Proximal Isovelocity Surface Area (PISA)

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If the molecules of a fluid move within a large cavity toward a small orifice the velocity increases and the velocity profile is hemispherical with the cavity of the hemisphere facing the orifice. The velocity over the surface of the hemisphere is the same (isovelocity), and because the hemisphere is proximal to the orifice, the surface area is known as proximal isovelocity surface area (PISA).
The flow toward a small orifice can be studied by color Doppler with the scale set. When the accelerated velocity exceeds the Nyquist limit (maximum value on the velocity scale), aliasing will take place and a semicircular shell of contrasting colors will cap the orifice. The semicircular shell is a hemisphere in three dimensions and its surface area can be calculated.

PISA surface area (hemisphere) = $2 \times r^2 \times \pi$

r: the distance from the orifice to PISA.

The velocity of the flow at PISA is the maximum velocity on the velocity scale of the color Doppler spectrum or the aliasing velocity (V_{al}). The flow at PISA:

Flow at the PISA = PISA x V_{al}

Flow at the orifice = $CSA_{orifice} \times V_{orifice}$

$V_{orifice}$: The flow velocity through the orifice can be measured by CWD. Continuous wave Doppler measures the maximum velocity at the smallest area in the direction of the measurement.

Flow continuity:

Flow at the PISA = Flow at the orifice

$PISA \times V_{al} = CSA_{orifice} \times V_{orifice}$

$CSA_{orifice} = PISA \times V_{al} / V_{orifice}$

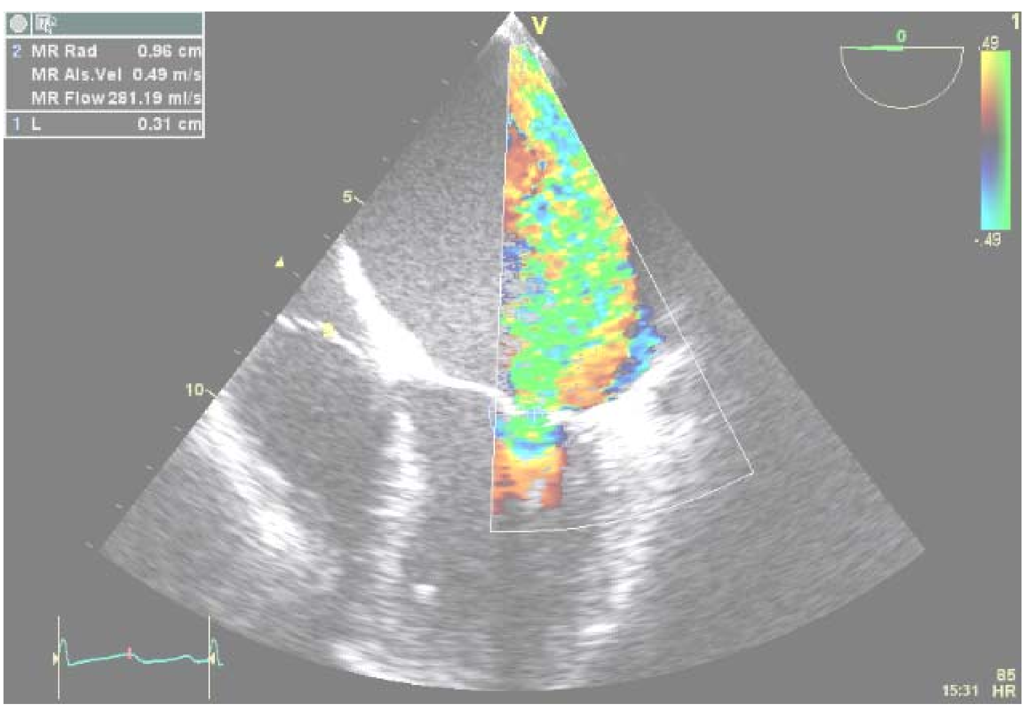
Summary for Clinical Paractice:

Using color flow Doppler and continuous wave Doppler a narrow area at MR or MS can be measured. Color Doppler is used to measure the flow at the PISA where the flow velocity is the aliasing velocity which is the maximum velocity on the color Doppler scale. The velocity at the orifice can be determined by continuous wave Doppler. The orifice area can be calculated by the continuity equation.

Example:

Calculation of EROA in MR:

The orifice area of mitral regurgitation is the effective regurgitant orifice area (EROA). The EROA is a volume independent parameter of the severity of MR. Calculation of EROA of the MR with PISA based on the continuity equation.



