Royal Brompton & Harefield NHS
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A lifetime of specialist care

Haemodynamics

Gradients & Calculations

Paediatricians with Expertise in Cardiology Special Interest Group

Inga Voges

MEASUREMENTS OF CARDIOVASCULAR STRUCTURES

- Identifying an abnormal measurement helps assessing the effect of a disease, determine when intervention may be necessary, and monitor the effect of the intervention.
- Size of cardiovascular structures are influenced not only by the hemodynamics of disease states and treatments but also by confounding factors (e.g. growth, age, gender, etc).

MCQ 1

Z value –
which of the following is NOT CORRECT

A The z-score of a variable is the position, expressed in standard deviations, of the observed value relative to the mean of the population distribution

B A z score of 0 corresponds to the population mean for that parameter

C Z scores can be converted to percentiles

D Z-score helps to track longitudinal changes with growth

E Z-scores are similar for boys and girls

Z-score

- In addition to reporting absolute values, it is useful to report quantitative m… …age- or size-appropriate n…
- In statistics, a… …ed to compare means from d… …ta sets of data.
- The score indi… …iations an observation is above or below the mean.
- **http://parameterz.blogspot.co.uk/2008/09/z-scores-of-cardiac-structures.html**

$z = (x - \mu) / \sigma$

X= observation
μ= mean, 0
σ= standard deviation,1

Portrait Christian Johann Doppler

MCQ 2

The simplified Bernoulli equation is NOT accurate when used in the following situation

A Pulmonary valve stenosis

B Aortic valve stenosis

C Tubular subaortic stenosis

D Supravalular aortic stenosis

E Pulmonary regurgitation

Doppler-Gradients Bernoulli equation

- Gradients can be estimated by the simplified Bernoulli equation:

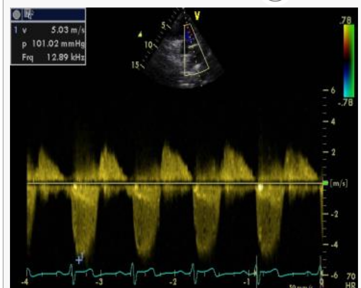
  $\Delta P = 4 \times v^2$

  (v= flow velocity)

- Mean gradient is calculated by integrating the gradient over the entire systole :

  $\Delta P \text{ mean} = \Sigma\, 4v^2/N$

Doppler-Gradients Bernoulli equation



Pulmonary stenosis with regurgitation

Doppler-Gradients Bernoulli equation

- **Assumptions:**
  - velocity proximal to the stenosis is lower than 1 m/s and can be ignored
  - Flow acceleration and viscous friction is negligible
- When proximal velocity is >1.5 m/s, proximal velocity should be included (modified equation)

  $\Delta P \text{ max} = 4 (v^2 \text{ max} - v^2 \text{ proximal})$

Doppler-Gradients Bernoulli equation

Pitfalls

- Improper beam alignment
- Poorly recorded signals (signal-to-noise ratio)
- Failure to detect an eccentric high-velocity jet
- Long, tubular stenoses
  - Viscous friction component becomes significant (eg. tunnel AS, long coarctation, subpulmonic PS)
- Changes in viscosity (eg anemia, polycythemia)
- Proximal velocity to the stenosis may be significant
  - use modified equation

MCQ 3

In a patient with aortic valve stenosis, the maximum systolic velocity across the aortic valve measured by CW doppler is 5.5 m/s. The maximum peak gradient is?

A 100 mmHg

B 120 mmHg

C 50 mmHg

D 75 mmHg

E None of the above

Simplified Bernoulli equation:

$\Delta P = 4 \times v^2$

Peak gradients

Value (m/s)	Gradient (mm Hg)
2,0	15
2,5	25
3,0	35
3,5	50
4,0	65
4,5	80
5,0	100
5,5	120
6,0	145

MCQ 4

What is the maximum velocity limit for a 3 MHz CW doppler operating at 4 cm depth?

A 40 cm/s

B 200 cm/s

C 2.5 m/s

D 4 m/s

E None of the above

Methods of measurement

PW Doppler (pulsed wave):
- Distinct region of interest (sample volume)
- Low imposed maximum velocity limit

CW Doppler (continuous wave):
- Lack of selectivity or depth discrimination
- High (no) maximum velocity limit

HPRF Doppler (high pulse repetition frequency)
- Several measuring sites

MCQ 5

Gradient in aortic stenosis can be estimated from?

