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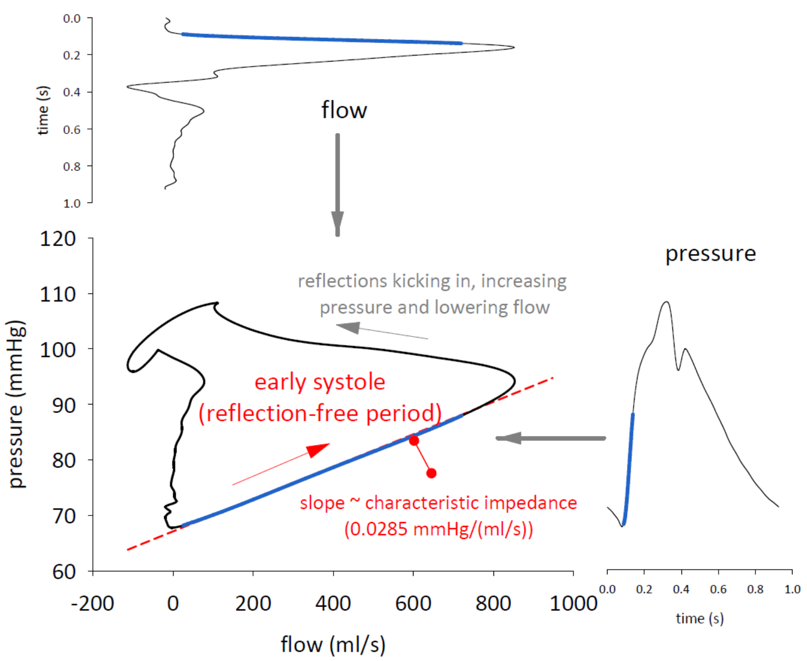
CHARACTERISTIC IMPEDEANCE

What is it?	In hemodynamics, the term impedance generally refers to the opposition that is experienced by pulsatile blood flow. When impedance is calculated in, for instance, the ascending aorta (the input impedance, see elsewhere), that opposition comes from local factors - related to the properties of the ascending aorta itself -, but also from the entirety of the downstream arterial tree. Characteristic impedance, Zc, quantifies the local factors generating obstruction to pulsatile blood flow. It can also be defined as input impedance in the absence of wave reflection, since in such a situation, downstream factors have no effect on the local relation between pulsatile pressure and pulsatile flow. Zc is mainly determined by the inertia of blood inside the vessel, together with the stiffness of blood vessels, which is clear from the mathematical expression for Zc = sqrt[(rho/A) (dP/dA)] with rho the density of blood, A the cross-sectional area and P pressure. rho/A reflects the inertial load, while dP/dA is the inverse of the local vessel compliance. This expression can be further converted to Zc = rho*c/A, with rho the density of blood, A the cross-sectional area of the vessel at the measuring location and c the Pulse Wave Velocity. Note that in the above, we used pressure and flow as variables. It is also possible to use pressure and flow velocity (U = Q/A) and express the relation between P and U, as is done in wave intensity analysis. In that case, Zc equals rho*c.
Why do we measure it?	Zc can be used to quantify the local properties of the artery where it is being measured, but has the drawback that it depends on vessel size and stiffness. It is especially calculated as a parameter that is required for wave separation analysis. Indeed, with Zc expressing the relation between pulsatile pressure and flow in absence of wave reflection, it can be stated that Pf = ZcQf, and Pb=-ZcQb with Pf and Qf forward pressure and flow waves, and Pb and Qb the backward components. The negative sign arises from the fact that, in contrast to pressure, flow has a positive and negative direction. Zc is the major determinant of the magnitude of the forward pressure wave, and can be calculated to assess the contribution of forward and backward waves to pressure.
How can it be measured	There are three different ways to calculate Zc: • Use the mathematical expression of Zc: assuming blood density close to 1060 kg/m³, measuring A, dP and dA provides the input to calculate Zc. If you know local pulse wave velocity, you can use the alternative formulation given above.

	• Estimation in the frequency domain: the modulus of the input impedance (see elsewhere) typically displays a plateau value for higher frequencies, with also a phase angle oscillating around zero. The average of the modulus of these higher harmonics (say 4th-10th harmonic) yields an estimate of Zc. • Estimation in the time domain (see figure): plotting instantaneous pressure as a function of instantaneous flow yields a flow-pressure loop. This loop typically displays a linear segment in early systole. At that instance, reflections did not yet reach the measuring location, implying that only forward components exist and the slope of the line is characteristic impedance.
Where is it measured?	Zc can, in principle, be calculated at any location where pressure, flow and/or area can be measured, ideally simultaneously. The most obvious location would be the ascending aorta (or pulmonary artery). Caution is warranted when measuring at a location close to reflection sites, where the frequency and time domain method may suffer from the presence of reflection, interfering with the early systolic rise or an input impedance pattern that lacks the clear plateau.
Figure	Figure from a publication  Illustration of how Zc can be derived in the time domain from pressure and flow. See 'How can it be measured, for a detailed description (third bullet). Figure adapted from Segers et al. 2022 In: Textbook of Arterial Stiffness and Pulsatile Hemodynamics in Health and Disease, Edition 1

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