Basic Hemodynamic and Doppler Calculations
Bernoulli Equation and Intracardiac Pressure Measurements

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Doppler echocardiography is used to measure blood flow velocity. The Bernoulli equation describes the relationship between the velocity acceleration through a narrowed orifice and the pressure gradient across that same orifice. Known or estimated intracardiac pressures combined with pressure gradient determinations, allow for estimation of a variety of intracardiac pressures. At the conclusion of this portion of this workshop, the participant should be able to: 1) understand the Bernoulli equation and its limitations, and 2) determine various intracardiac pressures using TEE.

**Bernoulli Equation**

The Bernoulli equation describes the relationship between the velocity acceleration of fluid through a narrowed orifice and the pressure gradient across that same orifice.

\[ \Delta P = \frac{1}{2} \rho \left( \frac{v_2^2}{2} - \frac{v_1^2}{2} \right) + p \left( \frac{dv}{dt} \right) dx + R(v) \]

The first part of the Bernoulli equation describes convective acceleration, the second part describes flow acceleration, and the third part \([R(v)]\) describes viscous friction. The last two parts can be ignored in most clinical situations because flow acceleration is not an issue at peak flow, and viscosity does not have significant affect through an orifice size greater than 0.25cm². The higher velocity \((v_2)\) through a narrowed orifice is usually significantly higher than the lower velocity \((v_1)\) proximal to the narrowed orifice, so that \(v_1\) can also be ignored in most circumstances. If one further assumes that the density of blood \((\rho)\) is \(1.06 \times 10^3 \text{ kg/m}^3\), the Bernoulli equation can be simplified to:

\[ \Delta P = 4\left( \frac{v_2^2}{2} - \frac{v_1^2}{2} \right) \]

\[ \Delta P_{\text{peak}} \approx 4v^2_{\text{max}} \]

This equation will be used in most measurements that involve pressure determination across stenotic valves and other narrow orifices, such as regurgitant valve orifices and septal defects. It is important to know the assumptions made to derive this simplified or “modified” Bernoulli equation, because these assumptions are not always valid in all clinical circumstances.
For example, when the velocity through the orifice is not significantly greater than the proximal velocity, the proximal velocity cannot be ignored. It is also important to recognize that the pressure gradient derived from peak velocity measurements is a peak gradient, not a mean gradient. Mean gradients are determined by software packages that consider all velocities through the duration of the blood flow through the narrowed orifice.

**Intra-Cardiac Pressure Determinations**

**Right Ventricular Systolic Pressure**

A patient must have a tricuspid valve regurgitant jet that can be interrogated with continuous wave Doppler of its peak velocity for determination of right ventricular (RV) systolic pressure. The tricuspid valve regurgitant peak velocity \( V_{TR} \) is used to estimate the systolic “gradient” between the right ventricle and right atrium using the simplified Bernoulli equation \[4(V_{TR})^2\]. An assumption or measurement of right atrial (RA) pressure added to the gradient between the RV and RA, equals RV systolic pressure.

\[
\text{RV systolic pressure} \approx [4(V_{TR})^2] + \text{RA pressure}
\]

Another method is possible for determining RV systolic pressure in the patient with a ventricular septal defect and a left to right shunt. The peak shunt velocity \( V_{VSD} \) is used to estimate the systolic “gradient” between the left ventricle (LV) and right ventricle using the simplified Bernoulli equation \[4(V_{VSD})^2\]. A measurement of systolic blood pressure in the absence of aortic stenosis is equivalent to LV systolic pressure. The subtraction of the “gradient” between the LV and RV, from the LV (systolic) blood pressure, yields RV systolic pressure.

\[
\text{RV systolic pressure} \approx \text{LV systolic pressure} - [4(V_{VSD})^2]
\]

**Pulmonary Artery Systolic Pressure**

It is possible to estimate both pulmonary artery (PA) systolic and diastolic pressure in certain clinical circumstances. A patient must have a tricuspid valve regurgitant jet that can be interrogated with continuous wave Doppler of its peak velocity for determination of PA systolic pressure. The tricuspid valve regurgitant peak velocity \( V_{TR} \) is used to estimate the systolic “gradient” between the right ventricle and right atrium using the simplified Bernoulli equation \[4(V_{TR})^2\]. An assumption or measurement of right atrial (RA) pressure, added to the gradient between the RV and RA, equals RV systolic pressure, which is equivalent to the PA systolic pressure in the absence of pulmonary stenosis and right ventricular (RV) outflow tract obstruction.

\[
\text{PA systolic pressure} \approx \text{RV systolic pressure} \approx [4(V_{TR})^2] + \text{RA pressure}
\]

**Pulmonary Artery Diastolic Pressure**

A patient must have a pulmonic valve regurgitant jet that can be interrogated with continuous wave Doppler of its peak velocity for determination of PA diastolic pressure. The
pulmonic valve regurgitant peak velocity \((V_{PR})\) is used to estimate the systolic “gradient” between the pulmonary artery and right ventricle using the simplified Bernoulli equation \(4(V_{PR})^2\). An assumption or measurement of right atrial (RA) pressure [equal to RV pressure during diastole (open tricuspid valve, no tricuspid stenosis)], is added to the “gradient” between the PA and RV to determine PA diastolic pressure.

\[
\text{PA diastolic pressure} \approx \text{RA pressure} + [4(V_{PR})^2]
\]

or

\[
\text{PA diastolic pressure} \approx \text{RV diastolic pressure} + [4(V_{PR})^2]
\]

**Left Atrial Pressure**

A patient must have a mitral valve regurgitant jet that can be interrogated with continuous wave Doppler of its peak velocity for determination of left atrial (LA) pressure. The mitral valve regurgitant peak velocity \((V_{MR})\) is used to estimate the systolic “gradient” between the left ventricle and left atrium using the simplified Bernoulli equation \(4(V_{MR})^2\). A measurement of systolic blood pressure in the absence of aortic stenosis is equivalent to LV systolic pressure. The addition of the “gradient” between the LV and LA, to the systolic (LV) blood pressure, yields LA pressure.

\[
\text{LA pressure} \approx \text{LV systolic pressure} - [4(V_{MR})^2]
\]

or

\[
\text{LA pressure} \approx \text{systolic blood pressure} - [4(V_{MR})^2]
\]

**Left Ventricular Diastolic Pressure**

A patient must have an aortic valve regurgitant jet that can be interrogated with continuous wave Doppler of its peak velocity for determination of left ventricular (LV) pressure. The aortic valve regurgitant peak velocity \((V_{AR})\) is used to estimate the diastolic “gradient” between the aorta and left ventricle using the simplified Bernoulli equation \(4(V_{AR})^2\). The subtraction of the “gradient” between the aorta and LV, from the diastolic blood pressure, yields LV diastolic pressure.

\[
\text{LV diastolic pressure} \approx \text{Aortic diastolic pressure} - [4(V_{AR})^2]
\]