A Subcostal view and parasternal long axis view

B Apical five chamber view and suprasternal view

C Parasternal short axis view and parasternal long axis view

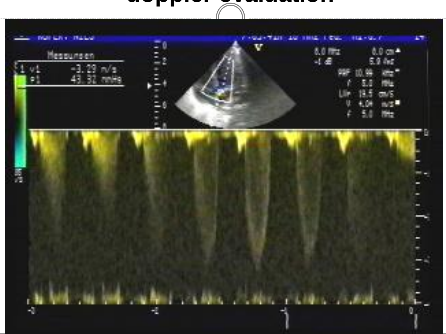
D Subcostal view and parasternal short axis view

E Apical two chamber view

Aortic stenosis

- Gradient can be estimated from apical five chamber view and suprasternal view
- CW-Dopper
- Peak gradient has a good correlation with invasive measurements

Aortic stenosis - doppler evaluation



Aortic stenosis

Signal too low (underestimation of severity)
- Tachycardia
- Reduced contractility
- Mitral regurgitation
- Atrial septal defect
- Aortic coarctation
- High peripheral resistance

Signal too high (overestimation of severity)
- Bradycardia
- Increased contractility
- Aortic regurgitation
- Ventricular septal defect
- PDA
- Low peripheral resistance

Special case - critical aortic stenosis

- Wide spectrum of LV size and function
  - Dilated LV – Borderline LV – Hypoplastic LV
  - Endocardial fibroelastosis
- Gradient across aortic valve depends on ventricular function and size of PDA
- Gradient across aortic valve depends on ASD size
- Flow across PDA depends on pulmonary and systemic resistance

Aortic stenosis

Classification of the severity of aortic stenosis

	Heart catheter peak-to-peak gradient	cw Doppler Vmax *ACC/AHA ESC*	Bernoulli peak instantaneous gradient	Bernoulli mean instantaneous gradient *ACC/AHA ESC*	Echo aortic valve area *ACC/AHA ESC*
Trivial					
Slight	< 30 mmHg	< 3 m/s	< 36 mmHg	< 25 mmHg	> 1.5 cm^2 *(> 1 cm^2/m^2)*
Moderate	30-50 mmHg	3-4 m/s	36-64 mmHg	25-50 mmHg	1-1.5 cm^2 *(0.6-1 cm^2/m^2)*
Severe	> 50 mmHg	> 4 m/s	> 64 mmHg	> 50 mmHg	< 1 cm^2 *(< 0.6 cm^2/m^2)*

MCQ 6

The continuity equation is an example of

A Law of conservation of mass
B Law of conservation of momentum
C Law of conservation of energy
D Poiselle's law
E Coanda effect

Continuity equation

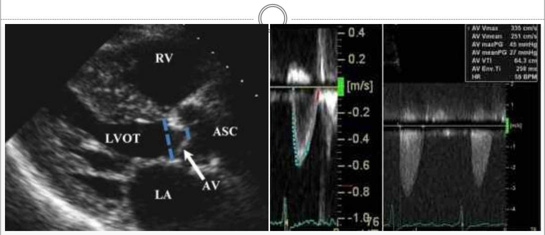
This equation is based on the conservation of mass:

Flow proximal to a valve equals flow across the valve

It is typically used to calculate the aortic valve (AV) area

$$\text{Area AV} = \frac{(\text{Area}_{LVOT})\,(\text{VTI}_{LVOT})}{(\text{VTI}_{AV})}$$

Example



1) Calculate area of LVOT, $A_{LVOT} = \pi * r^2$
2) Measure LVOT velocity and/or VTI_{LVOT}
3) Measure transvalvular velocity and/or VTI_{AV}

MCQ 7

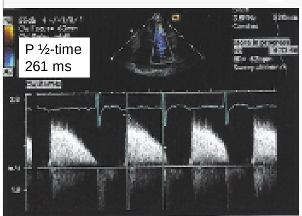
In mitral stenosis, the LVOT diameter is 2.0 cm. The LVOT VTI is 15 cm. The mitral valve VTI is 45 cm. The mitral valve area by the continuity equation is equal to:

A 2.0 cm^2
B 1.0 cm^2
C 0.5 cm^2
D 0.1 cm^2
E 1.15 cm^2

Area MV=
$(\text{Area}_{LVOT})\,(\text{VTI}_{LVOT})/(\text{VTI}_{MV})$

3 x 15/45

Mitral valve stenosis



The mitral valve area can be also determined by Doppler with the following formula:

220 ÷ pressure half-time

220/261= 0.8 cm²

MCQ 8

The formula that is used to calculate the peak pressure gradient in aortic coarctation is:

A 4 (v^2 max - v^2 proximal)

B 4 (v^2)

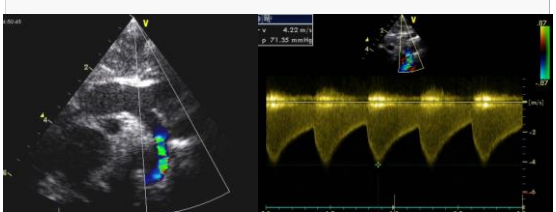
C 220 ÷ PHT

D CSA x VTI

E None of the above

Aortic coarctation

- Gradient can be estimated from suprasternal view
- CW Doppler, PW Doppler (abdominal aorta)



Aortic coarctation Bernoulli equation

- To best calculate the peak pressure gradient in aortic coarctation, the **lengthened Bernoulli equation** should be used.
- The lengthened Bernoulli equation calculates the velocity proximal to the obstruction which **may be increased** in aortic coarctation.

ΔP max = 4 (v^2 max - v^2proximal)

Aortic coarctation

- Peak gradient does not correlate with invasive measurements or blood-pressure difference between arms and legs
- Mild stenosis and large collaterals - Doppler echocardiography often overestimates the peak gradient
- Aortic regurgitation and BT-shunts can mask the diastolic part of the stenosis

MCQ 9

In patients with aortic valve stenosis/coarctation, the pressure gradients measured by Doppler include:

A Maximum peak instantaneous gradient and peak-to-peak gradient

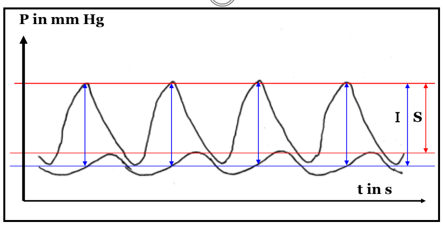
B Maximum peak instantaneous gradient

C Peak-to-mean gradient

D Peak-to-peak gradient

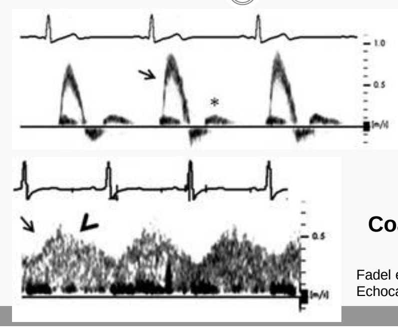
E Minimum instantaneous flow rate

Difference between peak gradient and instantaneous gradient



- Instantaneous gradient (**I**) is higher than peak gradient (**S**)!
- Doppler echocardiography measures the instantaneous gradient
- Blood pressure measurements determine the peak gradient

Pulsed-wave Doppler interrogation of the abdominal aorta



Normal

Coarctation

Fadel et al. Echocardiography 2014

Pulmonary valve stenosis

- Gradient can be estimated from subcostal or parasternal view
- CW-Doppler
- Peak gradient shows a good correlation with invasive measurements

Pulmonary valve stenosis

	Right Ventricular Systolic Pressure (mm Hg)	Transvalvular Pressure Gradient (mm Hg)
Trivial	<25	<50
Mild	25-49	50-74
Moderate	50-79	75-100
Severe or critical	>80	>100

Tricuspid jet velocity, when tricuspid regurgitation is present, provides an estimate of right ventricular systolic pressure.

MCQ 10

Right ventricular systolic pressure may be calculated when the following condition is present:

A Aortic regurgitation
B Mitral regurgitation
C Pulmonary regurgitation
D Tricuspid regurgitation
E None of the above

Determining the degree of PHT

- Tricuspid jet velocity, when tricuspid regurgitation is present, provides an estimate of right ventricular systolic pressure (RVSP) utilizing the simplified Bernoulli equation
- RVSP may be also calculated when ventricular septal defect, or patent ductus arteriosus is present.

