

## Ultrasound Physics in the Operating Room

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UCHSC

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### What can We Measure with Doppler Ultrasound?

- Velocities
- Pressure Gradients
- Diameters and areas
- Stroke Volume
- Area of Stenosis
- Effective Regurgitant Orifice Area
- Regurgitant Volume

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### What Can We Cover Today?

- Pulse Wave Doppler
- Continuous Wave Doppler
  - Stroke Volume Measurement
  - Continuity Equation
- Color Doppler
  - Proximal Isovelocity Surface Area (PISA)
  - Flow Velocity Propagation
  - Tissue Doppler

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### Pulsed Wave Doppler

- To measure the distance and the velocity of moving objects from the transducer
- Same crystal sends and receives the signal
- Exact localization of moving objects
- Limited maximum velocity measurement because of the need of pulse repetition

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### Pulsed Wave Doppler

- On the PWD velocity scale the maximum velocity is the Niquist limit
- Niquist limit =  $PRF/2$
- Increase the scale = Increase the PRF
- Velocity > Niquist limit = velocity from the opposite direction for the transducer

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### Continuous Wave Doppler

- To measure the maximal velocity in a certain direction
- One crystal sends the signal and a different crystal receives the arriving signal
- Essentially no limit in the maximum velocity measurement (no Nyquist limit)
- The site of the maximum velocity cannot be localized

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### Continuous Wave Doppler

- CWD measures the maximum velocity at the narrowest area in the given direction.

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### Pulsed Wave Doppler

- Measuring stroke volume

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### Stroke Volume

- $SV = CSA_{LVOT} \times VTI_{LVOT}$

SV = Stroke Volume

CSA = Cross Sectional Area

VTI = Velocity Time Integral

LVOT = Left Ventricular Outflow Track

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### $CSA_{LVOT}$

- $D_{LVOT} = 2.32 \text{ cm}$
- $CSA_{LVOT} = r^2 \times \pi$
- $CSA_{LVOT} = (D/2)^2 \times \pi$
- $CSA_{LVOT} = D^2/4 \times \pi = D^2 \times \pi/4$
- $CSA_{LVOT} = 0.785 \times D^2$
- $CSA_{LVOT} = 0.785 \times (2.32)^2 = 4.2 \text{ cm}^2$

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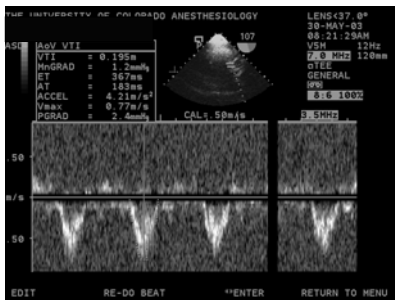
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$VTI_{LVOT} = 19.5 \text{ cm}$

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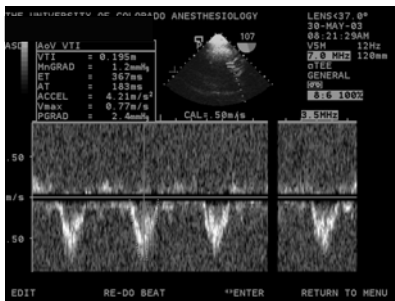
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$SV = CSA_{LVOT} \times VTI_{LVOT} = 4.2 \text{ cm}^2 \times 19.5 \text{ cm} = 82.3 \text{ cm}^3$

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### Continuity Equation

$CSA_{LVOT} > CSA_{AS}$

$V_{LVOT} < V_{AS}$

$Flow_{LVOT} = Flow_{AS}$

$CSA_{LVOT} \times V_{LVOT} = CSA_{AS} \times V_{AS}$

LVOT : Left Ventricular Outflow Track  
AS: Aortic Stenosis

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### Continuity Equation I

- Flow continuity:
  - velocity x area = flow (ml/sec)

$V_{LVOT} \times CSA_{LVOT} = V_{AS} \times CSA_{AS}$

$CSA_{AS} = CSA_{LVOT} \times V_{LVOT} / V_{AS}$

$V_{LVOT}$  measured by PWD  
 $V_{AS}$  measured by CWD

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### Continuity Equation I

- $V_{AS}$  is the maximum velocity at the narrowest area in the direction of the measurement.
- $CSA_{AS}$  is the narrowest area of the stenotic valve.

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**Continuity Equation II**

- Stroke volume (SV) continuity:  
 $CSA \text{ (cm}^2\text{)} \times VTI \text{ (cm)} = SV \text{ (cm}^3\text{)}$   
 $CSA_{LVOT} \times VTI_{LVOT} = CSA_{AS} \times VTI_{AS}$   
 $CSA_{AS} = CSA_{LVOT} \times VTI_{LVOT} / VTI_{AS}$

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**Color Doppler**

- Multiple sampling with pulsed wave Doppler along the 2D scan lines.
- The quantity and direction of velocity are measured in every point.
- Movement away from the transducer is blue and movement toward the transducer is red.

