LETTERS TO THE EDITOR

Fourier analysis of the intra-aortic balloon pump

To the Editor:

The brief communication "Fourier Analysis of the Intra-aortic Balloon Pump" (J Thorac Cardiovasc Surg 1999;117:827-8) correctly demonstrates that frequency domain analysis is a powerful tool for analysis of nonlinear systems, such as the arterial bed. However, there is a misunderstanding concerning impedance matching. Arterial blood flow impedance is the relative resistance of blood flow to a given pressure differential. Typically, one analyzes instantaneous blood pressure and flow at a point in the vasculature (ascending aorta) and calculates (using frequency domain techniques) the characteristic input impedance. This is commonly displayed as amplitude and phase shifts across a frequency spectrum. The amplitude of the impedance at a given frequency represents the relative resistance to blood flow at that frequency.¹

The statement "Matching the heart rate to the fundamental frequencies obtained from frequency domain analysis of the arterial waveforms would have major benefits for patients because of the impedance matching that would result" is incorrect. Matching the heart rate to frequencies in which the characteristic input impedance is at a minimum would result in a more efficient blood flow (ie, require less energy). However, that determination is a result of computing the "input impedance," not the frequency spectra of the pressure waveform.

Indeed, the data presented in this communication demonstrate the tautologous result of analyzing the data. The author states: "Optimal heart rate with the IABP in 1:1 mode was 77 beats/min, in 1:2 mode was 69, 101, and 135 beats/min, and in 1:3 mode 66, 89, 111, and 134 beats/min." When one measures the *actual* patient heart rates in the tracings, the results are, respectively, 77, 69, and 66 beats/min. The analysis performed in this report only demonstrates that the patient's heart rate was different at the various times the recordings were performed. This is intrinsically true, since spectral analysis of a pressure tracing measures the primary and harmonic frequencies of periodic events (ie, the patient's heart rate). It is impossible to quantify arterial impedance without measuring blood flow.

The goals of input impedance matching may be worthwhile to enhance blood flow. However, there are several functions that the intra-aortic balloon pump performs, and these should not be compromised in this effort. These functions include ventricular afterload reduction and increasing diastolic blood pressure to enhance myocardial blood flow. Scientific studies are required to help us demonstrate the advantages of careful input impedance analysis of the arterial bed.

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1. Grossi EA, Connolly MW, Krieger KH, Nathan IM, Hunter CE, Colvin SB, et al. Quantification of pulsatile flow during cardiopulmonary bypass. *Surgery* 1985;98:547-54.

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Reply to the Editor:

Arterial impedance can be represented by the term $f_a(\omega) + \sqrt{-1} \cdot f_b(\omega)$, where $f_a(\omega)$ and $f_b(\omega)$ are algebraic functions involving heart rate. Systemic vascular impedance is the modulus of this term, $|f_a^2(\omega) + f_b^2(\omega)|$. This term will have a fundamental frequency, resulting in maximum blood flow and minimum work by the heart. Hence matching the heart rate to the fundamental frequency could have beneficial effects.¹

The aim of Fourier analysis was to show that with a constant heart rate, the fundamental frequency and harmonics of an arterial blood pressure trace are different when a balloon pump is initiated in 1:1, 1:2, or 1:3 ratios of augmentation; that is, the fundamental frequency has shifted even though the heart rate is constant. The shift developed is dependent on the augmentation ratio.

The three Fourier analysis results presented were all carried out with the same underlying heart rate of 60 beats/min; thus the deduction by Grossi, that spectral analysis of a blood pressure tracing reveals the patient's heart rate, although true in all situations in the absence of a balloon pump, is completely incorrect in the presence of an intra-aortic balloon pump.

The aforementioned principle of two frequencies (heart rate and balloon frequency) being combined to create a third different frequency (Fourier fundamental frequency) is a widely established phenomenon in the field of electronics. It explains the operation of radio frequency sideband generation.

Fourier analysis does not interfere with ventricular afterload reduction and increasing diastolic blood pressure augmentation, because these will be optimized via balloon inflation and deflation timing, before Fourier analysis is performed.

With regard to the impossibility of quantifying arterial impedance without measuring blood flow, calculation of the augmentation index (the ratio of the difference between systolic blood pressure and blood pressure at the point of inflection to pulse pressure) can provide an indication of impedance matching via semiquantification of the peripherally reflected pressure wave.

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1. Poullis M. Fourier analysis of the intra-aortic balloon pump. *J Thorac Cardiovasc Surg* 1999;117:827-8.

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