MCQ 11

The peak tricuspid regurgitant velocity is 3.0 m/s. The right atrial pressure is estimated to be 10 mmHg. The right ventricular systolic pressure (RVSP) is:

A 6 mmHg

B 9 mmHg

C 36 mmHg

D 46 mmHg

E 29 mmHg

Determining the degree of PHT

Calculation of RVSP / Systolic pulmonary artery pressure (SPAP)

RVSP/SPAP mmHg =

4 x (tricuspid regurgitation peak velocity^2) + right atrial pressure

MCQ 12

The pulmonary regurgitation end-diastolic velocity is 1.0 m/s. The estimated right atrial pressure (RAP) is 5 mmHg. The pulmonary artery end-diastolic pressure (PAEDP) is equal to:

A 1 mmHg

B 5 mmHg

C 9 mmHg

D 14 mmHg

E 4 mmHg

Determining the degree of PHT

The PAEDP can be estimated from the end-diastolic pulmonary regurgitation velocity.

PAEDP mmHg =

4 x (PR end-diastolic velocity^2) + RAP

Determining the degree of PHT

- Right ventricular hypertrophy/dilatation
- Right atrial dilatation
- Flattening of the interventricular septum
- Dilated inferior vena cava/hepatic veins
- Shortened RVOT acceleration time (PW Doppler)
- Tricuspid regurgitation (PW/CW/Colour flow Doppler)
- Pulmonary regurgitation (PW/CW/Colour flow Doppler)
- RVSP mmHg and PAEDP mmHg

MCQ 13

The Doppler formula used to calculate systolic pulmonary artery pressure (SPAP) in a patient with VSD is:

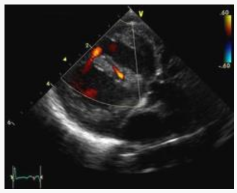
A BPs – BPd x 4

B BPs – 4 x (V_{max} VSD^2)

C BPd – 4 x (V_{max} VSD^2)

D 4 (V_1 ^{2})

E 4 x (V_{max} TR^2) + right atrial pressure



VSD

- A VSD can be associated with pulmonary arterial hypertension
- RV pressures can be estimated using Bernoulli equation. This also allows the calculation of the pressure gradient between RV and LV.

Right ventricular systolic pressure =
Systolic blood pressure − 4 × (VSD peak velocity^2).

- The RV systolic pressure equals **SPAP** except when there is an outflow tract obstruction of the RV.

VSD

- VSD can be described as small (<5mm), moderate (5 to 10mm) or large (>10mm)
- Restrictive VSD has a significant peak instantaneous gradient (>75mm Hg) and is not associated with LA or LV dilation or pulmonary hypertension
- Nonrestrictive VSD has a small peak instantaneous gradient (<25mm Hg) and has significant LA and LV dilation with pulmonary hypertension

MCQ 14

For a large non-restrictive VSD, the velocity across a pulmonary artery band is 4.0 m/s. The blood pressure is 90/60 mmHg. The systolic pulmonary artery pressure is:

A 8 mmHg

B 26 mmHg

C 64 mmHg

D 90 mmHg

E None of the above

VSD

Since there is a large VSD, the systolic blood pressure (BP) represents both the left ventricular and right ventricular pressure. The formula then is:

SPAP mmHg =
SBP – 4 x (pulmonary artery band peak velocity^2)

MCQ 15

For patent ductus arteriosus (PDA), the peak velocity is 5.0 m/s. The blood pressure is 120/50mmHg. The systolic pulmonary artery pressure (SPAP) is equal to:

A 120 mmHg

B 100 mmHg

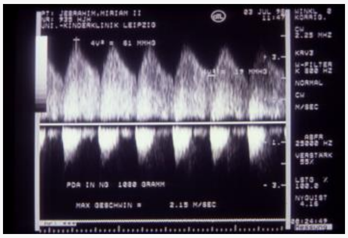
C 20 mmHg

D 1 mmHg

E 40 mmHg

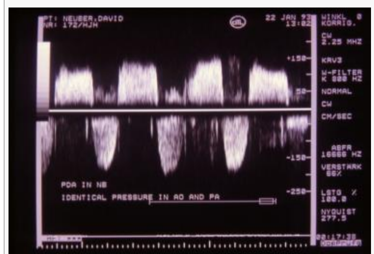
PDA

SPAP mmHg=
BPs – 4 x (Peak velocity of Blalock-Taussig shunt^2)



Continous left-to-right shunt in a patient with low pulmonary vascular resistance

