Scisense Pressure Technical Note

Pulse wave velocity (PWV) basics

During contraction the heart muscle creates a pressure wave which drives the blood out of the ventricle and through the vasculature. The pulse wave velocity (PWV) is the distance traveled by the pressure wave divided by the time for the wave to travel that distance.

$$PWV = \frac{\Delta x}{\Delta t}$$

The speed at which the pressure wave travels through the vasculature is dependent on the material properties of the vessels. Major arteries can be characterized as having viscoelastic material properties. Energy provided to a viscoelastic material during loading is both dissipated during unloading (viscous) and returned (elastic). The elastic return of energy creates reflected waves that travel back towards the heart. The relationship between the PWV and the stiffness of the vasculature can be expressed via the Moens-Korteweg equation, assuming that the artery wall is isotropic and experiences isovolumetric change with pulse pressure:

$$PWV = \sqrt{\frac{E \cdot h}{2r\rho}}$$

E = incremental elastic modulus
h = wall thickness
r = vessel radius
ρ = blood density

Fibroblast, vascular smooth muscle cells (VSMC), intermediate cells, pericytes, myocytes, mast cells, endothelium, nerves, mast cells, interstitial macrophages are all present in the vascular wall. The principally important vascular viscosity players are fibroblast and VSMC, as they produce the extracellular matrix (ECM). The principle ECM components which impact PWV are elastin and collagen (types I and III). Inherent PWV increases with distance away from the heart due to decreased elastin and increased collagen content. Collagen content often increases during various disease states due to remodeling which in turn increases the pulse wave velocity.

When vascular stiffening occurs a higher pulse wave velocity is observed. Increased aortic stiffness can also alter the pressure wave's shape due to decreased capacitative properties of aortic vessel wall. During the systolic phase the aortic wall expands to accommodate the increased blood volume. Due to lower stiffness, the elastic portion of the vessel wall dilates at the beginning. When the wall strain increases, the vascular elastic modulus increases because the collagen fibers begin engaging in order to maintain the aortic wall shape (4).

PHYSIOLOGICAL FACTORS THAT IMPACT PULSE WAVE VELOCITY

PWV has to be assessed and closely monitored within the context of heart rate (HR) and mean arterial pressure (MAP). If MAP increases, arterial stiffness increases and PWV increases due to the exhaustion of elastin-limits and collagen engagement. The nervous system has the ability to regulate vascular tone and thus PWV.

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SOME COMMON APPLICATIONS OF PULSE WAVE VELOCITY

- Measure regional elasticity of a vessel to predict the innate vessel properties, amount of remodeling, or stage of vascular disease.
- Compare regional physiological inherent vascular properties (e.g. PA vs. Ao).
- Assess phenotypic inter-species differences, or stage of vasculature change post-genetic (KO, KI, transgenic).
- Assess resistant hypertension and its treatment (persistently elevated and isolated systolic hypertension due to excess in aldosterone and an increased intravascular volume). Measure PWV to evaluate success of renal sympathetic denervation in the treatment of resistant hypertension.
- Assess the effect of sympathetic mediators based on changes in PWV in the aorta.

EXAMPLE METHOD: IN-VIVO CANINE MODEL

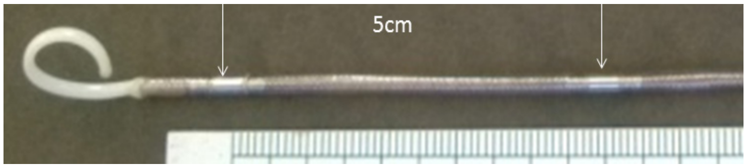
In the healthy dog, passive aortic stiffness is managed by elastin and collagen content. The inherent PWV increases with distance away from the heart due to decreased elastin and increased collagen content. Vascular remodeling causes an increase in the amount of collagen which increases the final velocity of PW propagation.

A Pressure Catheter with two pressure sensors simultaneously detecting pressure waves is inserted into the vessel of interest. The pulse wave distances (PWD) is determined by the spacing between the pressure sensors. In this case a 7F Pressure Catheter with 2 pressure sensors 5 cm (0.05m) apart from each other. Alternatively, this method can be used with two separate pressure sensors placed a known distance apart.

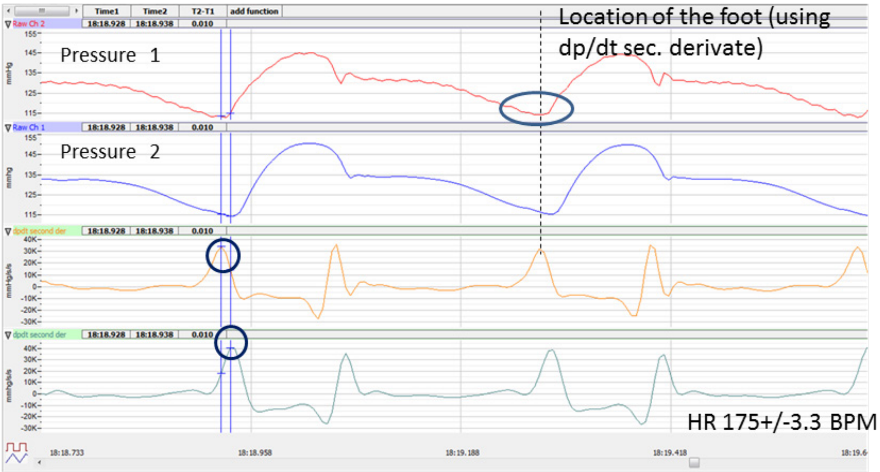
This method uses the determination of the location of the foot of the arterial pulse wave in order to calculated the pulse transit time (PTT) which is the time it takes the pressure wave to travel in between the 2 sensors. There are several options for locating the arterial pulse wave foot including the second derivative maximum or tangent intersection foot-to-foot methods (1). Using the second derivative maximum method the PTT is determined to be 0.01 seconds.

The Pulse Wave Velocity can then be calculated:

$$PWV = \frac{PWD}{PTT} = \frac{0.05\ \text{m}}{0.01\ \text{s}} = 5\ \text{m/s}$$



7F double pressure catheter with known distance (5 cm) between pressure sensors. This distance is known as the pulse wave distance (PWD).



The second derivative maximum is used to locate the foot of the pressure pulse wave in order to calculated the pulse transit time (PTT)between the two sensors.

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Pulse Wave Velocity (PWV) Basics Cont.

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