
Limitations Inherent to the Simplified Bernoulli Equation
Explain the Inaccuracy of Doppler Echocardiographic Estimates of Pulmonary Artery Pressures in Patients With Pulmonary Hypertension

To the Editor:

I would like to congratulate Rich and colleagues, who, in their recent article in CHEST (May 2011), showed clinically relevant discrepancies between Doppler-estimated and invasively measured pulmonary artery systolic pressure (PASP) in >50% of measurements, discrepancies not resolved by simultaneous measurement of the two entities. Imprecise right atrial pressure estimation, suboptimal alignment between the Doppler beam and the regurgitant jet, and the presence of severe tricuspid valve regurgitation were suggested as the causes of the discrepancy. However, even when beam alignment and right atrial pressure estimation are correct, significant discrepancies between the two measurements should be expected because of limitations inherent to the simplified Bernoulli equation. Indeed, the simplified Bernoulli equation assumes negligible viscous and inertial forces and complete conversion of potential energy (the pressure in the right ventricle) into kinetic energy (that of the regurgitant jet).

However, as highlighted in a recent mock circuit experiment, many conditions commonly encountered in clinical practice can result in an imperfect transformation of potential to kinetic energy. For example, an eccentric regurgitant jet would interact with the nearby atrial wall, causing viscous losses that are evident as the Coanda effect and that are associated with a 24% underestimation by Doppler of invasive pulmonary artery pressure. Increased blood viscosity observed in patients with hypoxemia, and, in particular, in patients with intracardiac defects and Eisenmenger physiology, can also cause discrepancies between Doppler and invasive estimates of PASP. Indeed, increasing hematocrit causes occurrences of viscous losses that are not accounted for by the simplified Bernoulli equation, leading per se to a 49% underestimation of invasive PASP by Doppler.

All factors mentioned so far are associated with underestimation of PASP by Doppler. However, overestimation was as common as underestimation in the article by Rich et al, and some other factors have to intervene to explain this finding. Experimental evidence suggests that when blood viscosity is reduced, such as during anemia, or when absolute right atrial size (in centimeters) is small, such as in children or young women, inertial forces not accounted for by the simplified Bernoulli equation may cause pressure recovery in the receiving chamber, causing overestimation of PASP by Doppler.

As mentioned by Rich et al, transthoracic echocardiography is an invaluable tool in the management of patients with pulmonary hypertension. Because conditions that limit the applicability of the simplified Bernoulli equation are ubiquitous in clinical practice, the education of clinicians in recognizing those conditions is of extreme importance.

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REFERENCES

Response

To the Editor:

We thank Dr Giardini for his interest in our study. Dr Giardini suggests that explanations exist beyond those cited in our article to explain the discrepancies in Doppler estimates of pulmonary artery systolic pressure (PASP). He cites limitations inherent to the modified Bernoulli equation, including the assumptions of (1) negligible viscous forces (which may not be the case under hypoxic, anemic, or polycythemic conditions), (2) the complete conversion of potential to kinetic energy (which may not occur in the presence of eccentric regurgitant jets), and (3) inertial forces (which may occur in small receiving chambers, resulting in the pressure recovery phenomenon).

We agree with Dr Giardini that alternative explanations, including some of those he cites, may exist to further explain Doppler-cardiac catheterization PASP discrepancies in patients with pulmonary hypertension. We were particularly interested in the possibility that viscous factors may have accounted for some of the inaccuracies we observed in our study. We, thus, created a multivariate model from our simultaneous Doppler-cardiac catheterization data to evaluate whether oxygen saturation and/or hemoglobin levels were associated with differences in Doppler-cardiac catheterization estimates of PASP. Neither oxygen saturation nor hemoglobin level were associated with differences in Doppler-cardiac catheterization estimates of PASP (β coefficient, –1.72 ± 1.95 and –2.24 ± 3.83, respectively;