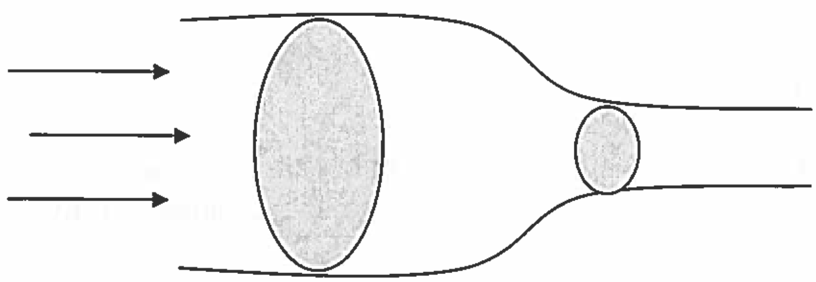
Continuity Equation

The continuity equation based on assuming a constant flow of fluid through a conduit. If there is a stenosis in the conduit, the velocity of fluid will increase at the site of stenosis to keep the continuity of flow. Flow (cm^3/sec) in a conduit is the product of cross-sectional area (CSA) of the conduit (cm^2) and the velocity of the fluid (cm/sec). Continuity of flow is an important principle to evaluate areas with unknown size such as areas of AS, MS or regurgitant areas of AI or MR. The figure below represents the flow in the left ventricular outflow track (LVOT) and at the level of aortic stenosis (AS).

$$CSA_{LVOT} > CSA_{AS}$$



$$V_{LVOT} < V_{AS}$$

Flow through LVOT = Flow through AS

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

LVOT : Left Ventricular Outflow Track
AS: Aortic Stenosis
CSA: cross-sectional area
V: velocity

Cross-sectional area (CSA) of LVOT:

CSA can be calculated from the diameter of the studied part of the conduit. For example the diameter (d) of the LVOT can be measured using the LV long axis view:

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

$$Area = (d/2)^2 \times \pi$$

$$Area = d^2 \times \pi/4$$

$$\pi/4 = 0.785$$

$$Area = d^2 \times 0.785$$

d = diameter of LVOT

Measurement of V_{LVOT}:

The velocity of the flow at the level of the measurement of CSA_{LVOT} is determined by using PWD in the LV deep transgastric or transgastric long axis view.

Measurement of V_{AS}:

The velocity of the flow through the stenotic aortic valve is measured by using CWD. In this way the maximum velocity is measured through the smallest area in the direction of the measurement. The deep transgastric view and the transgastric long axis view can be used to perform the measurement.

Measurement of CSA_{AS}:

From the measurement of CSA_{LVOT}, V_{LVOT} and V_{AS} the stenotic area of the aortic valve (CSA_{AS}) can be calculated by using the flow continuity equation.

Flow Continuity:

Flow = area x velocity (ml/s)

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

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

The alternative way to calculate the CSA_{AS} is based on the fact that the volume during a certain cardiac circle is also constant at different cross-sectional areas. For example during the systole the stroke volume (SV) is a product of CSA (cm^2) and velocity time integral (VTI) (cm).

Velocity Time Integral: The blood flow and velocity are phasic in the circulation because of the change throughout the cardiac cycle. A Doppler spectrum of the velocity of blood through a valve will yield a curve that has velocity (cm/s) on the *y* axis and time (s) on the *x* axis. When this curve is integrated, it yields a velocity-time integral (VTI) in units of centimeter (cm/sec x sec = cm). It indicates the distance the blood travels during a certain cardiac circle. The product of VTI (cm) and CSA (cm^2) will yield volume (cm^3).

The SV through the LVOT area equals the SV through the AS area. The VTI_{LVOT} and the VTI_{AS} can be determined using the Doppler spectrum of the velocity of blood through the LVOT and the AS area based on PWD or CWD measurement, respectively.

Volume Continuity:

Volume = area x VTI (ml)

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

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

Summary for Clinical Practice:

V_{LVOT} and VTI_{LVOT} are measured by PWD at the level of the measurement of d_{LVOT}.
V_{AS} and VTI_{AS} are determined at the site of the stenosis by CWD.
A known area, CSA_{LVOT}, is used to calculate an unknown area CSA_{AS} by the continuity equation.