

Supervision

All Echocardiography Fellows are under the immediate supervision of the Sonographer they are assigned to work with that day.

The level of supervision depends on the experience and level of training that the individual has. First year Fellows with little or no prior echo training will be supervised closely whereas second or third year Fellows may work more independently and seek assistance when needed.

Every opportunity will be given the Fellow to gain experience with scanning. The supervising sonographer, however, is responsible for the completion of studies and must decide when to take over and finish the exam.

Responsibilities

For the duration of the assigned rotation, the Fellow is expected to be present in the Echo lab between 8am to 4pm. They are expected to perform transthoracic echocardiograms under the supervision of the sonographer and covering staff physician. Their levels of training will dictate the amount of independence and responsibility they have. They are responsible for the equipment, the room and the patient care and safety.

The Fellow will collect the patient from the waiting room, do a height and weight on the patient and prepare the patient for the exam. After completion of the study, the Fellow will prepare and print a preliminary report, review the study with the covering physician and print the final report once the covering staff has electronically signed it.

The Fellow will process the paper work and reports according to the instructions given during their orientation.

They are expected to attend all teaching sessions.

In case the Fellow is unable to attend in the lab, they should notify the front desk (**416-813-4914**) to let the sonographer know of their absence.

Expectations for completion of level of training

Level 1- First Year

- a thorough understanding of the physical properties of ultrasound
- a thorough understanding of ultrasound instrumentation, and its proper and safe use
- a thorough knowledge of cardiac anatomy and physiology, both normal and that associated with congenital and acquired heart disease, that pertain to the pediatric age group
- a working knowledge of clinical pediatric cardiology and surgical techniques that apply to the pediatric population
- a thorough understanding of the limitations of all aspects of this noninvasive technique
- performance and interpretation of complete two dimensional and Doppler transthoracic echocardiograms in normal patients and those with simple forms of congenital heart disease (ie, ventricular septal defect, atrial septal defect, aortic stenosis, pulmonary stenosis, atrioventricular septal defects, coarctation of the aorta)
- during this two month training period, the trainee should perform and interpret 150 echocardiograms
- the trainee should maintain a log book of all echocardiograms performed

Level 2- Second Year

- perform and interpret transthoracic echocardiograms in patients with more complex forms of congenital heart disease both pre- and post-operatively (eg, Tetralogy of Fallot, univentricular connections, double outlet right ventricle, transposition of the great arteries)
- become proficient in the assessment of systolic, diastolic and regional myocardial function as it pertains to congenital heart disease;
- gain experience in transesophageal echocardiography:
- gain experience in fetal echocardiography.
- the trainee should perform and interpret at least 150 additional transthoracic echocardiograms and review another 100 echocardiograms.
- the trainee should perform at least 25 transesophageal echocardiograms under supervision
- the trainee should gain exposure to 20 to 30 fetal echocardiograms

Level 3- Third Year – Sub Specialty- Echo Fellow

- develop a high level of expertise in the performance and interpretation of transthoracic, transesophageal and fetal echocardiography:
- actively participate in the echocardiography training of sonographers and junior pediatric cardiologists
- learn how to develop and coordinate a quality assurance program
- actively participate in research projects with the aim of presenting original data at scientific meetings
- develop sound knowledge of umbilicoplancental circulation, the effects of various drugs on the fetal circulatory system and the impact of maternal drug therapy on the fetus.
- understand the genetic aspects of congenital heart disease
- at least 400 additional transthoracic echocardiograms should be performed and interpreted, and an additional 400 echocardiograms should be interpreted.
- at least 50 more transesophageal echocardiograms should be undertaken before performing and interpreting studies independently.

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Assessment Form

University of Toronto

Hospital for Sick Children

Division of Cardiology

Echocardiography Training Assessment

Name of Trainee: _____

Year of Program: _____

Level of training: _____

Name of Assessor: _____

Rotation and Date: _____

_____

Technical skills, equipment management and communication

	Needs Improvement	Meets Expectations	Outstanding	nable to assess
Demonstrates safe use of equipment by proper handling and use of power output, TGC, and gain controls.				
Demonstrates proper and diagnostic use of color, pulsed and continuous wave Doppler				
Demonstrates a working knowledge of the standards and guidelines for Echo as outlined by the ASOE				
Communicates effectively with patients, family and co-workers				
Utilizes an individual approach to patient care.				

Professional Development

	Needs Improvement	ctations	Outstanding	Unable to assess
Functions as a member of the Cardiac Program working collaboratively and interdependently in the Echo lab				
Demonstrates a level of knowledge compatible with the level of training and experience				
Demonstrates effective decision making that reflects sound judgment and good problem solving				
Attends and actively participates in staff education programs				
Identifies own learning needs and utilizes appropriate resources to enhance knowledge and skills				

General Comments

Signed:

Staff Cardiologist

This is to attest that I have read this document:

Signature of Trainee Date

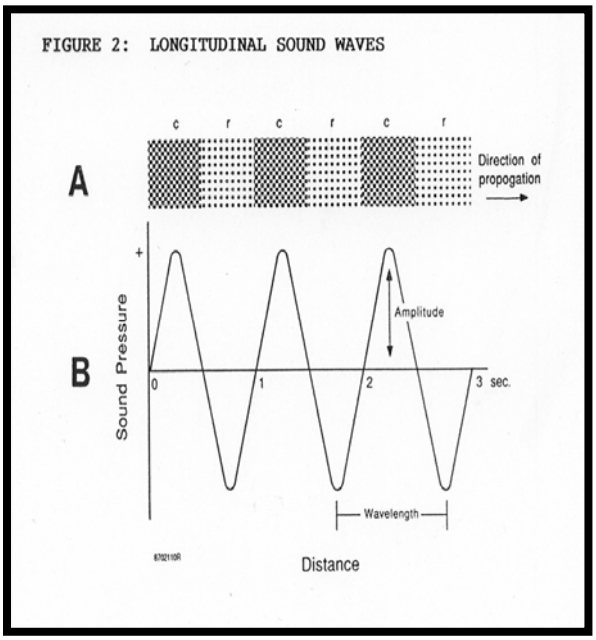
Physics of Ultrasound

Introduction

There are several reasons for learning how ultrasound works and how the interaction with tissue makes a picture. Understanding these relationships will help the sonographer produce images of high quality and overcome the obstacles and limitations of the equipment. The sound waves must interact with tissue interfaces to produce an image. The goal is to gain insight into the nature of ultrasound and the properties of the tissue it must interact with.

Sound is a form of mechanical energy that is transmitted by **longitudinal waves**. Waves carry energy from one place to another. These waves are travelling variations called **cycles.** Sound is described by the following parameters

Frequency
Period
Wavelength
Amplitude



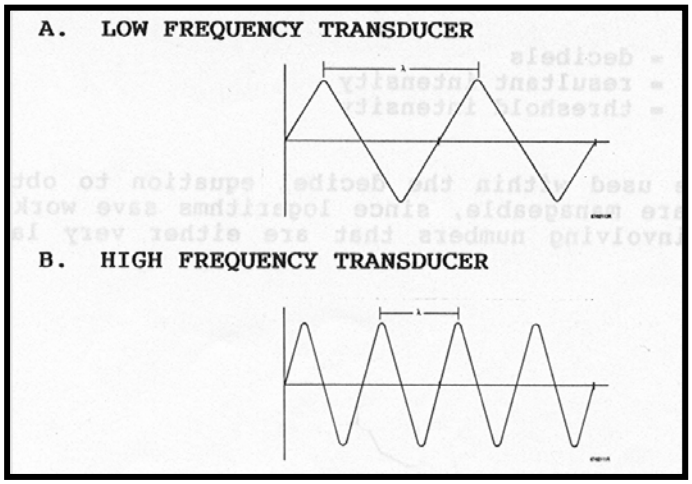
Frequency is the number of cycles per second and is measured in **Hertz (Hz).** A megahertz is 1,000.000 hertz (MHz). The human ear can detect frequencies in the range of 15 to 20 Hz. Ultrasound is any frequency greater than 20 Hz. Diagnostic ultrasound uses frequencies from 2 MZ to 10 MZ.
Period is the time it takes for one cycle to occur.
Wavelength is the length or space over which one cycle occurs.
Amplitude is the maximum variation that occurs in a cycle and is measured in decibels.

Another parameter involved is **velocity.** The velocity or propagation speed is the product of frequency and wavelength.

The velocity of sound is different for different mediums. The velocity of sound in a medium is dependent on the characteristics of that medium specifically stiffness and density. Stiffness is the hardness or the resistance of the material to compression. Density is the concentration of matter. Speed increases if the stiffness increases and density decreases.
The velocity of sound in soft tissue is taken as a constant at 1540 m/sec.

The relationship between these parameters can be expressed as follows

Velocity of sound = wavelength x frequency



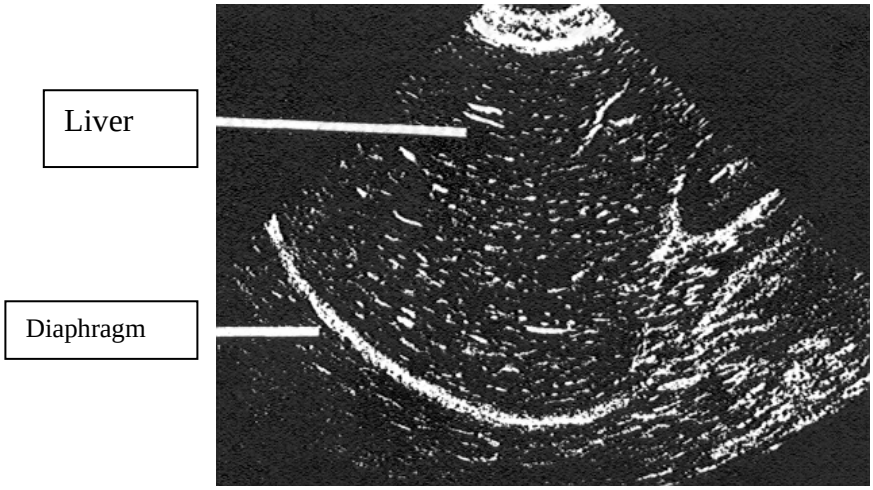
When the velocity of sound is taken as a constant as it is in soft tissue then frequency is inversely proportional to the wavelength. When frequency increases the wavelength decreases.

Intensity is the concentration of energy within a given area. It is the power divided by the beam area. Power is the rate of transmission and is measured in Watts. Intensity is the concentration of power within an area is not uniform across the ultrasound beam and is not uniform throughout time. Intensity is measured in milliwatts/cm2 (mW/cm2)
Any biological effects are directly related to the intensity and duration of exposure.

