P2.22: COMPARING COMPUTATIONS OF VASCULAR WALL PARAMETERS IN THE ABDOMINAL AORTA (AO) BASED ON PRESSURE CURVE FORMS FROM THE AO AND BRACHIAL ARTERY

J. Karlsson, J. Stalhand, H. Astrand, M. Karlsson, T. Lanne

P2.19

VALIDATION OF A NEW SYSTEM FOR THE ASSESSMENT OF FLOW MEDIATED DILATION: COMPARISON WITH A REFERENCE METHOD

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Endothelial function is linked to cardiovascular risk factors, provides prognostic information when studied non-invasively by measurement of flow-mediated dilation (FMD). Despite the large effort to standardize the methodology, the FMD examination is still characterized by problems of reproducibility and reliability that can be overcome with the use of automatic systems. In our lab, we developed a system for the assessment of brachial FMD from ultrasound images which is able to automatically evaluate the brachial artery diameter in real-time. In order to validate our system, we carried out a comparison with another automatic method, available at the Vascular Physiology Unit of the Institute of Child Health (London), that it is considered as a reference method in FMD assessment. Two protocols have been followed in order to evaluate the agreement between the systems.

Protocol 1: 47 VCR recorded FMD sequences have been analyzed. Mean baseline (Basal), maximal (Max) brachial artery diameter and FMD, as maximal percentage diameter increase (%FMD) have been evaluated for each sequence.

Protocol 2: brachial artery diameter (Diam) has been evaluated in 618 frames from 12 sequences. Diam value and %FMD have been considered for each frame. Bland-Altman analysis has been used. As shown in the table, the bias is negligible and the SD of the differences is satisfactory. In conclusion, the compared systems show a optimal grade of agreement and they can be used interchangeably. Thus, the use of a system characterized by real-time functionalities would represent a referral method for assessing endothelial function in clinical trial.

	PROTOCOL 1			PROTOCOL 2	
	Basal	Max	%FMD	Diam	%FMD
Mean of Diff.	-0.014 mm	-0.024 mm	-0.31 %	-0.093 mm	-0.26 %
SD of Diff.	0.028 mm	0.037 mm	0.58 %	0.028 mm	0.61 %

P2.20

ASSESSMENT OF THE CAROTID DIAMETER AND INTIMA-MEDIA THICKNESS FROM ULTRASOUND DATA: COMPARISON BETWEEN TWO METHODS

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The aim of this study was to compare a new device for the automatic evaluation of carotid diameter (D) and intima-media thickness (IMT) from ultrasound B-mode image sequences, with a RF echotracking system (RFES). A total of 90 scans of the right/left common carotid artery from 21 patients with various cardiovascular risk factors and 12 healthy volunteers were analysed. The measurements were performed in real-time by using the two systems sequentially. Different Regions of Interest (ROI) were adopted, as our device best works on 1cm width ROI and the other on 4cm width ROI; a subgroup of scans (31) were analyzed using the same ROI width for the two systems. Moreover, on the healthy volunteers the analysis was repeated twice with each device in order to evaluate the intraobserver variability. The agreement between the two systems was evaluated by Bland-Altman analysis; the bias and the standard deviation were 0.100mm and 0.190mm for D and 0.003mm and 0.057mm for IMT respectively. Moreover, in the subgroup where the same ROI width was adopted the bias and the standard deviation were: 0.060mm and 0.110mm for D and -0.006mm and 0.039mm for IMT. The coefficients of variation of the intraobserver measurements

were: 2%±2% (D) and 5%±5% (IMT) for the RFES and 2%±1% (D) and 6%±6% (IMT) for our device.

In conclusion, although it is common opinion that B-mode based devices have lower precision than the RF based ones, our system shows reproducibility comparable to that of the RFES and good agreement with it.

P2.21

COMPLEXITY OF 3D CAROTID BIFURCATION BLOOD FLOW PATTERNS IS NOT ADEQUATELY CAPTURED BY CURRENTLY USED ULTRASOUND MODALITIES

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Background: Ultrasound is still the preferred method for non-invasive investigation and blood flow visualization in the carotid artery, using pulsed Doppler and color flow imaging. These techniques are widespread, and data are often displayed in a (color-coded) format allowing easy interpretation. Nevertheless, in currently applied techniques, not all aspects of blood flow are captured, especially in regions with complex anatomical shapes such as the carotid bifurcation, and when flow is further complicated by presence of plaque.

