Vector map visualisation of phase contrast images demonstrates disruption of intra-atrial vortices in newborn infants

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Background and Aims:

Cardiac magnetic resonance (CMR) techniques have demonstrated specific intra-cardiac flow patterns within the complex looping structure of the adult human heart[1,2,3]. During adult right atrial (RA) filling an intra-atrial vortex is produced by in-flowing blood from the superior vena cava (SVC), which descends anteriorly within the RA, and blood from the inferior vena cava (IVC), which ascends along the posterior RA wall. Thus the vortex flows anti-clockwise when viewed from the subject's left side. It is suggested that this intra-atrial vortex may conserve the blood's kinetic energy, allowing it to 'slingshot' into the right ventricle, augmenting ventricular filling[2]. In the fetal circulation the Eustachian valve protrudes across the mouth of the IVC from the posterior wall of the RA and directs oxygenated blood flowing in from the placental circulation across the patent foramen ovale to the left side of the heart and the cerebral circulation. We hypothesised that the presence of the Eustachian valve could disrupt flow patterns in the newborn right atrium, potentially leading to loss of momentum of intracardiac blood and impaired ventricular filling. The aim of this study was to visualise intra-atrial blood flow patterns in newborn infants' phase contrast CMR images.

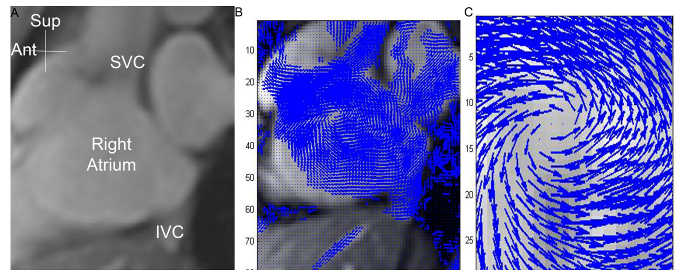

Figure 1 - Sagittal view of adult right atrium (A). Vortex during atrial filling (B) flows anticlockwise when viewed from left (C).

Methods and Analysis:

Phase contrast CMR was performed on a 3.0 Tesla Philips Achieva system (Best, the Netherlands) in two healthy adult volunteers during awake breath hold, and in five newborn infants while in natural sleep, without the use of sedation or respiratory compensation[4]. Two of the infants were preterm, born at 25 weeks gestation (birth weights 750 and 850 grams) and scanned at corrected gestational ages of 31 and 36 weeks. The other 3 were healthy term infants (gestation 38-40 weeks, birth weight 2982-3752 grams) and were scanned within 72 hours of birth. To limit scan duration, images were acquired in a single sagittal section across the centre of the right atrium, with flow encoded only in the head-foot (HF) and antero-posterior (AP) directions (separate acquisitions). Routine settings TR-5.3ms^{-1}, TE-2.9ms^{-1}, flip angle-10^{o}, slice thickness-8mm, FOV-320mm, voxel size-1.25mm, 20 phases/cardiac cycle; total scan duration 5 mins. Offline flow vector visualisation was performed using Matlab (Mathworks, MA, USA). A single arrow per voxel indicates direction and velocity (arrow length) of blood flow. Voxels where the magnitude of flow was below a user defined threshold were set to zero.

Results:

Vector maps produced in healthy adults showed the expected flow pattern, with anti-clockwise intra-atrial vortices seen (Figure 1).

Preterm infants - An anticlockwise vortex was not seen within the right atrium of either preterm infant at any time. Instead blood was seen to flow *anteriorly* from the IVC along the base of the right atrium, and from the SVC inferiorly along the *posterior* portion of the right atrium. A vortex was intermittently seen, but in contrast to the adult pattern the direction of flow within the vortex was *clockwise* when viewed from the subject's left side (Figure 2).

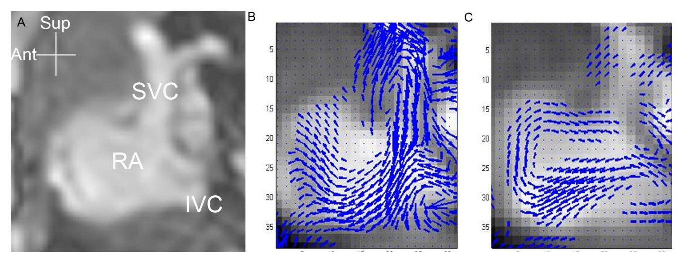

Figure 2 - Sagittal view of preterm right atrium (A). Blood from IVC flows anteriorly, producing clockwise flow during early (B) and late (C) atrial filling

Term infants - No consistent intra-atrial flow pattern was seen. One infant mimicked the pattern seen in preterm infants, with flow from the SVC travelling inferiorly and from the IVC anteriorly, but without vortex formation (Figure 3A). One infant showed relatively linear flow, with blood travelling anteriorly and inferiorly throughout the RA (Figure 3B). A third infant showed brief periods of adult pattern anti-clockwise flow (Figure 3C), though any vortex was transient, and flow often chaotic.

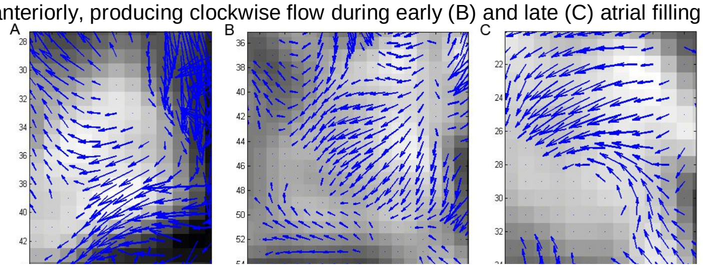

Figure 3 - Right atrial flow patterns in term infants. Flow may be clockwise (A), linear (B) or anticlockwise (C), but vortex formation is minimal.

Conclusions:

CMR phase contrast techniques can be applied in newborn infants, and vector maps can be produced to visualise neonatal intra-atrial blood flow patterns. Both preterm and term infants show significant disruption to the normal adult pattern of vortex formation within the right atrium which is likely due to the Eustachian valve deflecting the stream of blood entering the right atrium from the IVC. The significance of this deviation from the stable adult pattern in premature infants, and the lack of an established adult pattern of flow in term infants is unclear, but could have significant implications for cardiac function during early postnatal life. We now aim to use 3 dimensional techniques to systematically assess intra-cardiac blood flow pattern and momentum-conservation in a cohort of newborn preterm and term infants.

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2 – Kilner et al, Asymmetric redirection of flow through the heart. Nature 2000;404: 759-761.
3 – Fyrenius et al, Three dimensional flow in the human left atrium. Heart 2001;86:448-455.
4 – Foran et al, Three-tesla cardiac magnetic resonance imaging for preterm infants. Pediatrics. 2007;120:78-83