PDA

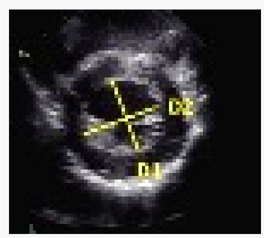


Bidirectional flow in a patient with elevated pulmonary vascular resistance

PDA – Pulmonary Hypertension

16 y old girl with large PDA and Eisenmenger syndrome

PDA – Pulmonary Hypertension



Eccentricity index = D2/D1

MCQ 16

For a BT-shunt, the end diastolic velocity is 2.0 m/s. The blood pressure is 110/50 mmHg. The pulmonary artery end diastolic pressure (PAEDP) is:

A 2 mmHg
B 34 mmHg
C 50 mmHg
D 110 mmHg
E 66 mmHg

PAEDP mmHg =
BPd – 4 x (PDA end diastolic velocity^2)

MCQ 17

The following is true of the Coanda effect EXCEPT

A Refers to the tendency of a stream of fluid to follow a convex surface, rather than a straight line

B Can be seen with aortic and mitral regurgitation jets

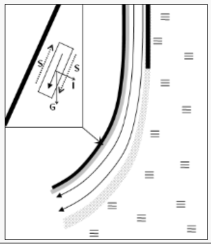
C Is a phenomenon noted on colour flow Doppler imaging

D Usually indicates a less severe jet of regurgitation

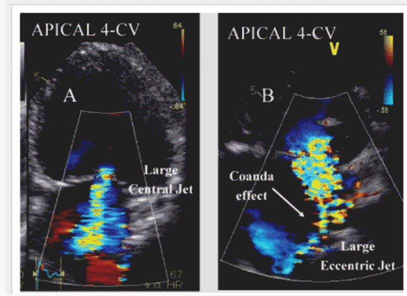
E Can give a false impression when jet area is used for assessing severity of the regurgitation

Coanda effect

- Coanda effect was originally described by romanian scientist as a phenomenon with application in aerodynamics
- A thin liquid jet, passing through a narrow channel which is followed by a curved surface, deviates according to the surface' shape, adhering to it



Coanda effect



Two patients with severe mitral regurgitation
.

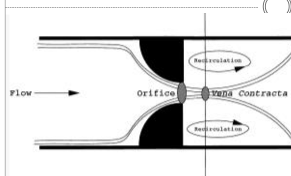
EAE recommendations 2010

MCQ 18

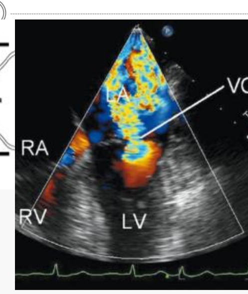
The following is true of vena contracta

A Indicates the flow acceleration proximal to a regurgitating valve
B Measurements are equally accurate, whether the flow signal is in the near field of the image or farther away
C Narrow sector width helps to get better image for accurate measurement
D Zoom function is not helpful
E Vena contracta in aortic regurgitation is measured on the apical 4-chamber view

Vena contracta



The Vena contracta represents the smallest CSA through which the flow passes and is therefore known as the effective orifice area.

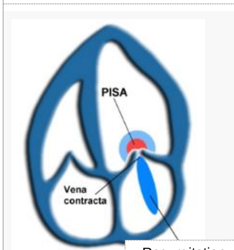


MCQ 19

The following is NOT CORRECT with regard to Proximal Isovelocity Surface Area (PISA)

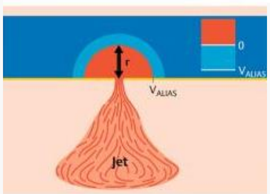
A PISA measurement gives an assessment of a regurgitation jet/lesion
B PISA is better visualised with mitral regurgitation compared to aortic regurgitation
C PISA measurement can be done on an apical 4-chamber view or apical long axis view
D The shape of the proximal isovelocity contour is semicircular
E PISA is more accurate with central jets compared to eccentric jets

PISA



- PISA is one way to calculate severity regurgitation (AR, MR, TR)
- The area of flow convergence is where we look for PISA.
- PISA will be larger in large degrees of regurgitation.