Methods and Results: We developed a 3D anatomically correct computer model of a carotid bifurcation with plaque, and calculated the complex flow field using numerical techniques (CFD; Computational Fluid Dynamics). Next, we coupled these data to an ultrasonic model (Field II) allowing simulation of ultrasound data based on the computed flow field. The pulsed Doppler simulations showed good agreement between the ultrasound velocities and the computed flow field. Simulated color flow images demonstrated that flow patterns are generally well obtained but that vortex formation in the bifurcation, internal carotid artery and downstream of the plaque are not easily discernable. These results were also confirmed in an experimental validation study.
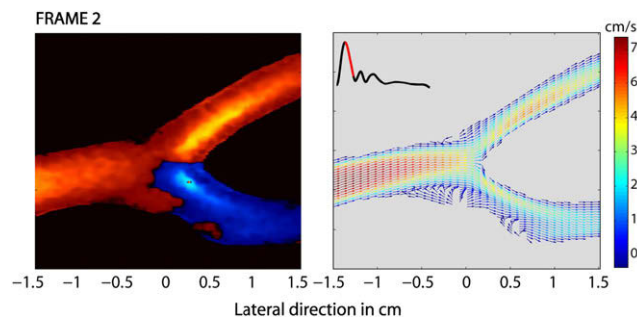
Discussion: Currently used ultrasound imaging modalities have important limitations to assess complex flow in the carotid artery. This complicates the use of these images to extract quantitative data related to flow such as wall shear stress. This virtual ultrasound environment is a powerful tool to assess limitations of currently used ultrasound imaging modalities and to develop new algorithms of upcoming techniques such as 3D ultrasound.

P2.22

COMPARING COMPUTATIONS OF VASCULAR WALL PARAMETERS IN THE ABDOMINAL AORTA (AO) BASED ON PRESSURE CURVE FORMS FROM THE AO AND BRACHIAL ARTERY

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With aid of the pulse pressure and radius wave form of the AO as input to a mechanical model, a set of aortic wall parameters can be identified describing different properties of the aortic wall, e.g. elastin, collagen content and distribution. This makes it possible to perform a deeper analysis of the components in the wall and the acting forces (VaMoS) [1]. To facilitate the use of VaMoS it would be preferable to use a more accessible arterial pressure wave form as indata. The aim was to test if pressure curves taken

from the brachial artery would be an acceptable substitute for the AO in the VaMoS computations.

Pulsatile diameter change in the AO was registered with aid of a wall track system, and pressure curves measured simultaneously in the AO and the brachial artery with aid of Millar catheters in healthy volunteers (n= 29, 23-72 years).

There were significant differences in 4 out of 6 aortic wall parameters when pressure curves from brachial artery was compared with AO, emphasizing that the VaMoS computation is sensitive to the pulse wave form and that pressure curves in the brachial artery is not an acceptable substitute for the AO when using VaMoS. A transfer function between the brachial and AO pressure curve form might lead to more accurate results.

[1] Stålhand J. 2008; DOI 10.1007/s10237-008-0124-3

P2.23
THE RESERVOIR PRESSURE CONCEPT: THE 3-ELEMENT WINDKESSEL MODEL REVISITED? APPLICATION TO THE ASKLEPIOS POPULATION STUDY

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Background: Traditionally the arterial system is either modelled as a lumped-parameter windkessel model, or as a wave system. Recently, a hybrid model has been proposed in which the arterial system is considered to be a reservoir while still allowing for superimposed wave phenomena. We applied this novel approach to non-invasively obtained carotid pressure waveforms from 2024 subjects from the Asklepios population to investigate the contribution of reservoir pressure to pulse pressure with age and gender and compared it to the windkessel pressure obtained from a more traditional 3 element windkessel model approach.

Methods: $PP_{res,WK}$ and $PP_{res,hybrid}$ were determined by applying a 3-element windkessel model and the hybrid reservoir pressure concept to scaled carotid artery tonometry readings, respectively. The evolution of PP_{car}, $PP_{res,WK}$ and $PP_{res,hybrid}$ was separately examined for men and women after stratification of the population into age quartiles.