Interaction of Sound and Tissue

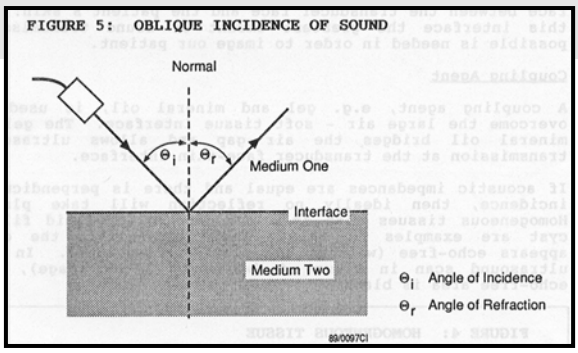
Tissue Properties

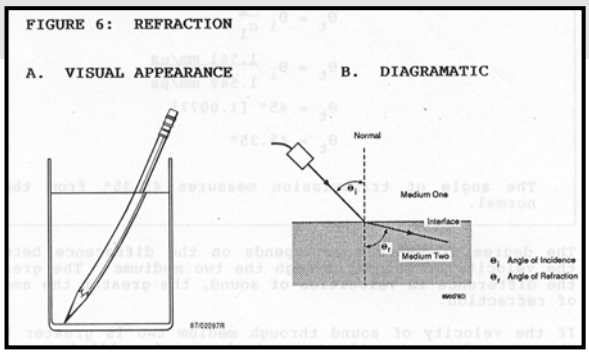
Acoustic impedance is the property of the tissue that causes the sound waves to be reflected back to the transducer. It is dependent on the density and velocity. Since the velocity of sound in soft tissue is taken as a constant then the acoustic impedance changes are dependent upon density. Differences in acoustic impedance results in interfaces that reflect the ultrasound back to the transducer. The amount of refection from an interface determines the amplitude of the echo from that interface. A strong interface would be the pericardium or a dacron patch. These are highly reflective surfaces.



This is an image of the liver and the diaphragm. The diaphragm is highly reflective since it is denser than the liver tissue

Attenuation is the progressive reduction of the amplitude and intensity of the ultrasound beam as it travels through tissue. Acoustic impedance contributes to the attenuation of the ultrasound signal. The farther the beam travels, the more it is attenuated. It is important to understand attenuation since it must be compensated for during the production of an ultrasound image. If attenuation is not compensated for then similar interfaces at different depths will look different.
Attenuation occurs due to absorption (converts to heat), reflection and refraction.





Reflection

Refraction

The attenuation increases with increasing frequency. So the greater the frequency the greater the attenuation of that sound signal. Also the greater the distance the signal has to travel the greater the attenuation. On average there is approximately 1 dB of attenuation per centimetre per megahertz.

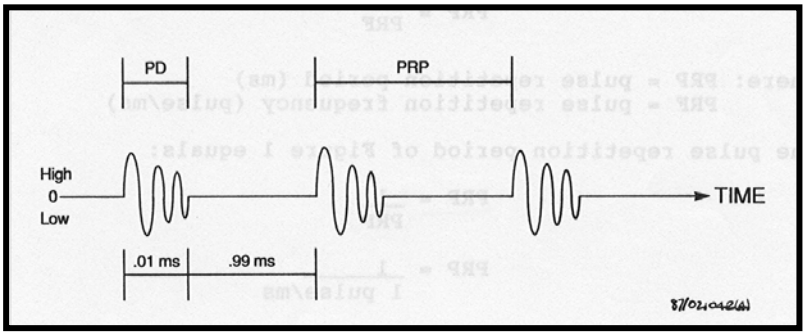
Ultrasound gel in used to “bridge” the interface between the air and skin.

Transducer Theory

The common phased array probe produces ultrasound that is not continuous but intermittent and is referred to as **Pulsed ultrasound**. A transducer does not emit and receive signals at the same time. The actual listening time is about 99%. A sound signal is sent by the transducer and must be received back to the transducer before another signal can be sent.

A wave of pulsed ultrasound is described by five parameters.

Pulse repetition frequency
Pulse repetition period
Pulse duration
Duty factor
Spatial pulse length



The frequency of the transducer is pre-set by the manufacturer, however many transducers now have the capability of providing the use of multiple frequencies in the one probe. The smaller the diameter of the probe usually the higher the frequency of the probe. Higher frequencies have shorter wavelengths and therefore have less penetration and a higher attenuation coefficient but are capable of more image detail due to better resolution.

Image production factors

The quality of the 2D image is affected by numerous factors some of which are often preset by the transducer and the inherent components of the equipment that is used. It is important to understand how the image quality is effected by the selection of transducer and how the components of the ultrasound machine may be manipulated to obtain the highest quality image possible for each situation

Spatial beam production

Simply, the narrower the beam width the better the image detail.
Usually the image detail is better in the near field area where the beam is narrow and focused. In the far field the beam diverges and detail is not as good. The length of the near field is dependent on the transducer diameter and the wavelength.
This factor can be controlled to some extent by paying attention to the focal zone. The beam is narrowest at the focused point of the transducer.
The frequency and the attenuation affect the depth of penetration of the beam. It is important to know how factors affect resolution and penetration.
Structures that are close to the near field can be imaged with higher frequency transducers that will produce images with good image detail or resolution. Structures that are in the far field need to be imaged with lower frequency transducers with some sacrifice to the detail.

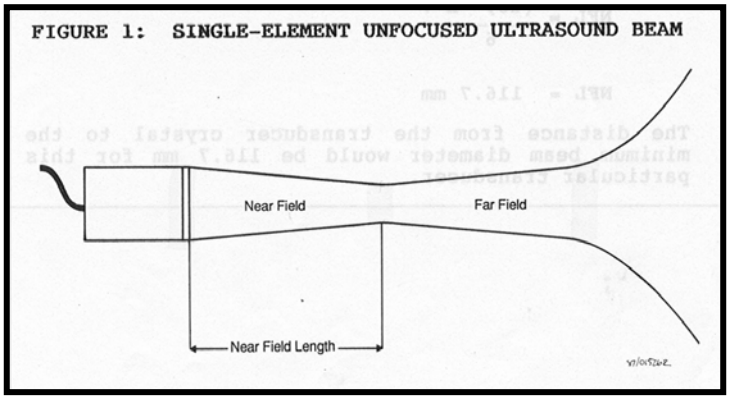


FIGURE 1: SINGLE-ELEMENT UNFOCUSED ULTRASOUND BEAM

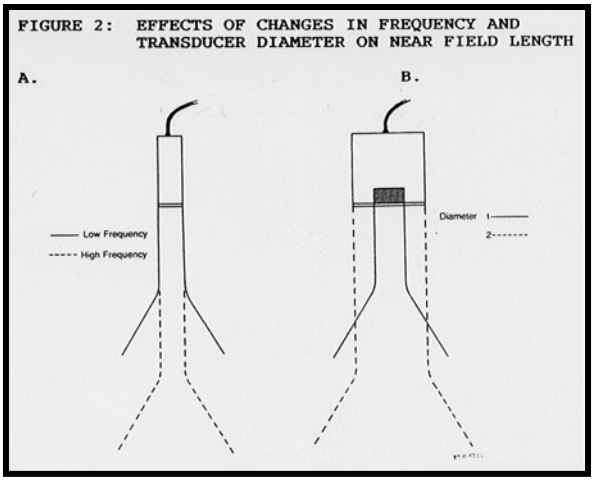
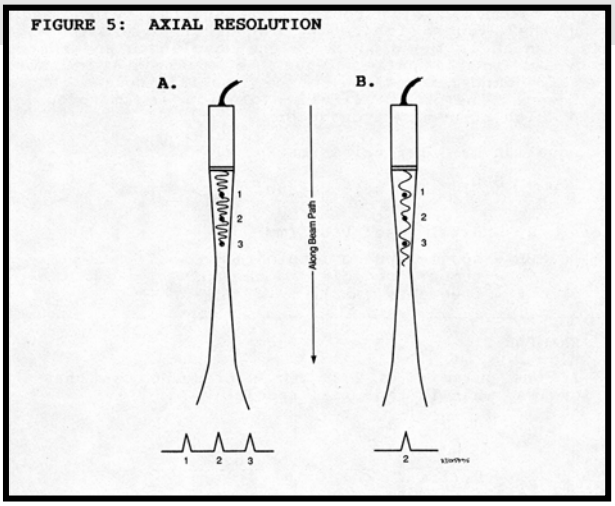


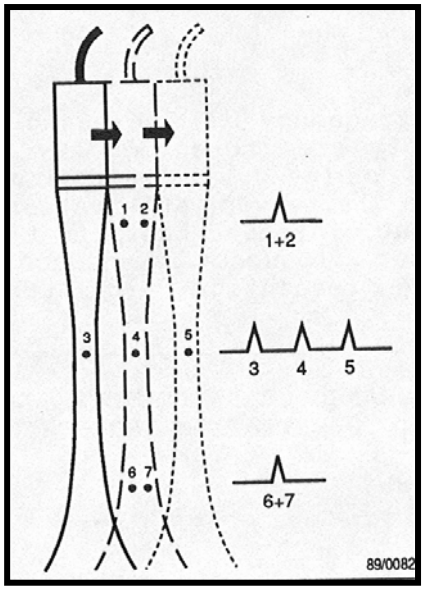
FIGURE 2: EFFECTS OF CHANGES IN FREQUENCY AND TRANSDUCER DIAMETER ON NEAR FIELD LENGTH

Image quality is dependent on the Resolution of the ultrasound equipment. Resolution is the ability of the ultrasound equipment to distinguish two adjacent structures as separate. This is dependent on the ultrasound beam production factors.

Resolution occurs in the Axial and Lateral plane and each is affected by different factors. Axial resolution occurs along the length of the beam and is dependent on the spatial pulse length.



Lateral resolution occurs perpendicular to the beam and is dependent on the beam width.



Overall Gain Settings

The overall gain amplifies all of the received signals by increasing the voltage of the signal. The operator must have knowledge of the appearance of the "normal" image to assess the brightness of the image as too high or too low. An image with improper gain settings will not be diagnostic.

Time Gain Compensation (TGC)

The TGC compensates for the loss of signal strength due to attenuation. If attenuation is not compensated for, similar structures at different depths will look different. It is operator controlled. The TGC will not compensate for loss of signal due to lack of penetration. This can only be dealt with by changing to a lower frequency transducer. Time of flight is the time it takes for a sound signal to travel from the transducer to the reflector and back to the transducer. This is sometimes referred as the go and return time. The TGC uses the time of flight to calculate the amount of compensation that is needed for each ultrasound signal returning to the transducer. The goal is to make similar tissue at different depths appear of similar texture on the image that appears on the monitor. The TGC is different from the overall Gain that amplifies all the returning signals equally. The TGC Controls are adjusted using the TGC curve. The near, middle and far fields are

adjusted according to the operators visual assessment of the image. Once the TGC is set, the overall gain can be adjusted and then if necessary change the transducer.