PISA radius = 0.96 cm Velocity at PISA (V_{al}) = 49 cm/s

PISA flow:

The figure shows a color Doppler study of mitral regurgitation. The transition line between blue and red represents the proximal isovelocity area (PISA) where the velocity is known exactly as the maximum velocity of the color scale (49 cm/s).
The flow can be calculated through the PISA area:

Flow = PISA x V_{al}

PISA = 2 x π x r^2

r = 0.96 cm

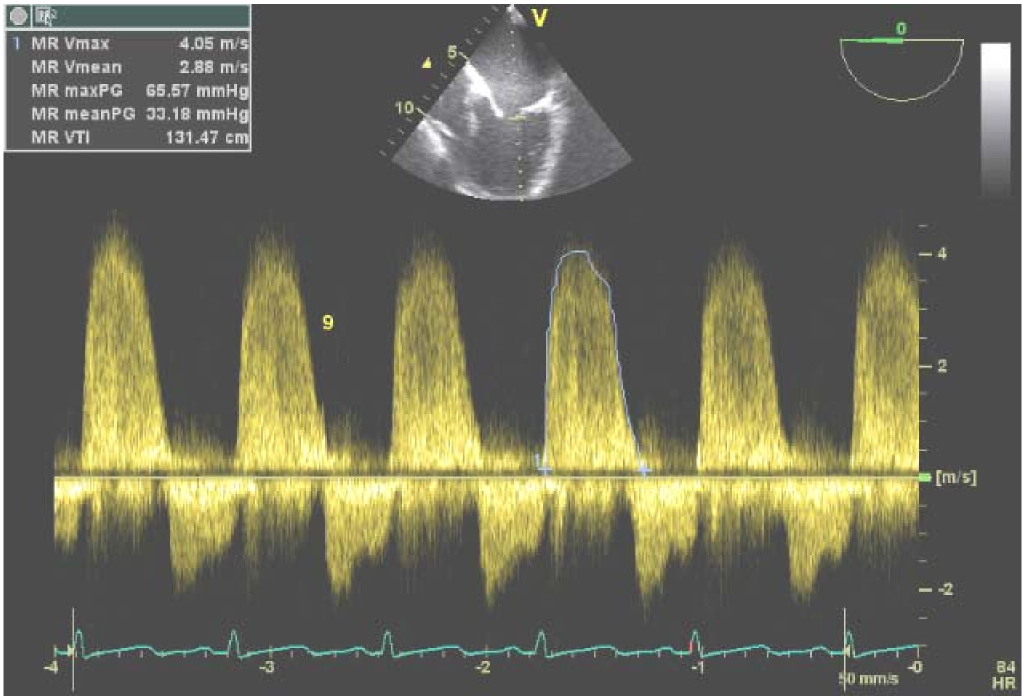
PISA = 5.78 cm^2

V_{al} = 49 cm/s

Flow at PISA = 49 cm/s x 5.78 cm^2 = 283 cm^3/s

Velocity through the MR orifice:

The maximum velocity (V_{MR}) through the MR orifice can be measured by CWD.



V_{MR} (Maximum velocity at the EROA) = 405 cm/s
VTI_{MR} (Velocity time integral of the MR) = 131.5 cm

Calculation of EROA:

Using the flow continuity equation:

Flow at PISA = Flow at EROA

PISA x V_{al} = V_{MR} x EROA

EROA = Flow at PISA/V_{MR}

Flow at PISA = 283 cm^3/s

EROA = 283 cm^3/s/405 cm/s = 0.69 cm^2

Severe MR: EROA $\geq$ 0.4 cm^2

Calculation of Regurgitant Volume (RV):

Knowing the EROA and the VTI_{MR} the regurgitant volume (RV) can be calculated:

$RV = EROA \times VTI_{MR}$

$EROA = 0.69\ cm^2$

$VTI_{MR} = 131.5\ cm$

$RV = 0.69 \times 131.5 = 90\ cm^3$

Severe MR: $RV \geq 60\ cm^3$

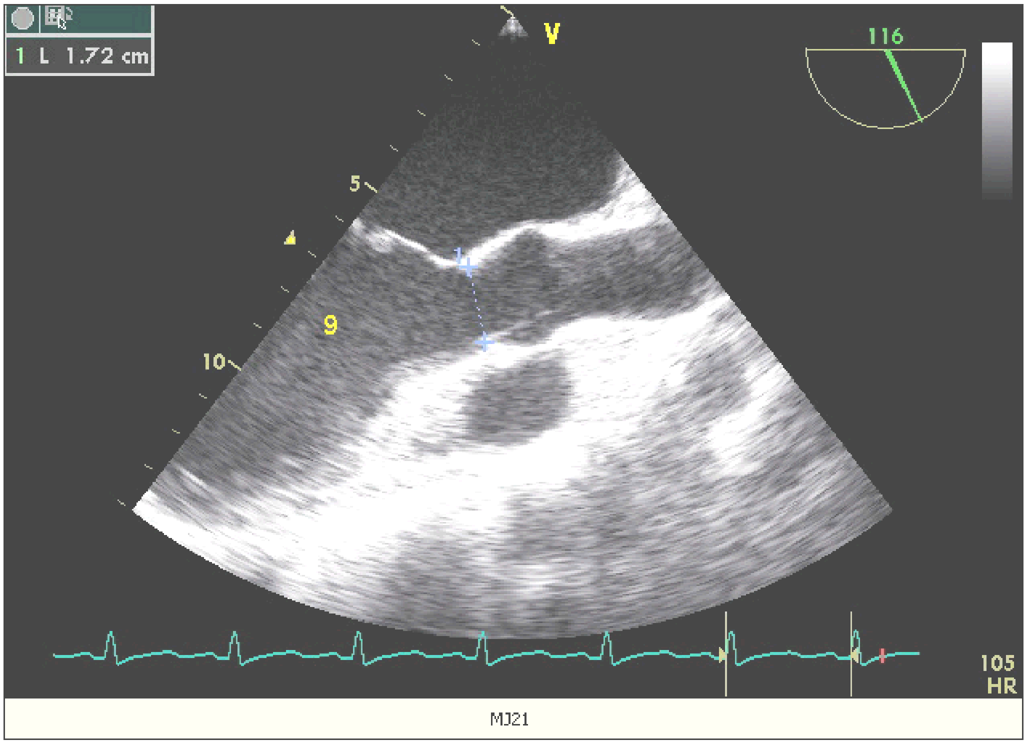
Calculation of Regurgitant Fraction (RF):

$RF = RV / SV + RV$

$SV = CSA_{AV} \times VTI_{AV}$

RV = regurgitant volume
SV: stroke volume
CSA_{AV} : cross-sectional area of the aortic valve

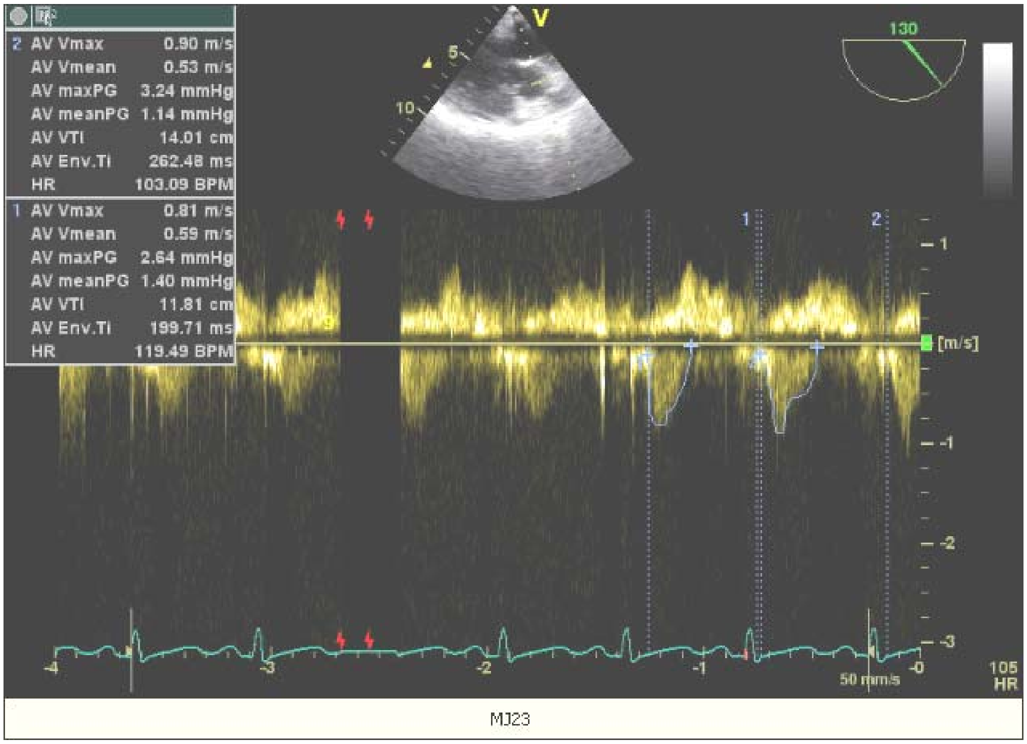
$CSA_{AV} = d^2 \times 0.785$



d= 1.72 cm

$CSA_{AV} = 1.72^2 \times 0.785 = 2.3\ cm^2$

VTI_{AV} can be measured as the area under the velocity curve of the aortic flow using either PWD or CWD:



VTI_{AV} = 13 cm (from 2 measurements)

SV = 2.3 cm^2 x 13 cm = 30 cm^3

Regurgitant Fraction (RF):

RF = RV/(RV + SV) x 100

RF (%) = 90/(90 + 30) x 100 = 75 %

Severe MR: RF $\geq$ 50 %