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**Color Doppler**

- Proximal Isovelocity Surface Area (PISA)
- Flow Propagation Velocity
- Tissue Doppler

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**Proximal Isovelocity Surface Area**  
PISA

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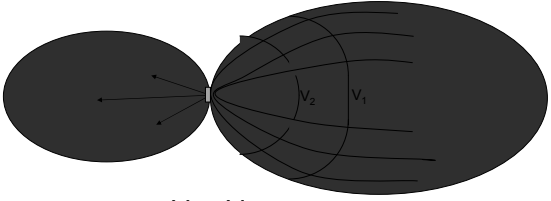
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**Continuity Equation with Color Doppler**

- Flow through a narrow area with isovelocity shells:



$V_2 > V_1$

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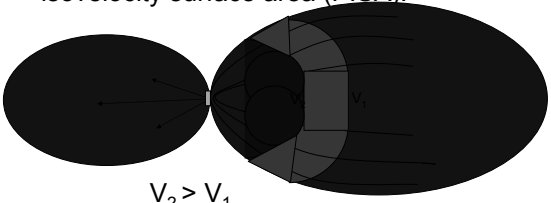
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**Continuity Equation with Color Doppler**

- Flow through a narrow area with proximal isovelocity surface area (PISA):



$V_2 > V_1$   
 $V_2 = \text{Aliasing velocity } (V_{ai})$

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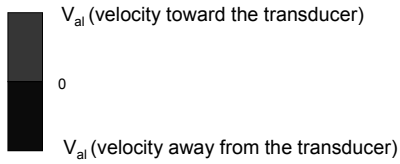
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**Continuity Equation with Color Doppler**

- Color Doppler Velocity Scale:



$V_{al}$  = Nyquist limit on the color Doppler velocity scale

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**Effective Regurgitant Orifice Area**

- How big is the orifice of the MR?
- Calculation of effective regurgitant orifice area (EROA).
- Orifice of the MR is a volume independent parameter of the severity of MR.

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**PISA**

- $PISA = 2 \times \pi \times r^2$   
 $r = 0.96$   
 $PISA = 5.78 \text{ cm}^2$
- Flow at PISA =  $V_{al} \times PISA$   
 $V_{al} = 49 \text{ cm/s}$   
 $\text{Flow at PISA} = 49 \text{ cm/s} \times 5.78 \text{ cm}^2 = 283 \text{ cm}^3/\text{s}$

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### PISA

- Using the flow continuity equation:
  - Flow at PISA = Flow at MR orifice
- Flow at MR orifice =  $V_{MR} \times EROA$
- $EROA = \text{Flow at PISA} / V_{MR}$

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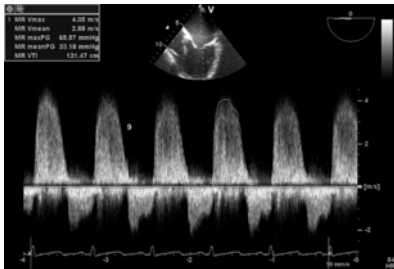
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$V_{MR}$  (Maximum Velocity through the MR orifice) = 405 cm/s

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### PISA

- $EROA = \text{Flow at PISA} / V_{MR}$   
 $EROA = 283 \text{ cm}^3/\text{s} / 405 \text{ cm/s} = 0.69 \text{ cm}^2$
- Severe MR:  $EROA \geq 0.4 \text{ cm}^2$

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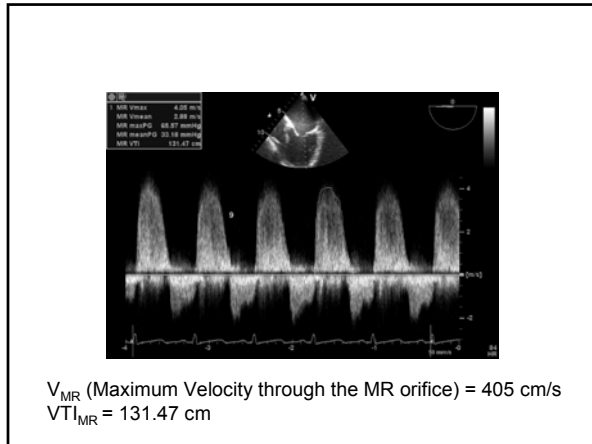
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**PISA**

- Regurgitant Volume (RV)
- $RV = EROA \times VTI_{MR}$
- $EROA = 0.69 \text{ cm}^2$
- $VTI_{MR} = 131.5 \text{ cm}$
- $RV = 0.69 \times 131.5 = 90 \text{ cm}^3$

Severe MR:  $RV \geq 60 \text{ cm}^3$

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**Flow Propagation Velocity**

- Color M-mode Doppler-derived  $V_p$  examines the spatiotemporal distribution of blood flow velocities along an entire portion of the LV cavity.

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**Flow Propagation Velocity**

- Vp provides information equivalent to multiple simultaneous pulsed wave Doppler echo measurements from the mitral orifice to the LV apex.

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**Flow Propagation Velocity**

- Two mechanism have been proposed as determinants of Vp:
  - Pressure gradient
  - Formation of vortices

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**Tissue Velocity Imaging**

- The low velocity tissue movement is recorded using color Doppler method
- The high velocity flow movement is filtered out
- The movement of different parts of the myocardium can be studied

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