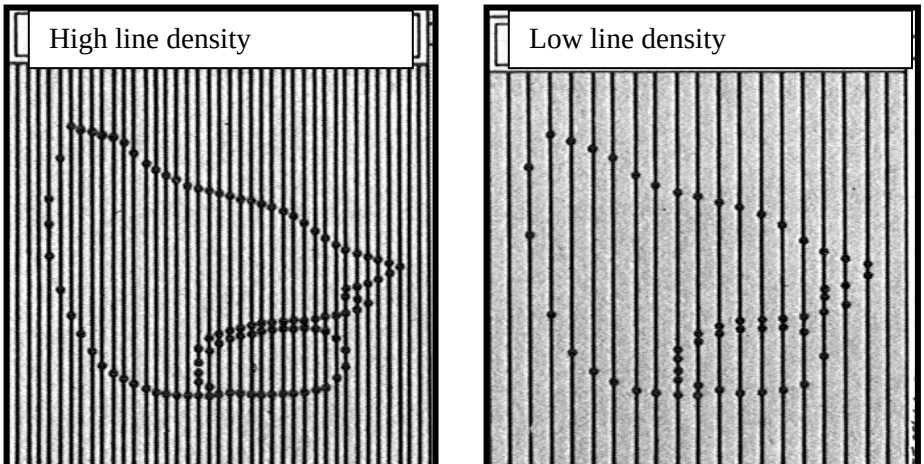
Instrumentation

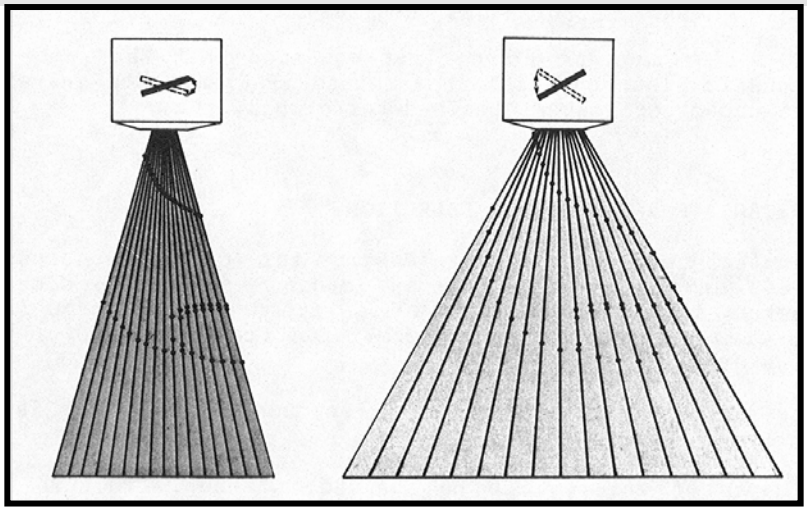
An ultrasound image is composed of a series of dots, which are interpretations of the pulsed sound signal that has been refined, changed and positioned to appropriately represent the structures it has been reflected from. Each signal is assigned to a shade of gray depending on the amplitude of the returning signal.
The transducer selection and the specific calculation package of choice predetermine for the most part the processing of the image.
The dynamic range is the ratio of power from the smallest to largest that the system can handle. It is expressed in decibels.
Compression is a process that decreases the dynamic range of the system. Increasing the compression will effectively reduce the number of shades of gray that will be used. This technique may be helpful to define the edges of structures. The less shades of gray available, the more contrast there will be between the tissue and fluid spaces.
Filters set the threshold level. It eliminates the low-level signals produced from weak reflectors or electronic noise. Filters are commonly used with Doppler modalities.

Factors affecting Image quality

Pulse Repetition Frequency (PRF)
PRF is the number of times the transducer is excited to generate a pulse. The velocity of sound and the depth to be imaged limits the PRF. As distance increases, the PRF decreases. The operator must maximize the depth setting.

Frame rate and line density
A real time ultrasound image is a series of pictures. Each complete picture that is produced is called a Frame. Each Frame is made up of many lines of information-one line for each pulse of ultrasound produced. The pulse repetition frequency, the number of lines per frame and the number of frames per second are all related. The frame rate is determined by the number of lines of information and the maximum depth to be imaged. Decreasing the frame rate will increase the line density. The faster the frames are changing, the less time there is for the lines of information to be processed. A compromise must be made between frame rate and line density. Where the frame rate and frequency are constant, a smaller sector angle will increase line density thereby increasing detail.





Decreasing the sector angle will concentrate the number of lines into a smaller area but maintain the frame rate. Using this option maximises the resolution of the image.

Image quality is maintained by:

- Maximising the depth setting
- Using a small sector angle
- Using one modality at a time
- Using zoom feature for small area of interest
- Using highest frequency transducer without compromising depth penetration

Criteria for Transducer Selection

- Depth of area to be scanned, whether structures are superficial or deep. It may be necessary to change transducers throughout the study to optimise the details of the area of interest. The higher frequency transducers may be used to image more superficial structures such as coronary arteries.
- The attenuation properties of the area to be scanned. An increase or decrease in attenuation can occur with various disease states
- Size of the patient, this affects tissue depths. As a rule, the larger the patient, the lower the frequency of the transducer to be used.
- Transducer face size, will the probe fit between the ribs. It may be helpful to have the patient inhale or exhale when scanning some areas.

Rule of Thumb

To obtain the best image detail, use the highest frequency probe available without compromising depth penetration.

Output and Safety

The guiding principle for the use of diagnostic ultrasound is defined as the **ALARA** principle- as low as reasonably achievable principle. What is reasonable is left to the judgement of qualified personnel.
The output display is situated in the upper right hand corner on the ATL machine. The indices are displayed as a mechanical and thermal index.
The variables involved in the level of intensities that are generated are: indices values, body size, location of bone relative to focal point, attenuation in the body, ultrasound exposure time. The ultrasound system displays indices related to the potential for bioeffects. The accuracy of the displayed index with respect to a particular patient's condition depends on , the extent to which the patient matches the conditions for the index formula and the extent to which the system correctly estimates the acoustic output for the particular settings.

There are four types of indices, one related to mechanical bioeffects and three related to thermal bioeffects.

Mechanical Index (MI) – indicates the potential for mechanical bioeffects in increments of 0.1. Examples of mechanical bioeffects are motion or streaming around compressible gas bubbles as ultrasound pressure waves pass through tissue, or energy released in the collapse, via cavitation, of transient gas bubbles.

Soft Tissue Thermal Index (TIs) – indicates the potential temperature rise for applications such as cardiac, fetal, or abdominal scanning, in which the ultrasound beam passes through and focuses on soft tissue. For scanned modes the maximum temperature increase occurs at or near the surface where the ultrasound enters the body.

Bone Thermal index (TIb) – indicates the potential temperature rise for applications such as second or third trimester fetal or neonatal cephalic (through the fontanel), in which the ultrasound beam passes through soft tissue and focuses in the immediate vicinity of bone.

Cranial Bone Thermal Index (TIc) – indicates the potential temperature rise for applications such as adult and pediatric cranial examinations, in which the ultrasound beam passes through the bone near the beam's entrance to the body.

Applying ALARA

2D and M-mode provide anatomical information. Doppler (Power, color, CW and PW) provides information about blood flow.
Scanned modes are 2D, Power Doppler and Color. These modalities disperse or scatter the ultrasound energy over an area. Unscanned modes (m-mode, Doppler) concentrate the energy in an area.
The decision as the amount of acoustic power that is used is up to the system operator.

Controls

Direct Controls.
Application selection and the output intensity control directly affect the acoustic intensity. Application selection refers to your choice of clinical option and a tissue specific pre-set.
Output has a direct impact on acoustic intensity. Once the application has been established, the output control can be used to increase or decrease the intensity output.

Indirect Controls
Indirect Controls are those that have an indirect effect on acoustic intensity. These controls affect imaging mode, pulse repetition frequency, focus depth, pulse length and scanhead selection.

The choice of imaging mode determines the nature of the ultrasound beam. 2D is scanning mode. Doppler is a stationary mode, which concentrates the energy in a single location. A scanned or moving mode disperses the energy.

PRF (pulse repetition frequency) or rate refers to the number of ultrasound bursts over a specific period of time. Several controls affects PRF; focal depth, display depth, sample volume depth, color sensitivity, number of focal zones, and sector width controls.

> Focus of the ultrasound beam affects image resolution. To maintain or increase resolution at a different focus requires a variation in output the focal zone.

Pulse length is the time the ultrasound burst is turned on. The longer the pulse, the greater the time average intensity. Increasing the sample volume increases the pulse length.

Scanhead selection indirectly affects intensity. Tissue attenuation changes with frequency. A higher scanhead operating frequency requires more output intensity to scan at t deeper depth. To scan deeper at the same output intensity, a lower scanhead frequency is required.

Receiver Controls usually have no effect on output. These include gain, TGC, dynamic range and image processing. The overall gain control on some machine may boost output along with returning signals.

In Summary

Select the correct transducer frequency and application for the job. Start with a low output level, optimise the image using focus, receiver gain and other imaging controls. If the image is not diagnostically useful at this point, then increase output.

The Doppler effect

When a sound is emitted from a source that is moving towards a receiver, the frequency of the sound will be higher than if the source were stationary. If the source is moving away from the receiver, then the frequency will be lower. This happens because the sound waves become compressed or farther apart depending on the direction of the moving source. This effect is evident with all types of waves. Johann Doppler, an Austrian physicist first observed this shift in frequency from his observations that the relative motion between the source and the observer changes the color of light from stars. This same effect uses radar to measure the speed of cars.

When there is relative motion between the transmitting source of sound waves and the reflector, the reflected frequency will be different than the transmitted frequency. This difference is known as the Doppler shift.

In the heart, Doppler is used to interrogate the movement of red blood cells. When the ultrasound beam is directed through the heart, the red blood cells act as moving reflectors. The ultrasound beam is reflected off the moving red blood cells and directed back to the stationary transducer. The transducer acts as both a transmitter and receiver. The velocity of the reflected frequencies are received and analysed. The direction and velocity of the moving red blood cells determine the frequency. The difference in the transmitted and reflected frequencies is the Doppler shift. The difference in the frequencies is directly proportional to the velocity of blood flow.

The Doppler shift will always be within the audible range of 15 Hz to 20 KHz.

Because the accuracy of the Doppler shift equation is dependent on the angle of incidence, the operator must make sure that the ultrasound beam is parallel or nearly so to the direction of blood flow. If the angle is greater than 20 degrees the maximum velocities will not be measured.

Doppler shift measures velocity not volume of blood flow. Even with color Doppler, the operator must be skilled to qualify the color jets and relate it to volumes.

