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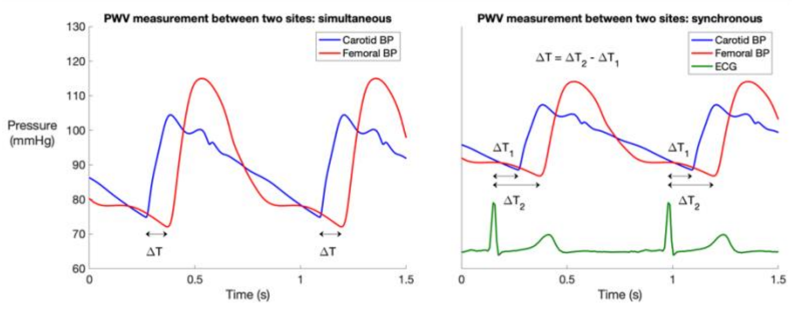
Pulse Wave Velocity

What is it?	Pulse wave velocity (PWV) is the speed at which the arterial pulse wave propagates along an arterial segment [O'Rourke 2002]. PWV is a marker of vascular ageing because it is related to the stiffness and diameter of the arteries, as demonstrated by the Moens-Korteweg equation [Tijsseling and Anderson 2012], which states that $\mathrm{PWV} = \mathrm{sqrt}((E\ h) / (D\ \mathrm{rho}))$, where *E* is the Young's modulus of the arterial wall, *h* is its thickness, *D* is its diameter, and *rho* is the density of blood. Both the stiffness and diameter of major arteries (principally the aorta) change with age [Hickson 2010], resulting in an increase in PWV [The Reference Values for Arterial Stiffness' Collaboration 2010].
Why do we measure it?	Aortic PWV has been observed to be predictive of cardiovascular morbidity and mortality, independently of other risk factors [Vlachopoulos 2010] [Ben-Shlomo 2014]. Individuals with 'Early vascular aging' (*i.e.* a higher PWV value than the normal value for their age) are at increased cardiovascular risk [Nilsson 2009].
How can it be measured	PWV is calculated from the time delay between two arterial pulse waves measured at different anatomical sites, and the difference in arterial path lengths from the heart to each measurement site. One arterial pulse wave is measured proximal to the heart (such as at the carotid artery), and another is measured further away from the heart (such as at the femoral artery). Typically pressure pulse waves are measured using applanation tonometry [The Reference Values for Arterial Stiffness' Collaboration 2010], although alternative pulse wave measurement techniques can be used such as blood pressure cuffs and optical photoplethysmogram probes [Obeid 2017]. The time delay between pulse waves can be obtained in two ways, as shown in the Figure. Firstly, if the pulse waves are recorded simultaneously then the delay can be calculated as the delay between the two pulse waves. Secondly, if the pulse waves are recorded sequentially then each pulse wave must be recorded alongside a simultaneous signal from which the time of cardiac ejection can be estimated (such as the electrocardiogram - ECG), allowing the time delay between the pulse waves to be approximated as the difference in time delays between each pulse wave and its marker of cardiac ejection. The arterial path length can be obtained by [Reusz 2020]: (i) estimating it as a proportion of the distance between measurement sites; or (ii) calculating the difference in surface distances between the heart and each measurement site. Having obtained a time delay and arterial path length, PWV is then calculated as PWV = length of arterial segment / pulse transit time ,

	where the ‘length of arterial segment’ is the arterial path length between the two sites, and the ‘pulse transit time’ (PTT) is the time delay between pulse arrival at the proximal and distal site.
Where is it measured?	PWV can be measured invasively along the aorta. However, the gold standard for non-invasive PWV measurement in clinical practice and research is between carotid and femoral sites [Van Bortel 2021], since the resulting arterial path consists mostly of the descending aorta, a principal site of vascular ageing. Several alternative pairs of sites have been used, including the radial and brachial arteries, and finger, ankle and toe sites. The choice of measurement sites influences the extent to which PWV measurements are representative of aortic PWV.
Figure	Figure adapted from Wikimedia Commons:  *(see file for high-resolution version)* Pulse wave velocity (PWV) measurement techniques: (left) between two sites using simultaneously acquired pulse waves; and (right) between two sites using synchronous pulse waves gated by an ECG signal. Adapted from: Charlton P.H., ‘File:Pwv measurement fig.svg’, https://commons.wikimedia.org/wiki/File:Pwv_measurement_fig.svg (accessed 26 April 2021). Reproduced under CC BY 4.0
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