Results:
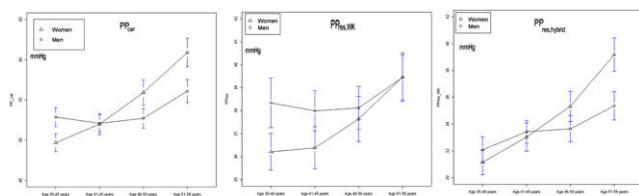
Discussion: PP_{car} increased with age regardless of sex, but was more pronounced in women. This increase is largely due to reservoir pressure, regardless of the model used. Hybrid model results closely resemble those obtained by a 3 element windkessel model, with a strong correlation (r=**, P<0.001) between $PP_{res,WK}$ and $PP_{res,hybrid}$.

P2.24
ESTIMATION OF ARTERIAL MECHANICAL PROPERTIES BASED ON A PATIENT SPECIFIC WAVE PROPAGATION MODEL

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Background: Arterial stiffness can be assessed using pulse wave velocity (PWV). However, distance measurement introduces an error and an average PWV is considered although arterial stiffness increases distally. A patient specific one-dimensional wave propagation model may reveal details of pressure wave propagation phenomena and mechanical properties of arteries.

Methods: For 6 healthy volunteers, ultrasound wall distension (WD), blood pressure (BP) waveform and blood velocity were assessed at 5 positions along the leg. Blood volume flow (BVF) for each position was estimated assuming Womersley profile. The Young's moduli and diameters of the arteries were derived from the BP and WD. The BVF at the iliac artery (IA) is used as input for the simulations. The in-vivo results were compared with simulated BVF and BP curves to adapt the model parameters iteratively.

Results: The group average diameter equals 7.4±0.6 for the IA, 1.9±0.8 for the posterior tibial (PTA) and 1.7±0.5mm for the pedal (PDA) artery. The ratio IMT/diameter increases along the arterial tree, from 7.5% to 21.1% and 27.5% in the IA, PDA and PTA, respectively. The distensibility equals 0.39±0.07 and 0.36±0.09MPa^{-1} at the IA and PDA; the PWV over IA to PDA segment is 7.4±1.0m/s. The distensibility resulting from the iterative method is 20% smaller than the first estimate based on the measurements while the PWV was the same.

Conclusion: The results show that the shape of simulated BVF is comparable with in-vivo estimations and that the wave propagation model can be used to estimate more accurately arterial mechanical properties.

P2.25
MATHEMATICAL MODELLING OF THE SYSTEMIC CIRCULATION: INVESTIGATING PRESSURE AND FLOW THROUGHOUT THE MICROCIRCULATION

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An early pathological process common to many vascular diseases is dysfunction of the small arteries. A variety of mechanisms are implicated including endothelial dysfunction. The final common pathway linking these functional pathologies to clinically significant disease is alteration of haemodynamic characteristics of the microcirculation, including the generation of small arteries at which the majority of the pre-capillary pressure drop occurs (resistance arteries).

We have extended a model of the systemic arterial system into the microcirculation. The model is divided into two parts: one comprising the larger arteries and one comprising the smaller arteries, coupled together through an outflow boundary condition at the terminals of the larger arteries. Blood flow and pressure in the larger arteries are predicted from a nonlinear 1D cross-sectional area-averaged model based on the Navier—Stokes equation. Inflow is ascending aortic flow measured using MRI. Small arteries in vascular beds are modelled as an asymmetric structured tree. Impedance is calculated throughout the asymmetric tree, allowing pressure and flow to be calculated at each vessel generation. Physical properties (dimensions, compliance etc) can be altered independently at each vascular generation of the microvasculature.

Using this model, we are able to simulate resistance artery pathologies identified as potential precursors of systemic disease. A detailed theoretical understanding of the haemodynamic impact of such resistance artery pathology on systemic blood flow and pressure has multiple potential uses. Current hypotheses concerning the pathophysiology of very early vascular disease eg 'essential' hypertension may be tested in silico and new hypotheses could potentially be generated.

P2.26
DYNAMIC ASSESSMENT OF VASCULAR RESISTANCES IN DIABETIC MICEUSING A NON-INVASIVE NMR IMAGING APPROACH

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The dynamic determination of peripheral vascular resistances requires simultaneous determination of organ perfusion and systemic arterial blood pressure (BP). We developed an integrated Nuclear Magnetic Resonance (NMR) approach combining measurements of systolic and diastolic BP with tissue perfusion by NMR-Imaging using Arterial Spin Labeling technique (NMRI-ASL) in small animals. This allowed non-invasive determination of local peripheral resistances in vivo. As a first example of application, we assessed the vascular conductance in skeletal muscle of type-2 diabetic mice.