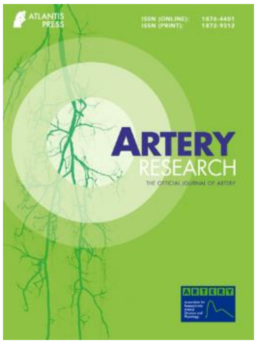

Artery Research

ISSN (Online): 1876-4401 ISSN (Print): 1872-9312
Journal Home Page: https://www.atlantis-press.com/journals/artres

P6.08: EVALUATING THE HEMODYNAMIC IMPACT OF ISOLATED NON-DISTENSIBILITY AND RESIDUAL NARROWING AFTER COARCTATION REPAIR USING A COMPUTATIONAL STUDY

L. Taelman, J. Bols, J. Degroote, V. Muthurangu, J. Panzer, J. Vierendeels, P. Segers

Conclusion: Within patients, short-term changes in arterial stiffness of $\sim$1 m/s in the presence of $>$10 mmHg BP lowering can be deemed entirely pressure dependent. This pressure dependency of arterial stiffness increases with age, in part explaining the well-established pattern between stiffness, BP and age at (reference) population level.

P6.06
AORTIC REFLECTIONS-RELATED TIME AND MAGNITUDE INDICES ESTIMATED FROM THE SUPERIMPOSITION OF CENTRAL PRESSURE AND FLOW WAVEFORMS

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Objectives: While in young subjects, central pressure and flow peaks occur simultaneously and before time to return of reflected pressure (Tr), Tr progressively shifts towards early systole with aging, and eventually occurs before pressure peak. Consequently such parameters along with the corresponding augmentation index (AIx) have been previously shown as relevant indices of arterial aging. However, Tr accurate determination using pressure alone remains challenging, especially in elderly subjects. Accordingly, our aim was to combine central pressure and flow waveforms to provide objective and reproducible reflections-related indices.
Methods: We studied 50 healthy subjects (24 women, age: 46$\pm$15years), who underwent ascending aorta velocity-encoded magnetic resonance (1.5T) and carotid applanation tonometry. For each subject, , time delays between Tr and peak flow ($T_{Qmax\text{-}Tr}$) and between pressure and flow peaks ($T_{Q\text{-}Pmax}$), which are related to the overlap between incident and reflected pressure waves, were automatically estimated using a custom software that enables superimposition of pressure and flow waveforms. Conventional AIx was also measured from carotid pressure waveform. Forward and backward pressure components obtained using aortic characteristic impedance were used to estimate reflection magnitude (RM) as the ratio between backward and forward pressure magnitudes.
Results: The obtained correlations for comparison against age, AIx and RM were higher for $T_{Q\text{-}Pmax}$ than for Tr or $T_{Qmax\text{-}Tr}$ (Table). Importantly association with RM, which is known to be a pure index of wave reflection, was superior for the combined index $T_{Q\text{-}Pmax}$.
Conclusions: Superimposition of pressure and flow waveforms helps for an objective and reproducible evaluation of central reflections-related indices.

Table. Comparison of reflection indices against age, augmentation index (AIx) and reflection magnitude (RM).

r (p)	Tr	$T_{Qmax\text{-}Tr}$	$T_{Q\text{-}Pmax}$
Age	-0.51 (p=0.0002)	-0.42 (p=0.003)	0.69 (p<0.0001)
AIx	-0.77 (p<0.0001)	-0.60 (p<0.0001)	0.82 (p<0.0001)
RM	-0.46 (p=0.001)	-0.52 (p=0.0001)	0.84 (p<0.0001)

P6.07
A STUDY TO DETERMINE IF THE REFLECTED WAVE TRANSIT TIME FROM BRACHIAL SUPRASYSTOLIC WAVEFORM ANALYSIS IS REPRESENTATIVE OF LARGE ARTERY STIFFNESS

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Background: Aortic stiffness is clinically important, but measurement can be time consuming. The 'reflected wave transit time' (RWTT) is thought to represent aortic stiffness and, since this can be measured quickly by brachial cuff oscillometry, could be a useful new test. This study aimed to compare RWTT with directly measured aortic (as well as brachial) stiffness in non-diabetics and also diabetics where there would be an expectation of increased stiffness (lower RWTT).
Methods: Aortic and brachial stiffness were recorded using tonometric pulse wave velocity (PWV; SphygmoCor) in 68 non diabetic (age 54.9$\pm$8.6 years,64.7% male) and 20 patients with type 2 diabetes (T2DM; age 60.5$\pm$9.6 years,55% male). RWTT was measured using brachial cuff oscillometry and suprasystolic waveform analysis (Pulscor®) as the time between the first and late systolic waves. Aortic PWV was also calculated from path length/RWTT in a subgroup of 69 patients.
Results: T2DM patients had significantly higher aortic PWV (9.6$\pm$2.7 vs 7.7$\pm$1.6 m/s, p=0.005), but no difference in brachial PWV (7.6$\pm$1.1 vs 8.1$\pm$1.4 m/s, p=0.14). RWTT between T2DM and non-diabetics was not significantly different (0.16$\pm$0.02 vs 0.17$\pm$0.02 s, respectively p=0.12). There were no significant correlations between RWTT and aortic PWV or brachial PWV in either T2DM or non-diabetic groups (r>-0.05, p>0.05 all). Furthermore, calculated aortic PWV was not significantly related to actual aortic PWV (p>0.05).
Conclusions: While brachial artery cuff oscillometric waveform analysis offers potentially useful clinical information, the transit time of pulse waves is not representative of large artery stiffness and, therefore, needs to be measured directly.