PISA



Setting the aliasing velocity (**V_a**) in order to obtain an hemisferic convergence zone, the regurgitant flow (**RF**) can be calculated as:

RF= $2\pi * r^2 * V_a$

The **effective regurgitant orifice area (EROA)** is calculated using the instantaneous regurgitant flow :

RA= $(2\pi * r^2 * V_a)/V_{max}$

The regurgitant volume is calculated as:

RV = $2\pi * r2 *$ VTI

MCQ 20

Atria - The following is not correct

A LA size can be assessed by M-mode and 2D measurements of

B Maximum LA volume is assessed at end-diastole

C Maximum RA size is assessed at end-systole

D LA volumes can be calculated using 3D echo

E RA volumes can be calculated using 3D echo

MCQ 21

Formula that may be used to calculate blood flow volume using the Doppler technique is:

A Cross-sectional area x VTI

B pi x $(D \div 2)^2$

C 0.785 x D2

D pi x $D^2 \div 4$

E None of the above

MCQ 22

Given the left ventricular end-diastolic dimension as 40 mm and systolic dimension as 20 mm, the fractional shortening is

A 20%

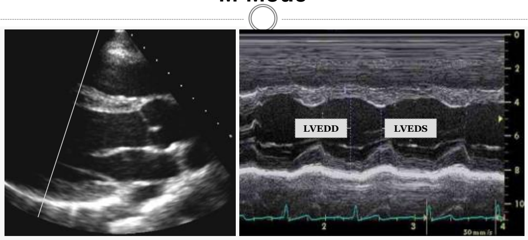
B 40%

C 50%

D 60%

E 10%

LV systolic function M-Mode



- LV fractional shortening (%):

[(end-diastolic – end-systolic)/end-diastolic] x 100

Normal: (25-40%)

MCQ 23

On an M-mode image of the left ventricle from parasternal long axis view, the following measurement is correct

A Diastolic LV dimension is measured at the opening of the mitral valve leaflet

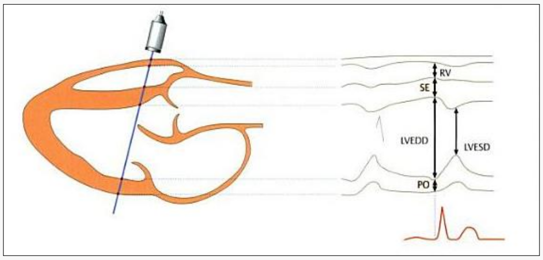
B Diastolic LV dimension is measured at the closure of the mitral valve leaflet

C Systolic LV dimension is measured at the peak of septal contraction

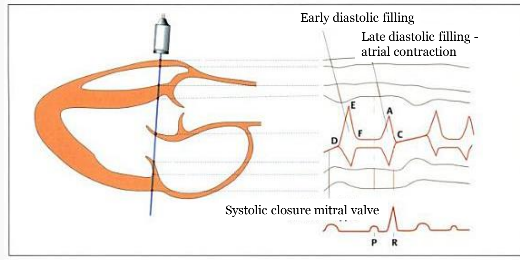
D Systolic LV dimension is measured at the mitral valve closure

E Diastolic LV dimension is measured at the maximum LV dimension

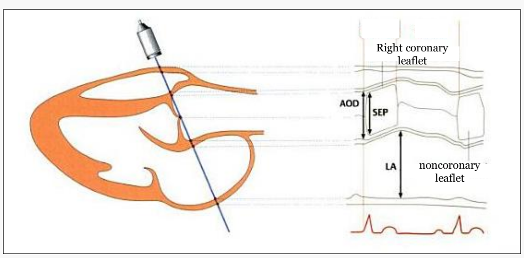
M-Mode measurements



M-Mode measurements



M-Mode measurements



MCQ 24

Regarding the measurement of systolic ventricular function

A The cube method is generally used when measurements are performed on the four chamber view

B The Simpson method can be obtained from apical 4-chamber and apical 3-chamber views

C The Simpson method can be obtained from apical 4-chamber and apical 2-chamber views

D Simpson's method is not the recommended method to determine ventricular volumes

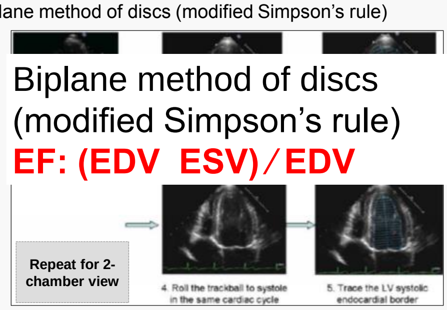
E None of the above

LV systolic function
2D measurement of LVEF

Biplane method of discs (modified Simpson's rule)