Doppler shift equation

$$f\sigma = +/- \frac{2Vfi \cos}{c} \quad \text{or} \quad f\sigma = fr - fi$$

Where: cos = angle between sound beam and blood flow vector

$f\sigma$ = Doppler shift in Hz)

fi = incident frequency

V = reflector speed (blood flow velocity) m/s

C = velocity of sound in soft tissue

fr = reflected frequency

Fast Fourier Transform

The information obtained from the Doppler shift is displayed as a real time image in graph form. A component of the ultrasound machine called the Fast Fourier transform analyses the reflected frequencies and displays it on a spectral analysis graph. The amplitude of each velocity is displayed as a dot of grey. The frequency is displayed above or below the baseline for flow towards the transducer or away from the transducer respectively. These flow patterns are descriptive depending on the characteristics and hemodynamic factors of that flow profile. For example, the spectral analysis graph depicting the flow profile of the mitral valve is different from that of the aortic valve or tricuspid valve. Disease states in the heart can be reflected in the flow pattern across the affected area.
The Doppler Spectral Analysis image is an echo picture that is affected by all the parameters that effect a normal 2D picture

The gain control affects the ratio of the output signal strength to the input signal strength. The gain controls should be manipulated to produce a clean uniform profile without any 'blooming'. The gain controls should be turned up to over emphasise the image and then adjusted down. This will prevent any loss of information due to too little gain.

The Transmit limit sets the output or power limit so that no matter how high the gain control is manipulated the power output will not exceed the pre-set limits.

The compress control assigns the varying amplitudes a certain shade of grey. This control is not of paramount importance with spectral analysis since the specific anatomy is not being assessed however if the compress control is very low or high the quality of the spectral analysis graph will be affected and this may lead to erroneous interpretation.

The reject button eliminates the smaller amplitude signals that are below a certain threshold level. This will help to provide a cleaner image and may make measurements more obvious.
The filter is used to reduce the noise that occurs from reflectors that are produced from walls and other structures that are within the range of the ultrasound beam.

The volume button should be at the appropriate level to hear the frequencies but not to annoy the person across the hall or wake up a sleeping child.

Doppler Modalities

Continuous Wave Doppler uses a transducer with two crystals, one continuously emits ultrasound pulses and the other one receives the reflected frequencies. Because the crystal does not have to wait for the returning signals, there is no limit to the velocities that can be recorded. The one draw back is that all the velocities along the entire length of the ultrasound beam are recorded so only the highest velocities can be measured. This is an excellent tool when used in conjunction with pulsed Doppler and color Doppler. One must remember that the ultrasound beam has width and length that extends beyond the scope of the 2D image and the pulsed Doppler. This is important since any flow in the range of CW beam will be recorded in the spectral analysis graph.
A point to remember is that even though the phased array probes now have imaging CW capabilities, the "blind" pencil probes tends to be a more accurate assessment of the maximum flow velocities that are being measured. This probe has a small face and is easily manipulated between the rib spaces. The draw back is that the image is not displayed on the screen, only the spectral tracing is visible, so the operator must be sure of what is being assessed.

Pulsed Doppler uses a single transducer crystal that transmits and receives the ultrasound pulses. The transducer sends a pulse and must receive that signal back before another pulse can be emitted. A sample volume is positioned at the area of interest. The velocity of sound in soft tissue is a given constant of 1540m/s. and the 'go and return time' is used to determine the depth of the sample volume.
The size of the sample volume can be adjusted accordingly. This sample volume is indicated by a white 'dot' on the cursor line. The velocity readings are from this area only.
The velocities (frequency shifts) that can be recorded are limited by the pulse repetition frequency or number of pulses that are emitted per second. The depth of the sample volume limits the pulse repetition frequency.

Theoretically the maximum velocities that a system can resolve is one half the pulse repetition frequency. This is called the Nyquist limit. If the PRF is 8KHz then the maximum frequency shift that can be recorded is 4KHz. If the PRF is decreased then the resultant shift will also decrease limiting the maximum velocity that can be accurately recorded.

If the frequency shift is higher than the Nyquist limit these velocities will alias or be shown as flow in the opposite direction.

To eliminate aliasing, move the baseline up or down to accommodate the spectral display. Changing to a lower frequency transducer will decrease the travel time because lower frequency transducers have longer wavelengths. If the velocities can not be recorded with PW then change to CW. Some ultrasound systems have high PRF capabilities. This uses several sample volumes spaced along the length of the cursor.

High Pulse Repetition Frequency Capabilities

Aliasing of the Doppler signal occurs when the PRF values are so high that the returning signals from one waveform are not received before the next waveform is sent.

The concept of using multiple "sample volume" positions to increase the velocities that can be accurately recorded is achieved by taking advantage of the phenomenon of "range ambiguity". The depth of the sample volume and the PRF limits the velocities that can be recorded. To increase the velocities that can be recorded, higher sampling rates are combined with a lower depth sample location (closer to the transducer).

The sample volume closer to the transducer "targets" information not only from it's own location but also from the more distal location. There is always a fixed distance between the two or more locations so the information is simultaneously received back to the transducer.

The draw back is that the operator does not know the details of the specific origin of the velocities and should use the 2D image along with the Doppler information to accurately interpret the findings.

Color Doppler displays the direction and flow velocities of the blood on top of the 2D image. A color is assigned to the direction of flow whether it is away or toward the transducer. It may be helpful to remember the word BART (Blue Away Red Towards).

The velocity is displayed in shades of these colors. The brighter the color the higher the velocity. When the flow is disturbed or not laminar, the pattern will be mosaic. This mosaic pattern is only produced if the "variance" is on. The variance is a color Doppler option that is present with all the cardiac presets.

Color flow Doppler provides Doppler shift information from an entire area unlike Pulsed Doppler, which samples from a specific point. Therefore, color Doppler requires more time to compute the lines of information onto the screen. Frame rate and line densities are reduced proportional to the time required. Keeping the color sector small will provide an acceptable frame rate and produce a flicker free image.

Using color flow allows the operator to visualize the blood flow in relation to the surrounding structures, provides a method for rapid interpretation of abnormal location and direction of flow and helps to guide Doppler interrogation of abnormal flow.

Summary

The Doppler shift is a change in frequency due to motion between the source which is the transducer and the reflector or RBC's. This change in frequency is recorded in both audible and visual format.

CW records higher velocities but cannot record at specific sites. Whereas pulsed Doppler is able to select a specific sample at a particular depth but the maximum velocities that can be recorded are determined by the Nyquist limit.

Color flow Doppler along with Pulsed and continuous wave Doppler should be used in conjunction with two dimensional imaging to provide a complete and accurate Echocardiographic examination.

Questions to ask when evaluating a Doppler spectrum

1. **What transducer position was used?**
2. **Where in the heart was the sample volume located?**
3. **From this location, which direction should blood be flowing?**
4. **In which portion of the cardiac cycle should flow occur?**
5. **Are increased velocities measured? If so, in which portion of the cardiac cycle?**
6. **If a velocity measurement was made, was a thorough interrogation made to align the beam parallel to flow?**
7. **Was spectral broadening noted and if so, in which portion of the cardiac cycle?**
8. **If a flow disturbance was detected, what was its origin?**

References

1. Doppler Ultrasound in Cardiology-Liv Hatle
2. Diagnostic Ultrasound
General Principles and Exercises-Kremkau

M-Mode measurements

The main advantage of using m-mode is the simplicity of measurement. In addition its high frame rate of 1000-2000/sec results in superior resolution when compared with conventional 2D which has a frame rate of approximately 30/sec. The m-mode cursor is guided from the 2D image as reference. In this institution the cursor is positioned from the parasternal long axis at the tip of the Mitral valve leaflets.
The dimensions of chamber walls, valves etc. can easily be tracked providing a rapid accurate and repeatable method for assessing and measuring changes that occur with growth and development.

The American Society of Echocardiography recommends that end diastole occurs at the onset of the QRS on the accompanying ECG. In faster heart rates this may lead to errors in measuring dimensions if this rule is followed exclusively. In small children, compromises are in order where end diastole can be represented at the point of maximum diastolic diameter.

Estimates of chamber sizes rely on various geometric assumptions being that the LV is a prolated ellipse. Specifically the minor axis is 1/2 that of the major axis.
Also the EF may only be assumed from m-mode where there are no wall motion abnormalities. In pediatrics wall motion abnormalities are rare however must be excluded to validate the measurements.
The numbers received from the m-mode are normalised for age.
Shortening fractions are relatively independent of changes in HR.

Test your Knowledge with the following exercises.

1. Sound is
   a. transmitted at the same velocity through all mediums.
   b. a form of mechanical energy
   c. is classified according to its wavelength
   d. is always audible to the human ear

2. Name the frequency range for
   a. Audible sound
   b. ultrasound
   c. Diagnostic sound

3. Sound is transmitted
   a. by pressure waves
   b. by longitudinal waves
   c. because of frequency shifts
   d. through vacuums.

4. The frequency of sound is measured in
   a. milliseconds
   b. watts
   c. Hertz
   d. Volts

5. Sound will travel **better** through which medium, air or soft tissue? Explain.

6. Explain how attenuation affects an ultrasound image.

7. Name the component of an ultrasound machine that will compensate for attenuation.

8. The gain controls of an ultrasound machine
   a. adjusts the frequency of the received signals
   b. adjusts the gray scale assignment
   c. adjusts the amplification of the received signals
   d. adjusts the brightness of the monitor screen

9. When the adjustment of the TGC curve does not improve the ultrasound image, one should
   a. change the position of the transducer on the patient's chest
   b. adjust the output of the machine
   c. adjust the brightness of the monitor
   d. change to a lower frequency transducer

10. EXPLAIN THE FACTORS TO CONSIDER WHEN SELECTING A TRANSDUCER.

Detailed evaluation of the heart by Echocardiography
Segmental Analysis

Subcostal Position

- Situs evaluation - visualisation of IVC and aorta in long and short axis
- Doppler descending aorta and IVC
- Color IVC/RA junction proximal and distally
- Subcostal 4 chamber
- Position of heart- levocardia, mesocardia, dextrocardia
- AV and VA Connections
- Assess IAS and IVS
- SVC and pulmonary veins (right upper and left lower)
- RVOT- right anterior oblique view.