P6.08
EVALUATING THE HEMODYNAMIC IMPACT OF ISOLATED NON-DISTENSIBILITY AND RESIDUAL NARROWING AFTER COARCTATION REPAIR USING A COMPUTATIONAL STUDY

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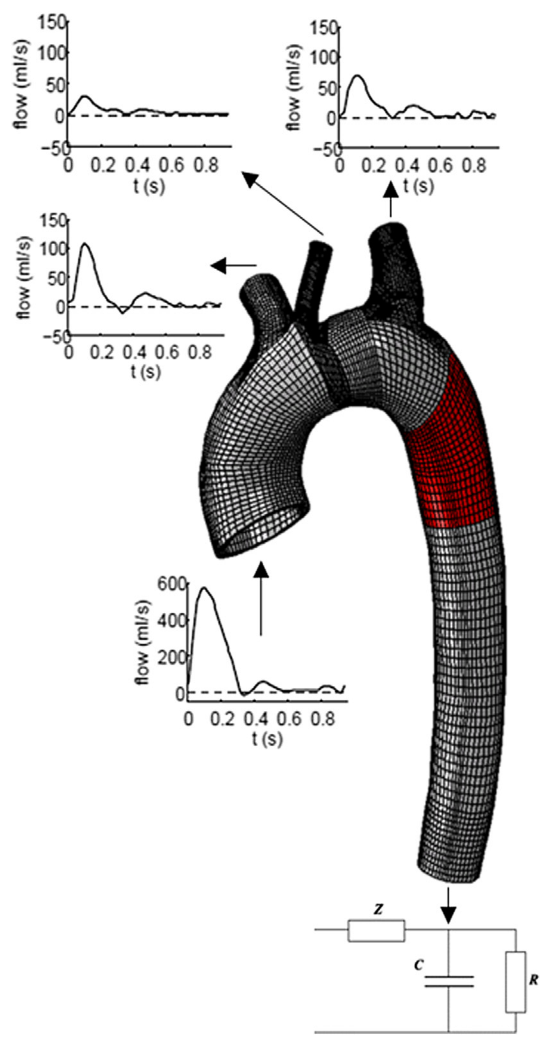

Figure 1 Patient specific model.

Background: Even after successful treatment of aortic coarctation, a high risk of cardiovascular morbidity and mortality remains. Uncertainty exists on the factors contributing to this increased risk among others the presence of (1) a residual narrowing, leading to an additional resistance in the arterial

system and (2) a non-distensible zone, disturbing the buffer function of the aorta. As the many interfering factors and adaptive physiologic mechanisms present in vivo prohibit the study of the isolated impact of these individual factors, an advanced computer model was developed.
Material and methods: The geometry and flow boundary conditions are obtained from MRI data of a healthy subject (Figure 1). A segment with varying length and stiffness was included distal to the left subclavian artery (red zone in Figure 1). Recurrent coarctation was studied by altering the diameter (coarctation index of 0.5 for severe and 0.65 for mild coarctation).
Results: Figure 2 depicts the effect of a local non-distensibility on the pressure evolution proximal and distal to the rigid zone. Data shown represent the presence of a stent (length 5cm, 100 x stiffer than reference material) or scar tissue (length 5 mm, 5x stiffer). Although the overall impact is very limited, the presence of a stent increased the proximal systolic pressure with 4.5 mmHg compared to the pressure in a healthy subject.
Conclusion: The model allows to study the isolated effect of local non-distensibility and narrowing which is impossible to obtain in vivo.

