Investigating the potential of MRI as a new non-invasive modality for Wave Intensity Analysis (WIA) in healthy and renal disease subjects

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Introduction Wave Intensity Analysis (WIA) is a recent one-dimensional model of blood flow in arteries based on blood pressure and velocity waveforms measured at a single point in the circulation [1]. WIA allows the identification of wave reflections, affected by arterial stiffness often found in aged individuals or suffering from diabetes or renal disease [2]. In humans, the non-invasive modality of choice used to record the velocity signals is Doppler ultrasound. However, patients with renal disease are increasingly investigated with MR imaging. This work assessed the potential of combining blood velocity measurements from MRI with blood pressure measures to allow characterisation of large vessel hydrodynamics. The pressure waveforms were recorded using applanation tonometry, a technique validated for our group of subject.

Materials and Methods Blood pressure measurements were taken and repeated three times in the left radial artery of 8 subjects using applanation tonometry (SphygmoCor, AtCor medical) before and after the MR scan. Central pressure signals calculated by the SphygmoCor built-in transfer function were then averaged and used for the analysis. Cross sections of the descending aorta were imaged with a 3 T Philips Intera system (Philips, Best, Netherlands) using single slice quantitative phase contrast angiography. Images were reconstructed to produce single slice flow velocity maps. Four of the subjects were healthy volunteers under the age of 30 (control group) and four were patients with advanced chronic renal failure (patient group). In each group, two subjects were female and two were male. The reconstructed velocity signals from the MRI were sampled to 128 Hz to match the sampling frequency of the SphygmoCor and WIA was applied as described by Parker *et al.* [1] using Matlab (Mathworks, MA, USA). Diastolic and Systolic Blood Pressures (DBP and SBP) were compared between the individuals. Pulse pressure (PP) was calculated as SBP-DBP. Peak velocity (Peak U) and velocity reversal (min U) were also identified from the signals. WIA provided a number of calculated parameters which describe the physical properties of the circulation: 1) The reflection ratio, defined by the amplitude of the backward component of pressure over the amplitude of the measured central pressure was calculated; 2) Wave speed (c) was calculated using the PU-loop method described by Khir *et al.* [3]; 3) WI_{+1}, WI_{+2} and WI_{-}, corresponding respectively to the two positive and one negative peaks of wave intensity were identified and their amplitude recorded.

Results Figure 1 gives an example of wave intensity plots for one healthy volunteer (top) and one patient (bottom). The three peaks of wave intensity, characterising left ventricular ejection, wave reflection and left ventricular relaxation were present. For patients with renal disease, the SBP and PP were elevated compared with the control group (see table 1). The reflection ratios were greater for the patient group than for the healthy volunteers and so were the wave speeds. WI_{+1} and WI_{+2} were not consistently higher or lower for all the individuals but WI_{-} was always more pronounced in the patient group.

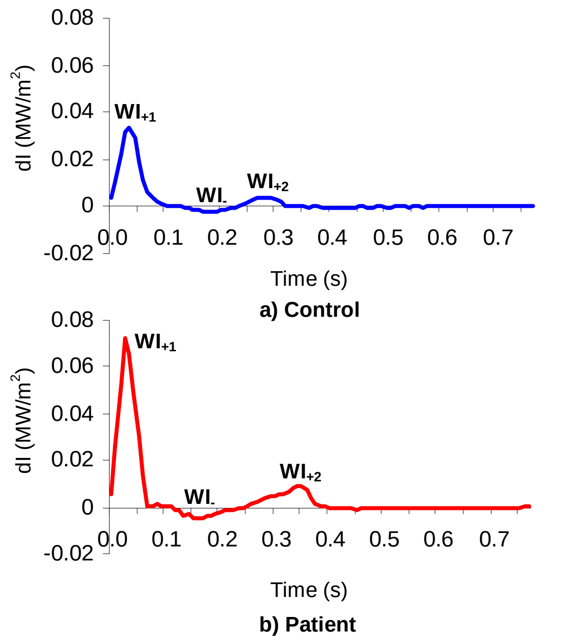

Figure 1: Two examples of wave intensity plots for a healthy volunteer (top) and a patient with chronic renal failure (bottom).

Table 1: Results for the control (top) and patient (bottom) groups. IQR stands for InterQuartile Range. Pressures are expressed in kPa, U and c in m/s, WI_{+1}, WI_{+2} and WI_{-} in MW/m^2.

	Sex	Age	DBP	SBP	PP	Peak U	Min U	Reflection ratio	c	WI_{+1}	WI_{-}	WI_{+2}
Controls:	Female	28	8.3	11.9	3.7	0.72	-0.004	0.12	4.1	0.025	-0.002	0.002
	Female	30	9.3	13.1	3.8	0.74	-0.004	0.13	3.0	0.039	-0.005	0.004
	Male	32	9.2	12.9	3.6	0.83	-0.048	0.14	2.0	0.031	-0.002	0.005
	Male	29	9.1	12.1	3.0	0.75	-0.005	0.10	2.7	0.034	-0.002	0.004
	Median	30	9.2	12.5	3.6	0.75	-0.004	0.13	2.9	0.032	-0.002	0.004
	IQR	2	0.2	0.8	0.1	0.03	0.001	0.01	0.5	0.004	0.001	0.0002
Patients:	Female	60	8.9	15.3	6.5	0.39	-0.026	0.19	3.8	0.019	-0.007	0.003
	Female	63	9.7	17.5	7.7	0.64	-0.022	0.18	4.7	0.072	-0.005	0.009
	Male	73	5.9	15.2	9.3	0.69	-0.031	0.25	4.9	0.071	-0.013	0.013
	Male	61	8.4	13.6	5.2	0.63	-0.020	0.18	3.2	0.029	-0.007	0.007
	Median	62	8.7	15.3	7.1	0.63	-0.024	0.19	4.3	0.050	-0.007	0.008
	IQR	5	0.7	0.7	1.6	0.02	0.004	0.03	0.9	0.042	0.001	0.0032

Discussion WIA was successfully applied to the signals recorded with MR and applanation tonometry in humans. The pattern of wave intensity plot described by Parker *et al.* [1] was observed for all the subjects: first a forward (dI>0) compression (dP>0) wave generated by the contraction of the left ventricle and causing the acceleration of blood in the aorta, then, a relatively small backward (dI<0) compression (dP>0) wave corresponding to reflection from the periphery and finally, a forward (dI>0) expansion (dP<0) wave provoked by the relaxation of the left ventricle, the main cause for blood deceleration and even in some cases reversal. The higher wave speed, wave reflection and SBP found in the patient group were consistent with the literature on arterial stiffness. Renal disease is associated with stiff arteries, resulting in higher wave speeds, early and strong wave reflections, causing an increase in SBP. Elevated wave speed and high blood pressure are both associated with higher mortality [2].

Conclusion This pilot study highlighted the potential of MR as a new modality for WIA, assisting the diagnosis and monitoring of arterial stiffness in renal patients.

References

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