Parasternal Views

Parasternal long axis

- Aortic valve annulus measurement
- Functional assessment using M-mode
- TV inflow and PV outflow
- Color flow Doppler- AI, MR and ventricular septum
- LA measurement on the m-mode or 2D

Parasternal short axis

- Trileaflet Aortic valve
- coronaries
- Short axis sweep from aortic valve to apex
- Investigate RVOT, TV
- Color to rule out VSD, TR, PI and obstruction.
- measure pulmonary valve annulus, Doppler across PV
- branch pulmonary arteries- measure, color
- Pulmonary veins- should see three-two left and the right lower

Ductal view

- visualization of the MPA and descending aorta to rule out the presence of a patent ductus and a posterior shelf in the descending aorta
- the isthmus area can be measured and should be assessed with PW/CW

Apical position

- Mitral and Tricuspid valves
- Measure annulus of MV/TV, Color and Doppler of the inflow, MR and TR
- Color of the septum-special attention to the apex
- 5 Chamber view-Doppler aortic valve
- Observe function and chamber sizes

- 2 chamber view

Supra Sternal Position

- Start in the transverse plane, the aorta in short axis, right pulmonary artery in long axis below aorta, IVC to the right and innominate vein above the aorta.
- Sweep towards the head following the innominate artery to the bifurcation to determine the presence of a left or right aortic arch.
- Observe the long axis of the arch and assess with color, pulsed and continuous wave Doppler. Measure the arch in the ascending , transverse and isthmal area.
- Observe SVC flow with color sweeping rightward to see the vein as proximal to the heart as possible.
- Follow the innominate vein to the left to rule out the presence of a left SVC.
- Additional views to rule out partial anomalous pulmonary veins. (See below)

Booking Echocardiography appointments

Outpatients:

Appointments for patients seen in the Cardiology clinic are booked through the booking office at extension 7336. This is for all outpatients with or without sedation who require a full or follow-up study.
Patients who require limited assessments such as functional studies or fluid checks are arranged through the "Echocardiography registration" desk at 4914. (Mima or Andre)

Patients needing sedation:

- All patients within the age range for sedation are assessed on an individual basis to determine if they are suitable for the sedation. Sedation is not given to patients if their condition is unstable or if contraindicated; i.e.- airway obstruction.
- Newborns that are term (40 weeks) plus 3 weeks of age and 3kgs and up to 3 years of age and less than 15 kgs are eligible to receive sedation.
- There are only 7 sedation "slots" per day

Inpatients:

- The physician who is covering the echo lab that day must approve appointments for inpatients.
- It is the responsibility of the Fellow requesting the echo to get the approval before booking the appointment
- Exceptions are: patients with Kawasaki disease, function and fluid checks, post ablation patients, rheumatology patients: these may be booked without the approval of the staff physician.

PICS System.

- Requests for inpatient echos are entered in the PICS computer system (on line requisition system) .
- The cardio database is accessible with a password
- The fellow is responsible for entering the request including all pertinent information and the reason for the request and if sedation is required.

Consultations:

- All requests for cardiology consults are directed to the responsible Fellow on consult service
- The "consult" Fellow can request an echo according to the inpatient or outpatient criteria.
- If there is need for an echo on an urgent basis, the Fellow should contact Mima or Andre (4914) to arrange the time etc.

- All patients who do not have an HSC history number will need pre registration information: full name and date of birth entered and assigned a number before any tests can be booked.
- Reports will be distributed to medical records and the assigned Cardiologist. The consult fellow will receive a report of the results and should include one in the “zebra” as well as to the requesting physician.

Tissue Doppler Imaging

Tissue Doppler Imaging (TDI) is an emerging non-invasive ultrasound technique that makes it possible to measure velocities at any point of the ventricular wall during the cardiac cycle. Over the last ten years, TDI has been proposed as a feasible and useful imaging tool that provides information on regional wall motion dynamics.

Trambaiolo, P.
Tonti, G.
Ricci, A.
Salustri, A.

The velocity of moving tissue can be studied with pulsed wave (PW) tissue Doppler sampling, which displays the peak velocities within a selected myocardial region against time, with high temporal resolution (approxi-mately 8 msec). In addition, the mean velocities can be calculated with time velocity maps and displayed as colour encoded velocity maps in either an M-mode or a two-dimensional format. While PW tissue Doppler can be analyzed in a manner similar to PW flow Doppler, providing regional evaluation of peak and mean velocities, the amount of information contained in colour tissue Doppler is still very underestimated. Since the introduction of TDI it has been clear that simple visual interpretation suffered from all the limitations of a qualitative method, and the need for quantification of regional left ventri-cular function became evident. Indeed, since all the points within the ventricular walls are velo-city-encoded in real-time, the colour-coded display should provide a huge amount of infor-mation which could form the basis for the application of accurate, reproducible quanti-tative evaluation.

Tissue Doppler analysis modalities

As with Flow Doppler, myocardial velocities can be analyzed by TDI with different modalities: pulsed wave (PW-TDI), colour two-dimensional (2D-TDI), and colour M-mode (MM-TDI).
The spectral PW-TDI method provides higher temporal resolution and resolves all peak velocities. With this modality a sample volume is placed within the myocardium (either in the endocardium or the epicardium) and the low Doppler shift of frequencies recorded from the heart wall moving through the sample volume

during the cardiac cycle is recorded. The pattern can be divided into two parts, systolic and diastolic, from which several measurements can be obtained: 1. The systolic phase is characterized by a positive wave (S) preceded by the time taken for regional isovolumic contraction (RIVCT); 2. The dia-stolic phase, which is more complex, is composed of 4 periods:
a) regional isovolumic relaxa-tion (RIVRT);
b) the rapid filling period char-acterized by a negative wave (E);
c) diastasis, and
d) filling due to atrial contrac-tion, represented by a second negative wave (A).
The 2D-TDI method provides acceptable spatial resolution along the direction of the ul-trasound beam but lower temporal resolution compared to pulsed TDI (pulsed measures peak velocities; colour encodes mean velocities). The temporal resolution varies according to the system used and ranges from 100 msec in first generation to 10 msec in the new fully-digital systems.
The main advantage of MM-TDI is related to the inherent highest frame rate of this modality which is relatively independent of two-dimen-sional image quality. Depending on the orienta-tion of the cardiac structures relative to the ul-trasound beam, the velocity signals appear red or blue according to the movements of the myocardium towards or away from the trans-ducer, respectively. Moreover, different colour coding scales reflect different velocities: low ve-locities are coded with dark colours, while high velocities are coded with bright colours.

Qualitative analysis of colour Tissue Doppler Imaging

The MM-TDI can be recorded either in par-asternal or apical views. The angle dependency of TDI implies that only measurement of tissue motion parallel to the exploring ultrasound beam can accurately resolve myocardial veloci-ties, although timing and velocity waveforms are angle-independent. Thus, the MM-TDI from the parasternal and apical views allow the anal-ysis of contraction and relaxation of circumfe-rential (intra-myocardial) and longitudinal (sub-endocardial) fibers, respectively.
Colour B-scan gives the best overview of cardiac dynamics because all of the scanned colour data are displayed simultaneously. More-over, a cine-loop with several image frames stored in an electronic memory allows an easy frame-by-frame analysis. The colour maps used

most often to display myocardial velocities are the yellow-red and green-blue. An important factor that must be considered before analyzing two-dimensional images is that TDI represents a combination of myocardial velocity data and is related both to the intrinsic rate of wall thick-ening and to overall cardiac movement during the cardiac cycle.

Semi-quantitative analysis of colour tissue Doppler

A semi-quantitative analysis can be per-formed by positioning a sample volume (3 by 3 pixels) on the M-mode and 2-dimensional im-age. Thus, the velocity value of a region of inter-est is displayed on the screen. This semi-quanti-tative TDI validated the qualitative observations and allowed the clinical application of the col-our tissue Doppler.

Clinical applications

1. Diastolic Function

Analysis of the motion of the myocardium during diastole with TDI has been performed in healthy normal subjects. The PW-TDI provides a mirror image of the initial inflow patterns, with a decrease in the E/A velocity ratio with age. Myocardial diastolic velocities have been report-ed in various diseases, allowing a differentiation between constrictive pericarditis and restrictive cardiomyopathy, as well as among the different patterns of myocardial hypertrophy.

2. Myocardial ischemia

Tissue Doppler analysis has been mainly uti-lized in the assessment of regional systolic ven-tricular wall motion in patients with coronary ar-tery disease. In fact, coronary artery disease is a process typically characterized by regional rath-er than global left ventricular dysfunction. Three very elegant experimental studies have been performed to define the pattern of myocardial velocities during regional ischemia and reperfu-sion. PW-TDI has also been used to study pa-tients with ischemic heart disease and a positive treadmill stress test (without a history of myo-cardial infarction) who underwent coronary an-giography. TDI has also been performed during stress, either physical or pharmacological.

3. Multisite stimulation in refractory heart failure

It has been hypothesized that “multisite” biventricular pacing can improve the contrac-tion synchronism of the left ventricle in pa-tients with severe left ventricular dysfunction, leading to an objective improvement of its glo-bal performance. In these patients, TDI could usefully be applied to select the candidates for biventricular pacing.

4. Left atrial appendage

Colour coded tissue Doppler (Fig. 2) ren-dered a qualitative assessment of LAA wall, de-picting both the timing and the sequence of

LAA contraction. With pulsed Doppler interro-gation a triphasic signal was recorded in all pa-tients, consisting of a positive wave followed by a biphasic wave. Evaluation of LAA wall using tis-sue Doppler is feasible and reproducible. While colour tissue Doppler analysis allows a qualita-tive assessment, pulsed Doppler gives new quantitative insights for the comprehensive as-sessment of LAA wall dynamics, which comple-ments the information obtained with flow inter-rogation

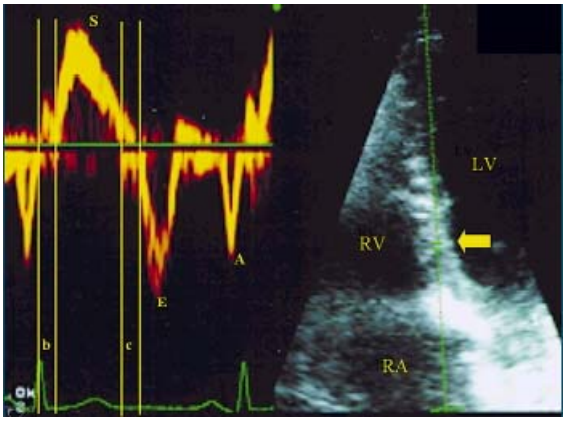


Fig. 1: Longitudinal pulsed wave Doppler of the myocardium, 4 chamber view : the sample volume (arrow) is positioned at the basal level of the interventricular septum. ("S"): Systolic phase; ("E"): Rapid filling period; ("A"): Atrial contraction; ("b"): Regional isovolumic contraction time (RIVCT); ("c"): Regional iso-volumic relaxation time (RIVRT); RV: right ventricle; LV: left ventricle; RA: right atrium.

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Limitations and advantages of qualitative evaluation of PW-TDI and 2D-TDI

Both spectral and colour TDI of the myocar-dium is available in the latest generation echo-cardiographic systems. Spectral (pulsed) Dop-pler interrogation of the myocardium is the most used in clinical setting because of its easy quantitative on/off-line analysis. In contrast, as already mentioned, on-line quantification of col-our maps is limited to the sampling of points or region of interest.

