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Pulmonary Vascular Impedance: Resistance *versus* Pulmonary Artery Diastolic-Pulmonary Artery Occluded Pressure Gradient

To the Editor:—The article, "Pulmonary Vascular Responses to Nitrous Oxide in Patients With Normal and High Pulmonary Vascular Resistance," by Drs. Schulte-Sasse, Hess, and Tarnow[1] introduces the question of which hemodynamic parameter best reflects drug-produced changes in impedance in the pulmonary circulation. In many hemodynamic studies (including this article), this question is answered by calculating pulmonary vascular resistance (PVR)

$$\text{PVR (dyn} \cdot \text{s} \cdot \text{cm}^{-5}) = \frac{\text{PAP} - \text{PAo}}{\text{CO}} \times 80 \quad \text{(Eq. 1)}$$

However, this calculation may be inappropriate and misleading in certain circumstances. For example, mean pulmonary artery pressure (PAP) and calculated PVR are influenced by both passive (flow, left heart filling pressure) and active (chemical, neurogenic) factors. The administration of a drug (*e.g.*, nitrous oxide) may decrease CO (negative inotropic effect) and increase PAP (active vasoconstriction). The effect of these changes would be to increase calculated PVR. However, the cardiac depression resulting from nitrous oxide inhalation may increase pulmonary artery occluded pressure (PAo) and decrease calculated PVR. The overall impact of these opposing responses on the passive and active factors may make conclusions based on changes in calculated PVR difficult to interpret. Furthermore, the equation for PVR is based on the principle of Ohmic resistance which states that resistance is related to the pressure drop across the vascular bed divided by the flow (Poiseuille's law). However, the validity of this relationship in the pulmonary circulation assumes blood flow is continuous throughout the cardiac cycle and the pulmonary vessels are sufficiently rigid that pressure generated within them results from flow rather than volume.[2] This assumption is more likely to be valid in hydraulic systems with rigid walls than in the compliant pulmonary vascular bed. In fact, the resistance vessels (muscular arteries) in the pulmonary circulation are so highly compliant that pulmonary blood flow and PVR are negligible at the end of cardiac diastole.[2] This explains the observation that in the absence of increased PVR (impedance), no significant gradient exists between pulmonary artery end-diastolic pressure (PADP) and PAo. Indeed, this pressure gradient (PADP-PAo) has been suggested as a better measure of obstruction to flow in the pulmonary circulation compared with calculated PVR.[2] The advantage of this pressure gradient compared with calculated PVR is demonstrated in the data of Harvey and Enson.[2] These authors compared PVR values and (PADP-PAo) gradients in several groups of patients with mitral stenosis and severe pulmonary hypertension. They observed significant changes (100%) in calculated PVR values between patient groups despite the absence of changes in the measurement of PAP, PAo, PADP, and (PADP-PAo) gradients in each

group. The group with the lowest CO had the highest PVR despite a normal (PADP-PAo) gradient. In this situation assessing impedance based on PVR calculations overemphasizes the importance of CO.

In contrast to calculated PVR the (PADP-PAo) gradient may better reflect drug-produced (*e.g.*, nitrous oxide) pulmonary vasoconstriction since this gradient is less dependent on CO and PAo in several disease states.[3,4] The use of this gradient in measuring the response of nitrous oxide on PVR (impedance) has not been studied. The data by Drs. Schulte-Sasse, Hess, and Tarnow can not be used since PADP values were not reported. However, use of this pressure gradient in assessing pulmonary vascular responses to nitrous oxide inhalation was tested (using Student's *t* test for paired data) using the data resported by this author in a previous study.[5] Compared with awake measurements the inhalation of 50% nitrous oxide in oxygen in patients with mitral stenosis and pulmonary hypertension resulted in a significant ($P < 0.05$) increase (5 mmHg) in the (PADP-PAo) gradient. Furthermore, changes in the (PADP-PAo) gradient were not related to CO (r = 0.19) or PAo (r = 0.3) which suggests that in constrast to calculated PVR, this gradient is less likely to be influenced by passive factors such as flow and left heart filling pressure. Although a significant ($P < 0.05$) direct correlation (r = 0.66) existed between changes in calculated PVR and the (PADP-PAo) gradient following inhalation of nitrous oxide, calculated PVR overestimated and underestimated resistance to flow at the end of cardiac diastole as determined by the (PADP-PAo) gradient in some patients (fig. 1).

In conclusion, I feel that changes in resistance in the pulmonary circulation resulting from pharmacologic agents such as nitrous oxide are best expressed by the (PADP-PAo) gradient and not calculated PVR since this pressure gradient is less dependent on passive factors which influence the calculation of PVR.

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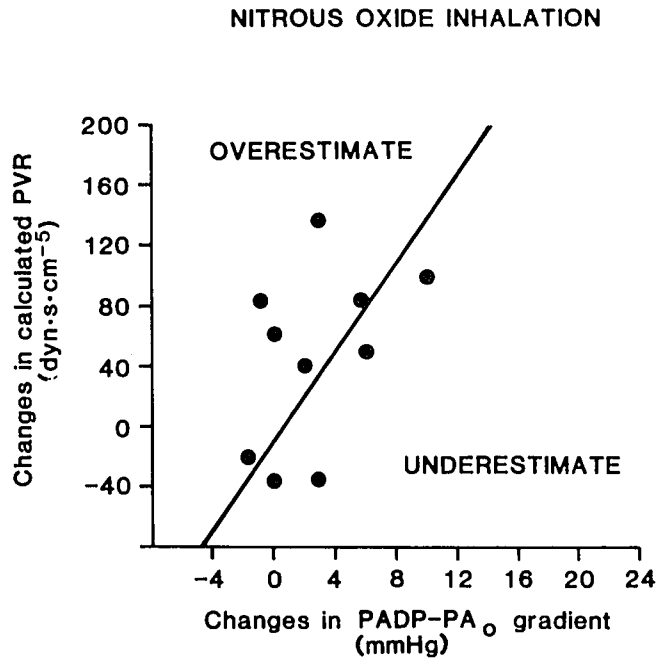

FIG. 1. Comparison between changes in calculated PVR and PADP-PAo gradient following nitrous oxide inhalation (50%) in 11 patients with mitral stenosis and pulmonary hypertension. Solid line is line of best fit. Data modified from Hilgenberg JC *et al.*[5]

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In reply:—Dr. Hilgenberg's arguments are based on the data of Harvey and Enson[1] which imply that a high calculated PVR overestimates the impedance to flow in the presence of a small (PADP-PAo) gradient and a low cardiac output. The Harvey and Enson paper is interesting but does not really find solutions to the problem. Our comment on their final paragraph is that their major premise is mutually exclusive in that they state: