

Sensitivity of cardiac magnetic resonance imaging to fluid shifts induced by an external leg compression device

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## Synopsis

**The assessment of thoracic fluid status is crucial for diagnosis, management, stratification, and follow-up of heart failure patients. Indicator dilution theoretical framework allows absolute volume estimation; magnetic resonance contrast agents have been proposed as indicators, with the advantage of a non-invasive detection. In this pilot study, we investigated the changes in intra-thoracic blood volume (ITBV) measured by cardiac magnetic resonance during a fluid shifts induced by a pneumatic leg compression device. Preliminary results on 8 healthy volunteers suggest the sensitivity of the proposed measurement technique; a significant increase in ITBV after the leg compression was observed.**

## Purpose

Heart failure (HF) is characterized by frequent episodes of symptom worsening. Early detection of hemodynamic congestion would improve patient care and prevent more life-threatening situations, which are often due to redistribution of fluid, leading to pulmonary congestion<sup>1</sup>. The assessment of thoracic fluid status is therefore crucial for diagnosis, management, stratification, and follow-up of HF patients. Indicator dilution methods allow absolute volume measurement, when the difference in mean transit time (MTT) between two anatomical sites and fluid flow are known<sup>2</sup>; in this context, dynamic contrast enhanced MRI (DCE-MRI) has been proposed as a minimally invasive technique for the measurement of intra-thoracic blood volume (ITBV), showing accurate volume measurement in *in vitro* settings<sup>3</sup>. In this study, we sought to evaluate the sensitivity of ITBV measurement to fluid displacement in healthy volunteers, induced by a leg compression device.

## Methods

**Healthy subject experiment:** 8 healthy subjects (34±12y, 8 males) were recruited and underwent repeated ITBV measurements at the Catharina Hospital Eindhoven (Eindhoven, the Netherlands) after providing informed consent.

**Measurement:** All the data were acquired on a 1.5T Ingenia scanner (Philips Healthcare, Best, the Netherlands) using a phased-array cardiac coil. DCE-MRI images in four-chamber view were acquired using a non-steady-state spoiled fast-gradient echo sequence (T1-TFE); T1-weighting was achieved by a non-slice selective saturation pre-pulse applied 85 ms before the acquisition of the central line in k-space. A flip angle (FA) of 25° was used with a TR/TE of 6/2.9 ms, resulting in a voxel size of 1.6 x 1.6 x 10 mm; parallel imaging and half-scan were

used to reduce image acquisition time to approximately 150 ms. Acquisition was triggered in mid-diastole to minimize the effect of cardiac motion; the dynamic measurement was performed with one heart beat time resolution at end-expiratory breath-hold, to minimize influence of intra-thoracic pressure. Repeated injections of 0.2 mmol of gadoteridol (ProHance®, Bracco, Switzerland) were administered intravenously using an automated injector (Spectris MR, Medrad, Indianola, PA, USA). The contrast agent bolus was diluted into 5 mL saline solution and it was injected at 5mL/s rate, followed by 15 mL saline flush; subsequently a dynamic series of at least 45 images was acquired. Cardiac output (CO) was measured using phase-contrast MRI (PC-MRI); a retrospective gated fast field echo sequence (FA 20°, TR 5 ms) across the aortic arch was used.

**Leg compression procedure:** In order to induce a fluid displacement, a pneumatic compression device was used. Compression was applied by a Lympha-mat® Digital gradient pump (Bösl Medizintechnik, Aachen, Germany) in combination with sleeves which were inflated around both subject legs; a pressure of 80 mmHg was used. The sleeve inflation was typically completed in 240 s, after the set pressure was reached it was kept constant for 300 s. The ITBV was measured before and after the inflation.

**Data analysis:** Regions of interest (ROI) were manually traced in the right (RV) and left ventricular (LV) blood pools; IDCs were derived averaging the MR signal intensity within the ROI. The local density random walk<sup>3</sup> model was fitted to the obtained IDCs using a non-linear least squares approach implemented in custom software. Pulmonary transit time (PTT) was defined as the difference between the MTTs of the LV and RV IDCs. ITBV was obtained as the product of PTT and cardiac output (CO). CAAS Flow 1.2 (Pie Medical Imaging, Maastricht, the Netherlands) was used to draw a ROI in the aorta semi-automatically and to derive the CO. Cardiac index (CI) and ITBV index (ITBVI) were obtained indexing CO and ITBV, respectively, to body surface area using to the Du Bois formula.

## Results

An example of a DCE-MRI image together with the derived IDCs is shown in Fig.1. The baseline PTT and CI were  $7.6\pm 0.9$  s and  $2.8\pm 0.3$  L/min/m<sup>2</sup>, respectively, and the resulting ITBVI was  $351\pm 36$  mL/m<sup>2</sup>. After the leg compression, the ITBVI increased by  $40\pm 41$  mL/m<sup>2</sup> ( $p<0.05$ , paired Student's t-test). Representative changes from a volunteer in DCE-MRI and PC-MRI are shown in Figure 2; changes in ITBVI after the pneumatic compression are presented in Figure 3.

## Conclusion

Preliminary results suggest ITBV measurement by MRI to be sensitive to fluid shifts caused by an external pneumatic compression device. Further research will include the comparison of the DCE-MRI derived measures with alternative, non-invasive markers of thoracic fluid content.

## Acknowledgements

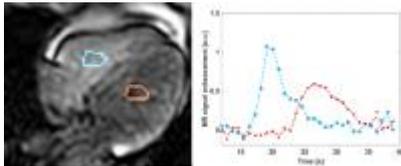
The authors acknowledge G. Wahyulaksana, BSc. for the assistance in implementing the leg compression protocol, M. Kohler, MSc. for operating the MRI scanner.

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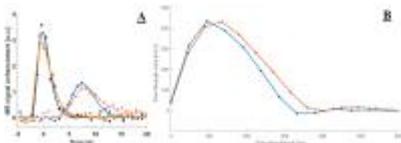
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Abstract ID: 6163

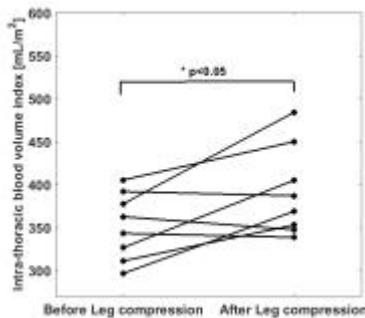
## Figures



**Figure 1.** Left: Example of DCE-MRI image with overlaid regions of interest (ROI) in the left (red) and right (blue) ventricle (LV and RV); Right: corresponding indicator dilution curves derived averaging the DCE-MRI signal intensity within the ROI for RV (blue) and LV (red).



**Figure 2.** (A) Indicator dilution curves derived by DCE-MRI in the right (dark orange, dark blue) and left (orange, blue) ventricle for one volunteer before (dark blue and blue) and after (orange and light orange) the application of pneumatic pressure on the legs. (B) Flow through the aortic arch measured by phase contrast MRI for one volunteer before (blue) and after (orange) the application of pneumatic pressure on the legs.



**Figure 3.** Intra-thoracic blood volume index changes for the considered population before and after the application of pneumatic pressure on the legs. (\*=paired Student's t-test)