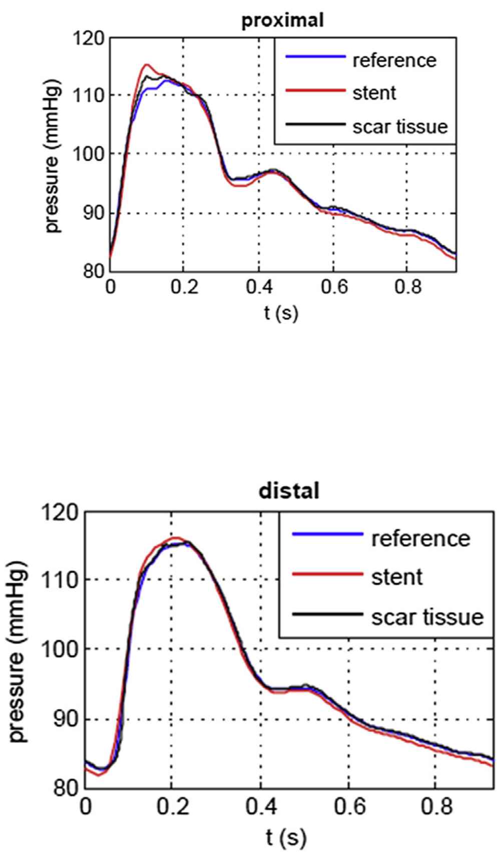

Figure 2 Proximal and distal pressure.

P6.09
MULTIPLE REFLECTIONS, NOT A SINGLE DISTAL AORTIC REFLECTION DETERMINE PRESSURE WAVE SHAPE

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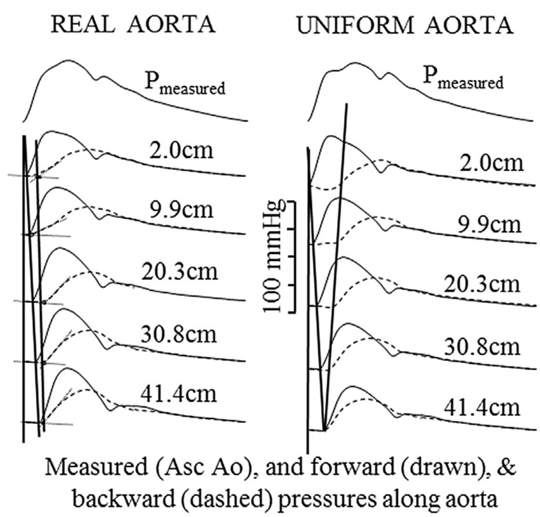
Arterial pressure and flow waves travel and are reflected. Waveform analysis and wave separation gave insight into these phenomena and parameters thus obtained are indicators of cardiovascular events. However, the interpretation of forward and reflected waves is still not generally agreed upon. We used an anatomically accurate (data from Hickson, 2010) model of the entire systemic arterial tree and also set all aortic diameters equal at mean aortic diameter ("uniform aorta"), leaving other arteries unchanged, and calculated forward and backward waves in the standard way (Murgo, 1981). In the anatomically accurate model, timing of the feet of backward and forward waves is location independent, as also recently reported by Tyberg, 2013. In the uniform aorta the delay between forward and backward waves is smallest in the distal aorta and largest in the ascending aorta. In both models pressure amplification over the aorta is ∼1.35. Changes in microcirculatory resistance have little effect on wave shapes. We conclude that multiple local reflections in the aorta importantly contribute to pressure (and flow) wave shape. Thus pressure wave shapes depend on arterial geometry: aortic diameters and side branches. Distal aortic (bifurcation) and peripheral reflections are not the major contributors to overall reflection and wave shape. We suggest that studies of aortic dimensions and effect of side branches are needed to better understand aortic pressure wave shapes and wave travel.



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Murgo JP et al., Circulation 1981; 63, 122.
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P6.10
SENSITIVITY OF WAVE SEPARATION IN THE ARTERIES TO ERRORS IN ESTIMATING WAVE SPEED

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Objectives: Examine the effect of erroneous estimation of wave speed (C) on the magnitude and time of the separated pressure (P) and velocity (U) in arteries.
Methods: Pressure and flow were measured in the aorta of 11 dogs and C has been determined using the PU-loop technique. The waves were separated into the forward and backward directions using wave intensity analysis (WIA), with C varying from C-99C% to C+99C%. The following parameters were studied: **a)** Peak of forward (P+, U+) and backward (P-, U-) pressure and velocity waveforms, **b)** The onset and peak times of P+, U+ , P-, and U- all with respect to ventricular ejection time.
Results: Incorrect values of C resulted in an inaccurate estimation of the $P_{\pm}$ and $U_{\pm}$. An error of (+,-)50% in C results in an amplitude error of 7,7% in P_{+}, 6, 8% in P-, 20, 60% in U+ and 30, 116% in U-. Also, an error of (+,-) 50% in C results in an error in peak time of 7, 11% for P+, 15, 5% for P-, 7, 10% for U+ and 2, 20% for U-. Incorrect determination of C did not affect the onset of the forward waves while it resulted in error of 47,47% for P- and 38,38% for U- (Figure 1,2).
Conclusions: The separation of P and U waveforms using WIA is sensitive to changes of C, whose correct estimation is important for the accurate determination of the magnitude and peak time of the forward and backward waveforms.

P6.11
EVALUATION OF A NOVEL AND EXISTING TECHNIQUES FOR THE ESTIMATION OF PULSE TRANSIT TIME

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