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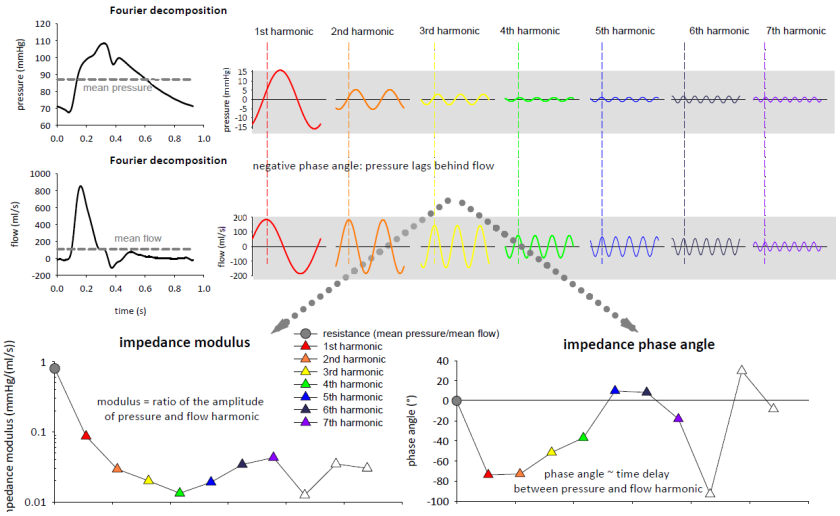
INPUT IMPEDANCE

What is it?	Input impedance (Zin) expresses the mathematical relation between pressure and flow at a given location, and fully quantifies the arterial tree downstream from that location, encompassing any factor that affects the relation between pressure and flow. Impedance is a concept adopted from electrical engineering, which only considers sinusoidal waves. Given that arterial pressure and flow signals are usually quasi periodic, they can be decomposed into a steady signal (the 'DC' component) and a series of sine waves (also called harmonics; the 'AC' component) with frequencies that increase as multiples of heart rate. Ten harmonics usually suffice to accurately represent arterial pressure and flow waves. The ratio of corresponding harmonics of pressure and flow yields impedance for those frequencies. For a given frequency, we need to express the relation between two sine waves (one for the pressure and flow harmonic). This requires two numbers: the ratio of the amplitude of the pressure and flow harmonic (impedance modulus), and the phase difference (impedance phase) to quantify their timing. The input impedance is thus not a single number, but usually presented graphically with two plots: one showing the impedance modulus as a function of frequency (having units of flow/pressure, e.g. ml/(mmHg.s)), and a second one showing the phase (in degrees or radians).
Why do we measure it?	Input impedance is a concise and powerful way to comprehensively quantify the entire arterial system, independent of cardiac function, and quantitatively determine the interrelation of pressure and flow. If Zin is known, pressure can be perfectly predicted from flow, and vice versa. It is a powerful tool for modellers to assess and quantify how well the behaviour of the modelled system matches the system that one wants to model. Measuring input impedance is relevant in basic cardiovascular (patho)physiology research on the overall behaviour of the arterial tree and in studying cardio-vascular interactions. The clinical utility of input impedance is rather low, as it is remains unpractical to (simultaneously) assess central pressure and flow waveforms, and input impedance is a too encompassing property to identify slow and subtle changes in arterial properties. In addition, Zin is highly dependent on body size requiring complex normalization when used in comparative studies.
How can it be measured?	The figure below illustrates all steps necessary to calculate impedance. The pressure and flow waveforms are decomposed into their mean (DC) component signal and harmonics (~ spectral components), sine waves with a frequency at a natural multiple of cardiac frequency and a time lag. For each frequency, impedance represents the ratio of the corresponding pressure and flow harmonic, with the impedance modulus being the ratio of their amplitudes, and the phase angle the difference of their phase angles. Negative phase angle implies that flow is ahead of pressure. The

	value at 0Hz is the ratio of mean pressure and flow, i.e., total arterial resistance.
Where is it measured?	Input impedance is not directly measurable, but is calculated from measured pressure and flow waves. This can be applied to any location in the arterial tree and Zin then quantifies the system downstream from the measuring site. It is usually measured in the ascending aorta and pulmonary artery.
Figure	 Figure (modified) from: - *First Author: Segers Patrick* - *Title: Essential Principles of Pulsatile Pressure-flow relations in the arterial tree* - *In: Textbook of Arterial Stiffness and Pulsatile Hemodynamics in Health and Disease, Edition 1,* - *DOI or link to publication: not yet available* - *Figure number: 3.1*
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