Image processing in tissue Doppler analysis

The off-line analysis of colour tissue Doppler maps involves:
1. grabbing and storage of the images in digital

format because video tape recording yields poorer resolution and has more inherent arti-facts;
2. filtering of the images in the computer;
3. calculation of the value of each pixel, by de-coding its colour against a lookup table extract-ed from the calibration bar displayed in the im-age.

Quantitative approach for colour tissue Doppler images

There are two different potential sources of data to utilize for quantitative analysis of colour tissue Doppler. Tissue Doppler data can be col-lected either before (“raw data”) or after image processing (“image memory data”)
A new method for quantification is based on a software (by Dr Tonti) installed in a computer connected to any commercial echocardio-graphic system by an RGB cable. The colour ve-locity images are loaded in the software (from a magneto-optical device, by means of a video grabber, scanned from hard copy or from a file stored in a mass memory device) and convert-ed in numerical matrix. The tissue Doppler in-formation can be acquired as a single frame (M or B representation), or as a cineloop. After digital filtering of the images for the removal of noise and colour dropouts each image is trans-formed into a two-dimensional matrix (Figure 3) in which the brightness of each pixel (that in col-our Doppler code correlates linearly with the de-tected velocity) is converted in the respective numerical value: in this way the colour-coded map is transformed in numerical values of brightness.

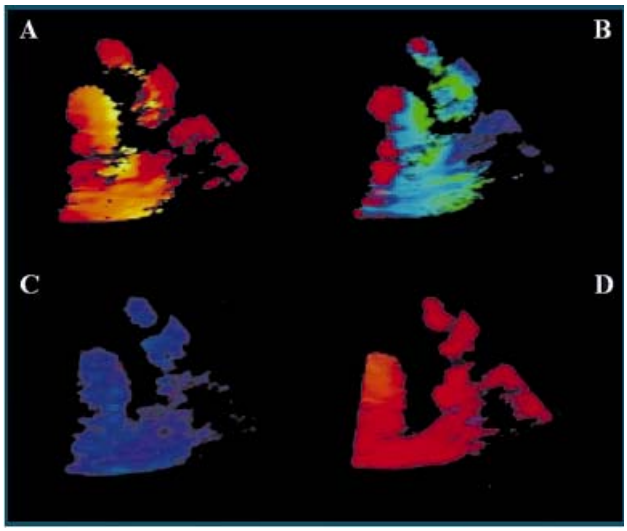

Fig. 2: Two-dimensional colour coded velocities of left atrial appendage walls. Left atrial appendage walls are depicted in lighter red (A) and blue

colour (B) because of the motion of the appen-dage to and from the probe (contraction and relaxation). Left atrial appendage has also passive emptying and filling and the relative wall movements are coded in blue (C) and redcolour (D), respectively

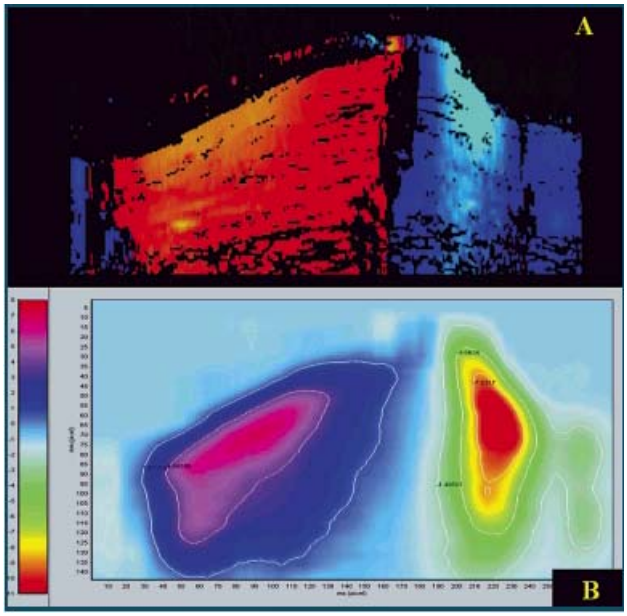

Fig. 3: Velocity decoding of M-mode TDI images:
Panel A : M-mode TDI representation of the posterior left ventricular wall from the parasternal window.
Panel B : velocity decoding of each pixel of the image of panel A. The velocity is represented as an iso-velocity shaded map with contours of iso-value lines; the correspondence between colours and velocity is dis-played on the colour bar on the left of the image.
The measure unit for time and distance are expressed in pixels.

Conclusions

Tissue Doppler analysis has the potential to objectively quantify regional ventricular wall motion. Over the last ten years there has been an increasing need for quantitative appro-aches in TDI. The availability of high frame

rate and high resolution acquisition systems has led us towards off-line analysis of digital images. Application software can be imple-mented as useful tools for the quantification of parameters used on regional myocardial ve-locity data. These should provide new insights into regional radial and longitudinal systolic and diastolic function. Further studies will be needed in the future to standardize and devel-op these automated measuring methods and to ascertain whether these techniques are of clinical value.

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Literature:
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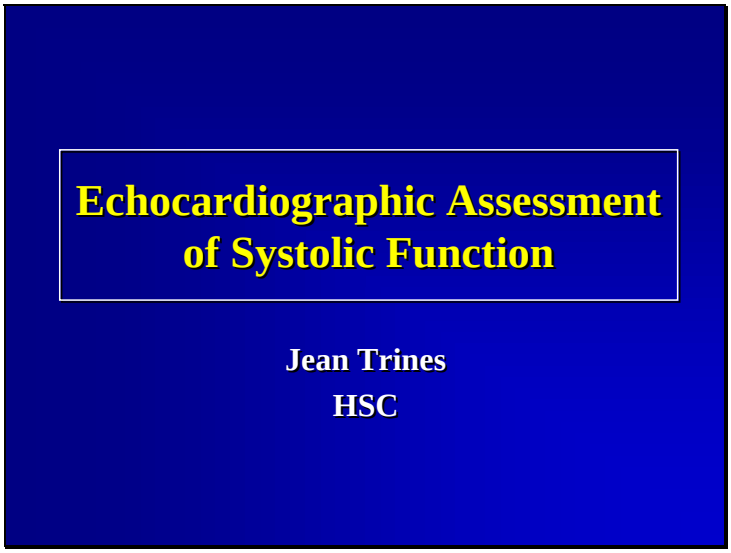


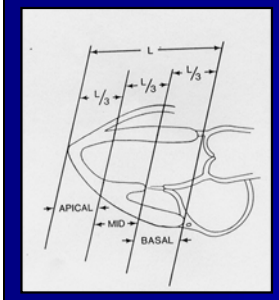
Slide 2

Ultrasound Methods used to Quantify Systolic Function

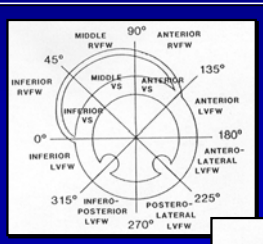
- M-Mode Parameters
  - Ejection Fraction
  - Shortening Fraction
  - Velocity of fibre shortening
  - Velocity of fibre shortening- heart rate corrected
- 2D assessment of systolic function
- Rate of Pressure rise- dP/dT
- Left Ventricular Wall Stress

Slide 3

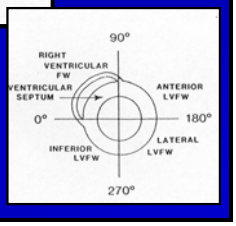
Ecocardiographic Examination



Parasternal View



Mid-ventricular



Apical Region

Slide 4

M-Mode measurements

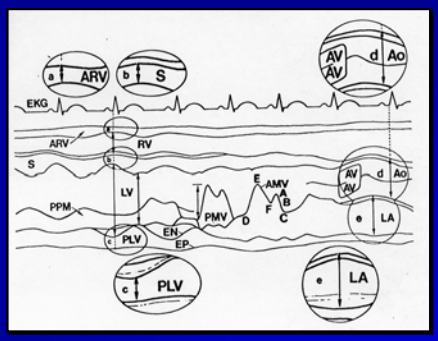
- Provides high resolution imaging and excellent time dependent analysis
- Sampling rates in excess of 1000 frames/s
- Easy measurements
- Limitations
  - “ice pick view”
  - dependent on transducer angulation
  - assumes 3D volumes

Slide 5

Standardisation of M-mode Measurements

American Society of Echocardiography
Circulation 1978;58;6:1072-83

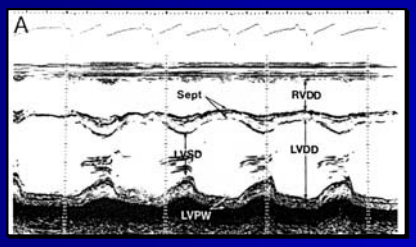
- At end expiration
- In small children, ED may not be R wave
- ES-nadir of septal motion and peak of posterior wall
- Level of MV leaflets or level of chordae



Slide 6

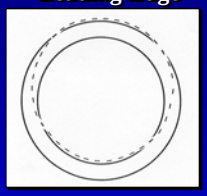
M-Mode Considerations

Proper transducer position, gain settings and careful attention to cursor position will contribute to accuracy.

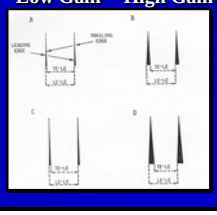


Standard M-Mode display

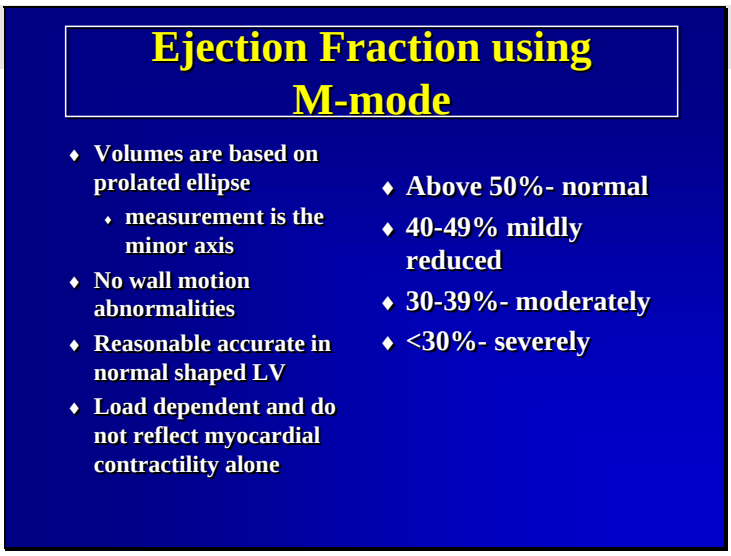
Leading Edge



Low Gain High Gain

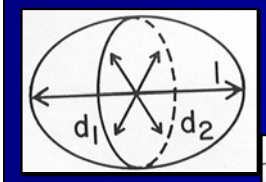


Slide 7


Ejection Fraction using M-mode
Volumes are based on prolated ellipse
measurement is the minor axis
No wall motion abnormalities
Reasonable accurate in normal shaped LV
Load dependent and do not reflect myocardial contractility alone
Above 50%- normal
40-49% mildly reduced
30-39%- moderately
<30%- severely

Slide 8

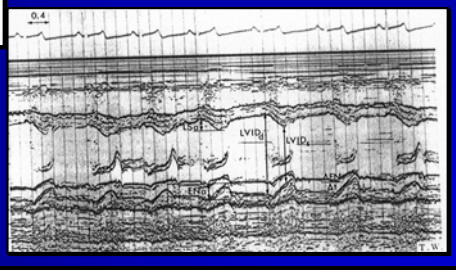
M-Mode Measurement of EF



Prolate ellipse showing two minor axis

$$4/3\ \Pi\ \frac{L}{2} \times \frac{D1}{2} \times \frac{D2}{2}$$

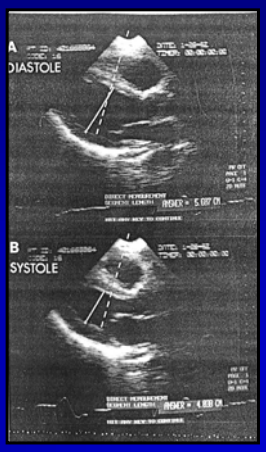
LV M-mode echo showing standard measurements and cyclic variations with respiration



Slide 9

M-Mode deviations and Pitfalls

- Cannot compensate for translation of heart
- Is reproducible but operator dependent
- All factors of each individual should be considered ie; patient with AI or MR
- Accuracy decreases with dilated heart



Slide 10

Fractional Shortening by M-Mode

- %SF = $\frac{\text{LVDD - LVSD}}{\text{LVDD}}$ X 100
- Normal value of 36%-- 26-44
- Preload and afterload dependent
- No assumptions
- Not reflective of global function
- ↑ SF with ↑ after load
- Congestive Heart failure - 16%

Slide 11

Mean VCF

Velocity of Circumfirential Fibre Shortening

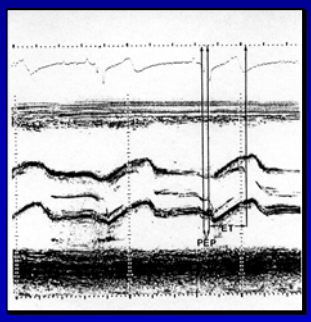
- Mean VCF= $\frac{\text{LVDD-LVSD}}{\text{LVDDxLVET}}$
- Normal values:
  - 1.5 +/- 0.04 circ/sec for babies
  - 1.3 +/- 0.03 circ/sec for 2-10 years
- The gradual decrease to adulthood reflects the dependence on heart rate and after load.

Slide 12

Mean VCF/VCFc

- **Requirements**
  - standard m-mode
  - LV ejection time -
  - m-mode of aortic valve, from opening to closure
  - R-R interval prior to the ET
- VCFc= $\frac{\text{LVDD-LVSD}}{\text{LVDDxLVETc}}$
- LVETc = $\frac{\text{LVET}}{\sqrt{\text{R-R}}}$

Normal -.98+/-0.07 circ/s



Slide 13

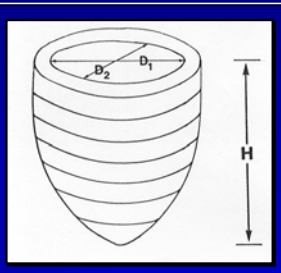
2D Assessment of Ejection Fraction

- Volumes estimates of planimatered area of LV- Simpson's Rule
- Single plane- 4 chamber
- Bi plane- 4 chamber + 2 chamber or apical long
- Modified Simpson's Rule- area from 4 chamber and minor axis from PSLAX

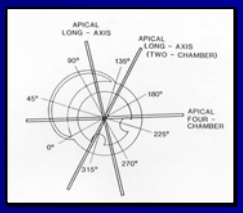
Slide 14

Simpson's Rule Method

- Volume of any object equals the sum of the volumes of multiple slices of known thickness that compose the object.



2 minor axis
Height
# of slices



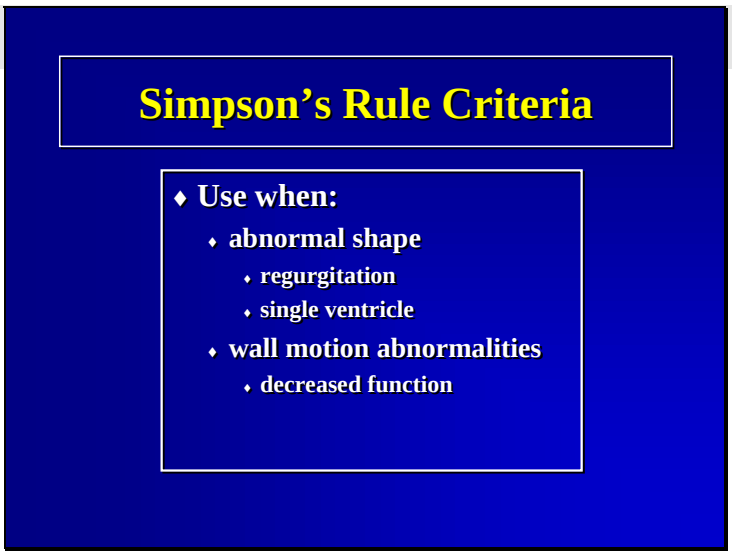
Orientation
of apical 4ch,
2 ch and long

Slide 15

Simpson's Rule

- Dependent on image quality
- Easy to foreshorten the apex
- Edge detection may be difficult
- End diastole is the frame before MV closes
- End systole is the frame before MV opens

Slide 16


Simpson's Rule Criteria
Use when:
abnormal shape
regurgitation
single ventricle
wall motion abnormalities
decreased function

Slide 17

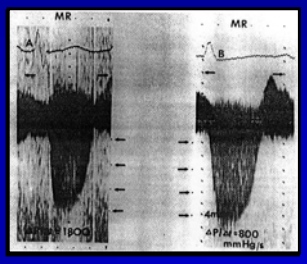
The Rate of Ventricular Pressure Rise (dP/Dt)

- Initially an independent determinate of LV function in pts with MR.
- Normal function has a rapid rise
- Compromised function has a slower rise
- Used on single ventricle
- Pt are own control

Slide 18

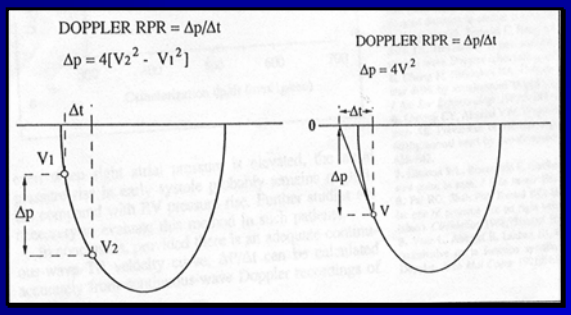
dP/dT

- Distance is measured between 1 and 3 meters
- Pressure rise according to Bernoulli is 32
- Rate of rise is 32/tmmHg/sec



Slide 19

Determining dP/dT



Slide 20

Ventricular Wall Stress (WS)

- Measures the force within the wall of the ventricle developed by the myocardium after the onset of ejection acting against afterload.
- Directly related to afterload
- Independent of preload.

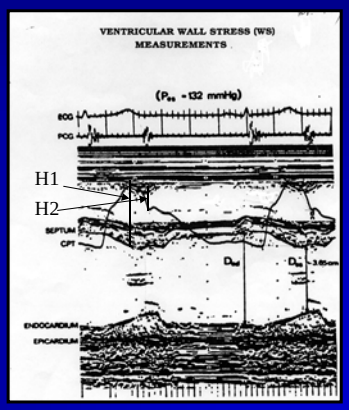
Slide 21

Meridional Wall Stress

- Measures the forces along the longitudinal axis
- WS= $\frac{(P)(D)(1.35)}{(h)(1+H/D)(4)}$

P = pressure (H2/H1 X PP)
D = minor axis dimension
h = wall thickness
1.35 = factor to convert mmHg to g/cm2

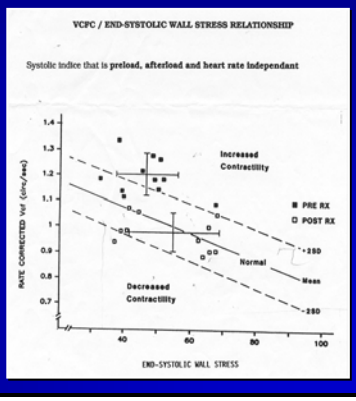
- Mmode
- Carotid pulse tracing
- Heart sounds
- Blood pressure



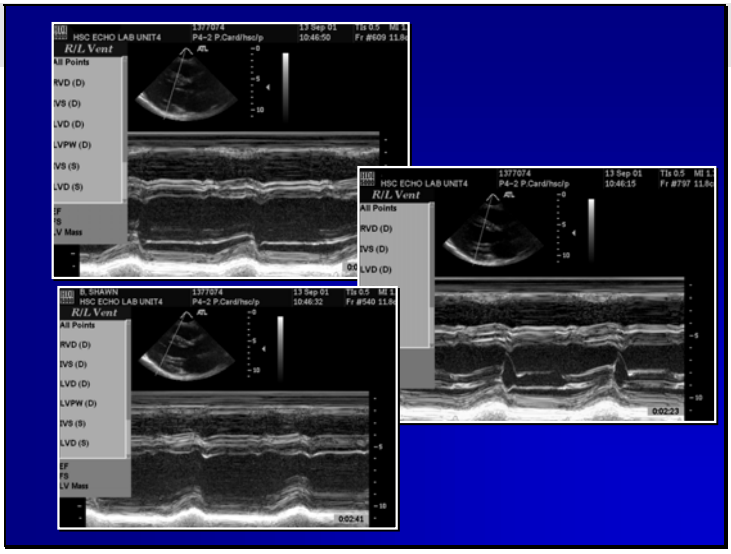
Slide 22

Wall Stress/ VCFc Relationship

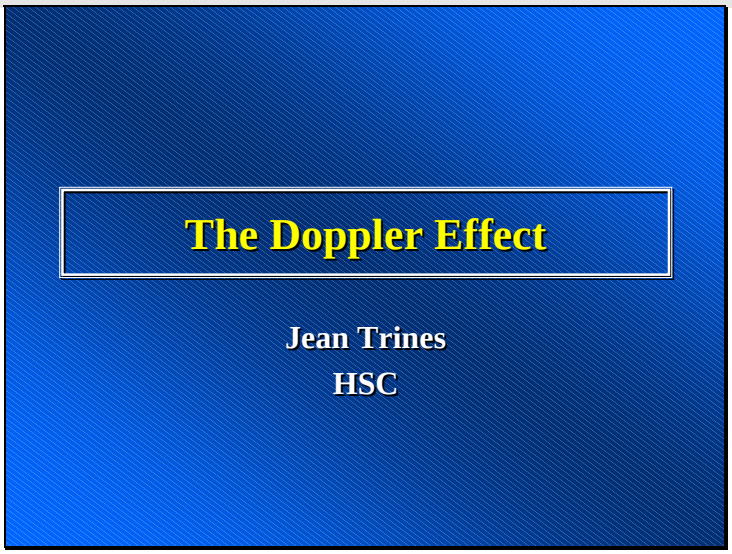
- **The linear relationship is used to study the effects of therapeutic interventions on after load, systolic performance and contractility.**