Biplane method of discs (modified Simpson's rule)

EF: (EDV ESV)/EDV



ASE recommendations 2005

MCQ 25

The formula used to calculate stroke volume (SV) by Doppler is:

A EDV – ESV

B CSA x VTI

C (CSA x VTI) x HR

D (CSA x VT1) x HR ÷ BSA

E None of the above

LV systolic function

SV is calculated as the product of the cross-sectional area of the valve or vessel through which the blood is flowing and the velocity time integral (VTI):

SV = CSA x VTI

The cardiac output (CO) can then be obtained by multiplying stroke volume by the heart rate:

CO = SV x HR

MCQ 26

Left ventricular end-diastolic pressure (LVEDP) may be calculated when the following condition is present:

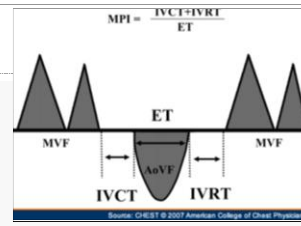
A Aortic regurgitation
B Mitral regurgitation
C Pulmonary regurgitation
D Tricuspid regurgitation
E None of the above

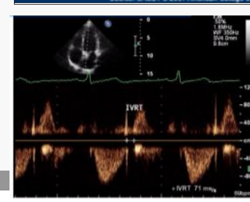
Calculations:
LVEDP = BPd – $4V^2$(AR)
LAP= BPs - $4V^2$ (MR)

MCQ 27

LV diastolic function - which of the following is not correct :

A PW Doppler of MV inflow velocities is used to assess LV diastolic function
B The isovolumic relaxation time represents the time from AoV opening to MV opening
C Deceleration time from peak E-wave to its return to baseline is a parameter of diastolic function
D LV diastolic filling can be characterized by the ratio between E-wave and A-wave





Isovolumic relaxation time, measured from aortic valve closure to onset of mitral valve filling

E Kinova et al. In book: Cardiotoxicity of Oncologic Treatments

LV diastolic function

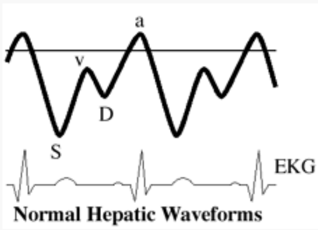
MV E wave peak velocity	Apical 4-chamber	Diastole	LV diastolic function
MV A wave peak velocity	Apical 4	Diastole	LV diastolic function
MV A wave duration	Apical 4	Time from beginning to end of A wave	LV diastolic function
MV deceleration time	Apical 4	Time from E wave peak velocity to return to baseline	LV diastolic function
Isovolumic relaxation time (IVRT)†	Apical 3-chamber	Time from AoV closure to MV opening with simultaneous CW Doppler of LV outflow and inflow	LV diastolic function

MCQ 28

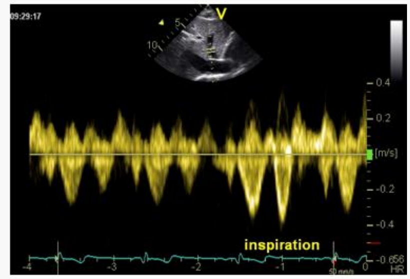
Hepatic venous doppler – which of the following is NOT CORRECT

A The patterns are similar to pulmonary vein flow
B Impaired ventricular relaxation goes ahead with hepatic flow reversal with exspiration
C An S/D ratio of <0.5 is noted with restriction
D During exspiration the S-wave is greater than the D-wave
E None of the above

Hepatic venous Doppler

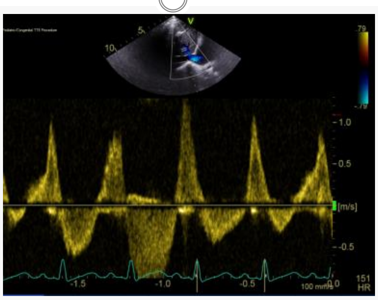


Hepatic venous doppler



Hepatic venous doppler

Prominent A-wave



Hepatic venous Doppler

Restrictive Cardiomyopathie

- Prominent atrial and ventricular reversal
- Increased prominence of reversal waves with respiration

Cardiac tamponade

- During inspiration the S-wave is greater than the D-wave
- During expiration there is a very limited or absent D-wave with prominent reversals.
- These flow variations may precede chamber collapse

THANK YOU!