Intra-thoracic blood volume measurement by contrast magnetic resonance imaging

M. Mischi[1], H. C. van den Bosch[2], J. A. den Boer[3], J. Verwoerd[4], R. J. Grouls[2], C. H. Peels[2], and H. H. Korsten[2,3]

[1]Eindhoven University of Technology, Eindhoven, Netherlands, [2]Catharina Hospital, [3]Eindhoven University of Technology, [4]Philips Medical Systems

Introduction

The intra-thoracic blood volume (ITBV) is an important parameter related to the cardiac function and, in general, to the cardiovascular condition. Congestive heart failure is usually related to an increase of cardiac preload and, therefore, ITBV. [1, 2] As a result, the ITBV assessment is valuable for cardiovascular diagnosis as well as for follow up of patients after surgical intervention.

In the clinical practice, accurate ITBV measurements require the employment of invasive thermo- or dye-dilution techniques, where a double central catheterization is needed. [2] An indicator dilution curve (IDC) can be measured in the left ventricle (LV). The transpulmonary mean transit time (MTT) of the indicator between the injection site, usually the right ventricle (RV), and the detection site is derived by analysis of the measured IDC and multiplied by the cardiac output (CO) for the estimation of the ITBV.

In this paper, a minimally invasive method for the ITBV measurement by contrast magnetic resonance imaging (MRI) is presented and validated in vitro. The feasibility of the measurement in a volunteer is also shown. Several studies confirm that the relation between magnetic resonance (MR) signal enhancement and gadolinium DPTA concentration is approximately linear for low concentrations, allowing quantitative applications. [3]

Methods

The proposed approach for the ITBV assessment consists of a peripheral intravenous injection of a small bolus of a paramagnetic contrast agent and its subsequent simultaneous MRI detection in the RV and LV in a four-chamber view. This technique aims therefore at the assessment of physiological parameters related to non-imaged organs. Two regions of interest (ROIs) can be placed on the RV and LV for the RV and LV IDC measurement (Fig. 1).

The derived IDC's are used for the estimation of the MTT. A model fitting is necessary to deal with poor sampling rates, flow artefacts, low signal-to-noise ratios, and contrast recirculation issues. To this end, the gamma variate, which is widely employed for IDC fitting, is adopted. [4, 5] The contrast MTT between the detection sites is given by the difference of the first statistical moments of the fitted IDC's. The ITBV can be simply derived from the MTT by multiplying it by the CO. For an accurate estimation of the CO, the spin phase is integrated over the aortic sectional area and the cardiac cycle observed in a retrospective gated flow sensitive scan across the aortic root with a velocity encoding (VENC) of 1 ms^{-1}. [6]

A simple in vitro model of the transpulmonary circulation was built to validate the proposed method. Two tubes, the input and output of a tube network that represented the circulation volume, passed through the magnet. Inside the transmit coil their path was folded into a flat meandering pattern. In the tubes, a flow of 2 $Lmin^{-1}$ was generated by a Medtronic 550 bio-console centrifugal pump and controlled by an electromagnetic flowmeter. Four different volumes could be defined by clamping part of the tubes in the network. The fluid dynamic system was filled with an aqueous solution of 0.12 mM $MnCl_2$ to reproduce the magnetic properties of blood. [7]

The MRI scanner was a 1.5 T Gyroscan Intera (Philips Medical Systems, Best, the Netherlands) equipped with an array of two surface coils, placed on both sides of the tubes. The MRI pulse sequence was a cardiac triggered one-shot spoiled turbo-field-echo (T1-TFE) in single slice through the plane of the tubes. The flip angle was 25 degrees with a repetition time TR = 5.7 ms and an echo time TE = 2.7 ms. Parallel imaging using SENSE was used to decrease the shot length. [8] The resulting shot duration was 370 ms. After each R-peak, a non-selective saturation prepulse was added to the sequence to reduce inflow artifacts. The pulse sequence allowed acquiring a dynamic image series at the required rate of one frame per beat. The trigger was set to 80 beats per minute.

A calibration experiment was performed prior to the in vitro volume measurements for the determination of a contrast concentration range for which the relation between concentration and MR signal was sufficiently linear. According to the calibration results, a bolus of 0.025 mmol of Gadoteridol® (Bracco, Milan, Italy) was injected in the transpulmonary circulation model. Essentially the same sequence was tested in a volunteer after an intravenous injection of 0.1 mmol of Gadoteridol®. The dose was increased due to the larger dilution volumes. A four-chamber view slice was chosen to detect the bolus passages.

Results

The results of the volume measurements where satisfactory, showing a correlation coefficient R = 0.99 between the real and estimated volumes. The results are shown in Table 1. The feasibility test in a healthy volunteer was also promising. Fig. 2 shows the IDCs measured in the RV and LV together with the gamma variate fits. The correlation coefficients of both fits were larger than 0.95. The measured MTT and CO were 7.0 s and 7.8 $Lmin^{-1}$, respectively, resulting in an ITBV of 910 mL.

Conclusions

A new method for a minimally invasive assessment of the ITBV is proposed. The MRI detection in the central circulation of a gadolinium bolus injected in a peripheral vein allows the ITBV assessment by analysis of two IDCs measured simultaneously in a dynamic scan in the RV and LV. The in vitro validation produced satisfactory results and a test in a volunteer showed the clinical feasibility of the measurement. Future research will focus on the investigation and comparison of different models for the MTT estimation, as well as on the optimization of the pulse sequence aiming at a further reduction of the inflow artifacts.

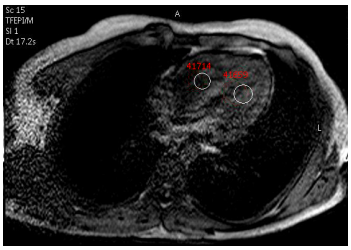

Fig. 1: MRI 4-chamber view. Two ROIs are placed on the RV and LV.

Table 1 - In vitro volume estimates

True	Estimated
413.5 mL	407.1 mL
482.5 mL	470.2 mL
665.5 mL	650.5 mL
1051.5 mL	1031.9 mL

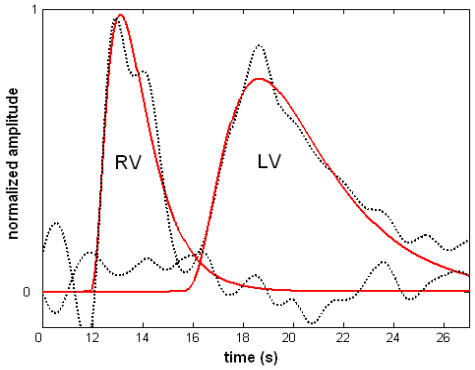

Fig. 2: RV and LV IDC measured in a volunteer (dotted lines). The gamma variate fits (solid lines) are also shown (R > 0.95).

References

[1] S.G. Sakka et al., *Journal of Critical Care*, 14, 78-83, 1999.

[2] C. Wiesenack et al., *Journal of Cardiothoracic and Vascular Anesthesia*, 15, 584-588, 2001.

[3] J. Morkenborg et al., *Magnetic Resonance Imaging*, 21, 637-643, 2003.

[4] R.L. Evans et al., *Journal of Applied Physiology*, 14, 457, 1959.

[5] H.K. Thompson et al., *Circulation Research*, 14, 502-515, 1964.

[6] D.H. Szolar et al., *Journal of Magnetic Resonance Imaging*, 6, 78-89, 1996.

[7] J. P. Hornak, *The Basics of MRI*, 1996.

[8] K. P. Pruessmann et al., *Magnetic Resonance in Medicine*, 42, 952-962, 1999.