Slide 23


HSC ECHO LAB UNIT4
RIL Vent
All Points
RVD (D)
IVS (D)
LVD (D)
LVPW (D)
IVS (S)
LVD (S)
LV Mass
0:02:23
0:02:41

Slide 1



Slide 2

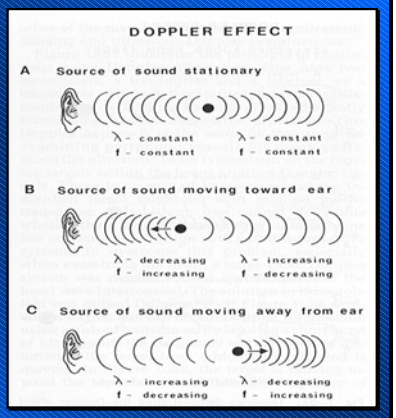
The Doppler Effect

- Christian Johann Doppler(1803-1853)
- Ultrasound is above the audible range but the Doppler shift will always be within the audible range 15Hz-20KHz
- The skilled operator listens to the Doppler sounds to determine normal and abnormal flow patterns.

Slide 3

The Doppler Shift

- When there is relative motion between the source and the reflector, the reflected frequencies will be different.
- Blood cells are moving reflectors.
- The direction and velocity of the cells determines the shift.
- This difference is directionally proportional to the velocity of the blood



Slide 4

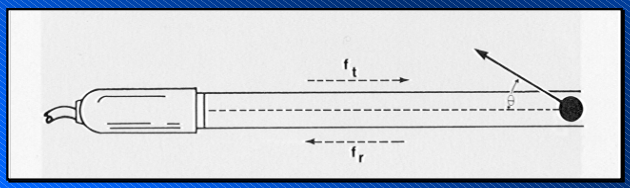
The Doppler Shift Equation

- $f_d = \frac{+/- 2Vfi \cos}{c}$ or $f_d = fr - fi$
- Where:
  - cos = angle between sound beam and blood vector
  - f_d = Doppler shift in Hz
  - fi = incident frequency
  - V = reflector speed in m/s
  - C = velocity of sound in soft tissue
  - fr = reflected frequency
- Example: fi=5MHz
  - fr=5.01MHz ($f\Delta$=5.01-5)
  - $f\Delta$=0.01MHz /10,000Hz (10KHz)

Slide 5

Angle Dependent

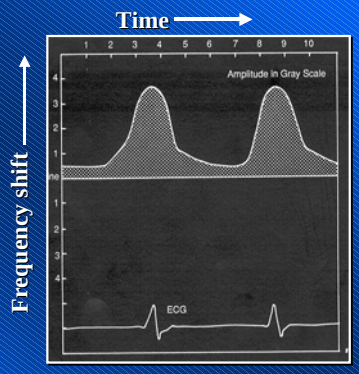
- Accuracy of the Doppler is dependent on the angle of incidence.
- Ultrasound beam must be parallel to flow or nearly so or maximum velocities will not be measured (up to 20 degrees)
- Doppler measures velocity not volume



Slide 6

Fast Fourier Transform

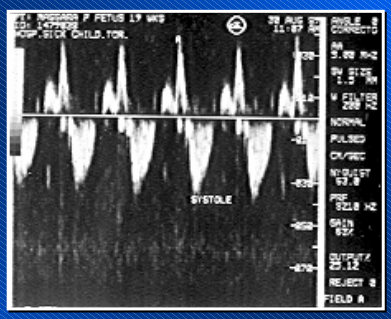
- The Doppler shift information can be displayed as an image.
- The Spectral Analysis Display represents the amplitude of each velocity by a dot in a shade of grey.
- The frequency shift, direction of flow, is displayed above or below the baseline



Slide 7

The Spectral Display

- Is an ultrasound image
- Control, gain, filter etc.
- The display is characteristic for the flow interrogated



Slide 8

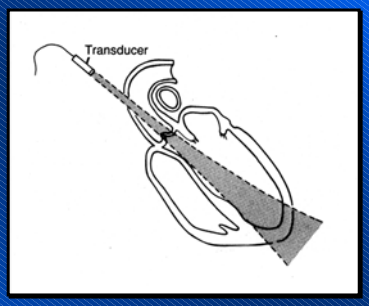
Types of Ultrasound Doppler Devices

- Continuous-wave (CW) Doppler
- Pulsed Doppler
- Colour Flow Doppler

Slide 9

Continuous Wave Doppler

- Two crystals- one emits, the other receives
- Can record high velocities since there is no waiting
- Must be aware of line of sight since highest velocities are all recorded



Slide 10

Points to remember when using CW

- Is not specific to one area.
- Blind CW is usually more accurate
- Can measure very high velocities

Slide 11

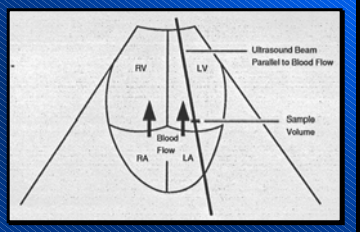
Pulsed Doppler

- Uses a single transducer crystal
- Records velocity readings from one particular depth.
- Uses the “go and return time”
- Velocity of sound in soft tissue is constant(1540m/s)
- Sample volume has size and shape.

Slide 12

Pulsed Doppler

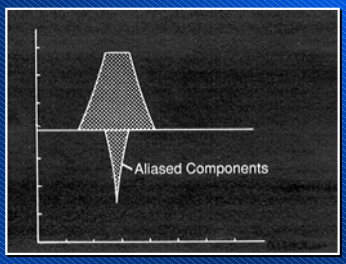
- Area to be sampled can be chosen by operator
- Velocities that can be measured are limited by the PRF
- Nyquist limit
- Angle dependent



Slide 13

PW- Nyguist limit and aliasing

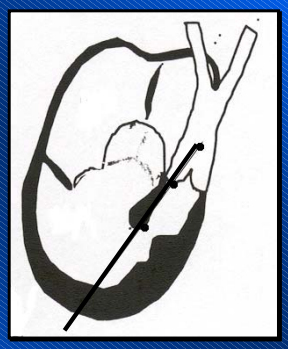
- PRF
  - limited by the depth
  - go and return time is longer at more depth
- Nyguist limit
  - 1/2 PRF
  - this value determines the maximum velocities that can be measured.
- Aliasing
  - occurs when the Nyguist limit is reached



Slide 14

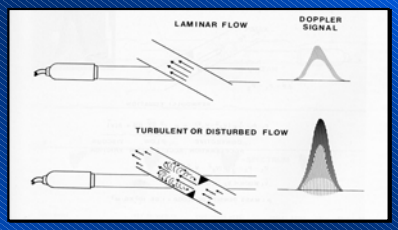
PW-Aliasing Troubleshooting

- Change to lower frequency transducer
  - velocity = wavelength X frequency (frequency inversely proportional to wavelength)
- Move base line position.
- High PRF
  - uses range ambiguity



Slide 15

PW- Spectral Broadening



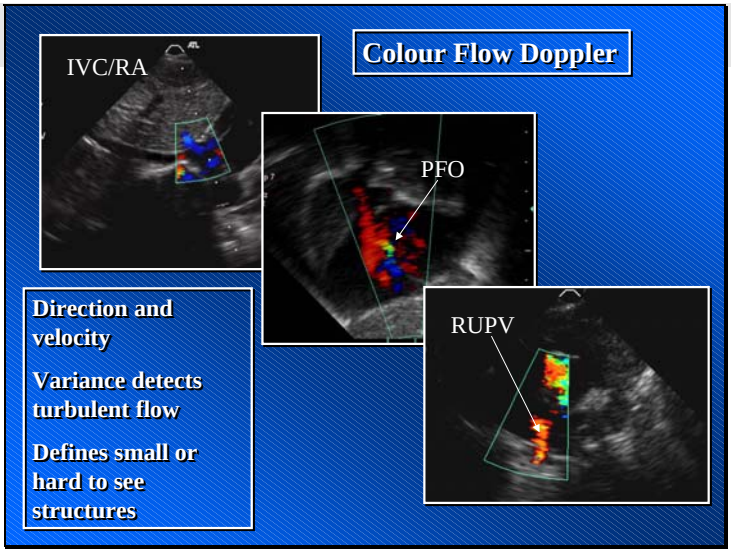
- Laminar flow has a narrow range of frequencies.
- Turbulent or high velocities have a wide range of frequencies

Slide 16

Colour Doppler

- Assigns a colour to direction and velocity
- Displayed in real time
- All properties of Doppler apply
- Affects frame rate and line density
- Allows operator to see flow in relation to anatomy
- Rapid screening for abnormal flow
- Helps to guide Doppler sampling

Slide 17


Colour Flow Doppler
IVC/RA
PFO
RUPV
Direction and velocity
Variance detects turbulent flow
Defines small or hard to see structures

Slide 18

Questions to ask when evaluating a Doppler Spectrum

- What transducer position was used?
- Where in the heart was the sample volume located?
- Which direction should the flow be?
- In which portion of the cardiac cycle should flow occur?
- Are increased velocities measured? In what portion of the cycle?
- Was spectral broadening noted?
- If a flow disturbance was detected, what was the origin?

Slide 19

Summary

- The Doppler shift is a change in frequency due to motion between the source and reflector. This change is recorded in audible and visual format.
- CW records higher velocities of flow, but does not sample at a specific depth.
- PW samples at a specified depth but is limited by the PRF (Nyquist limit)
- Colour Doppler depicts direction and velocity of flow on the 2D image in real time.

Protocols for Specific Cardiac Patients

Echocardiography protocols and management protocols for specific cardiac patients can be accessed on the cardiology server under References / Echo Lab / echo protocols and protocols

Index