

POSTER PRESENTATION

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# Vortex ring mixing in the left ventricle of the human heart

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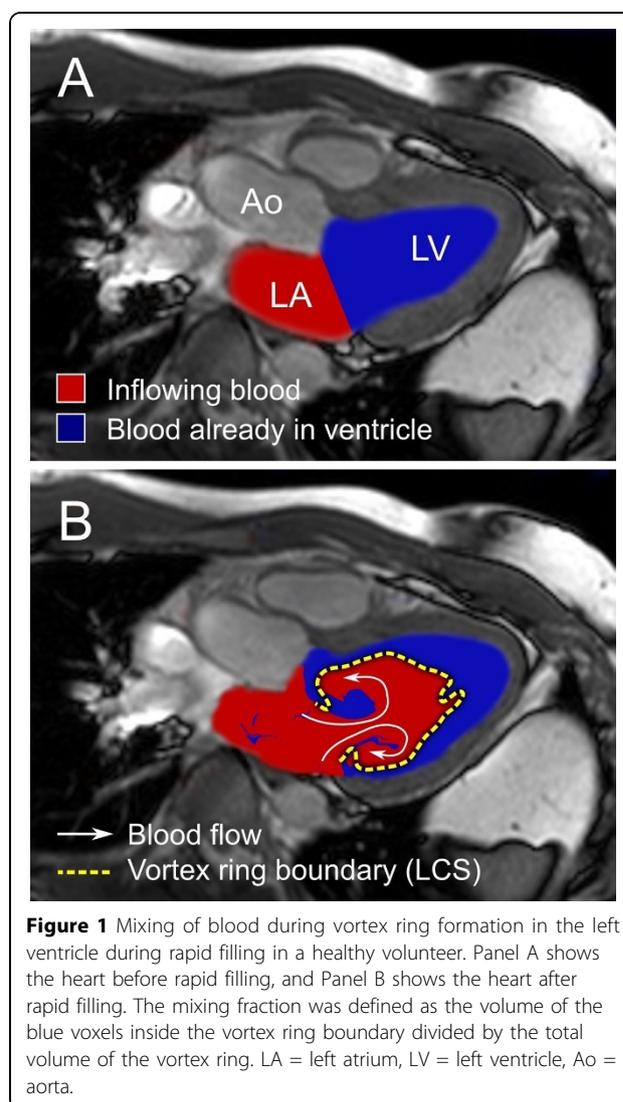
## Background

During rapid filling of the left ventricle, a vortex ring forms downstream from the mitral valve. Previous experiments in water tanks have shown that vortex ring formation is an optimized method for fluid transport. The rotation of the vortex ring leads to mixing of the inflowing blood and blood that was already in the ventricle (Figure 1). In water tanks, the amount of mixing decreases with increasing vortex formation ratio (VFR), a dimensionless parameter relating inflowing volume to the annulus diameter (Figure 2). However, the flow and anatomy of the left ventricle is more complex which may affect this established relationship. Therefore, we aimed to investigate if the relationship between VFR and mixing ratio demonstrated in water tank experiments holds in the human heart.

## Methods

Nine healthy volunteers and four patients with dilated ischemic cardiomyopathy underwent cardiovascular magnetic resonance including 4D PC-MRI. Particle tracing was used to track blood flowing into the left ventricle during rapid filling (Figure 1). Lagrangian Coherent Structures (LCS) were used to define the boundary of the vortex ring. The entrained volume was defined as the volume of blood from the ventricle (Figure 1, colored blue) inside the vortex ring (Figure 1B, yellow line). The mixing fraction was computed as the entrained volume divided by the total vortex ring volume. Differences between patients and healthy volunteers were tested using the Mann-Whitney U test.

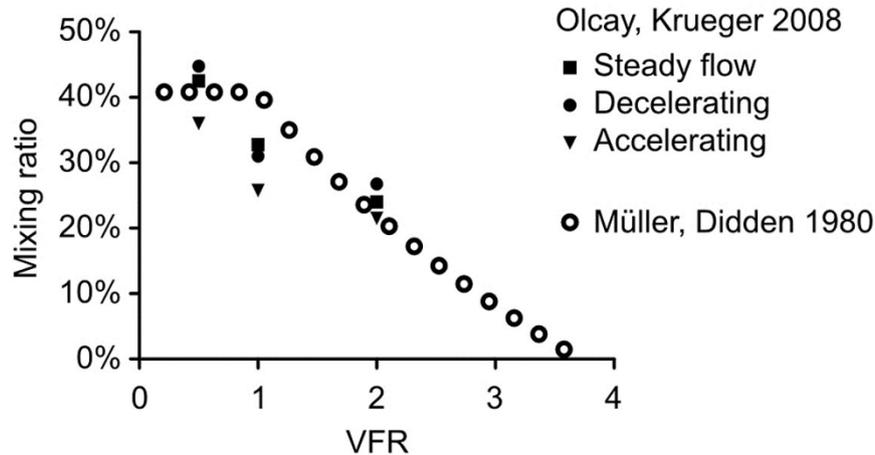
VFR was computed as follows: End-systolic volume (ESV) and the volume of the left ventricle at diastasis



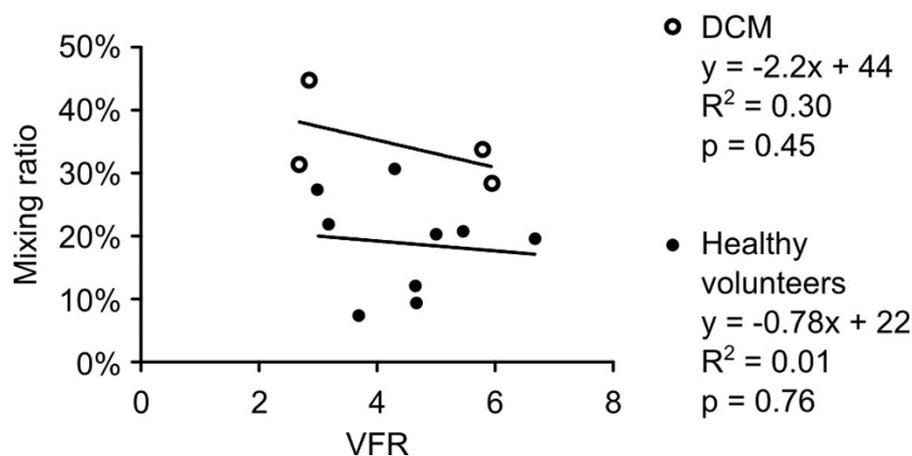
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### A: Previous studies - water tanks



### B: Present study - left ventricle



**Figure 2** Panel A shows the previous results from experiments in water tanks on the relationship between vortex formation ratio (VFR) and the mixing ratio. The previous studies found that the mixing ratio decreased with increasing VFR. Panel B shows the results from the current study. In contrast to the previous experiments in water tanks, there was no relationship between VFR and the mixing ratio in the left ventricle. Solid lines: linear regression for patients and healthy volunteers respectively.

(diastolic volume, DV) were measured by manual delineations in short-axis cine images. E-wave volume (EWV) was computed as  $DV - ESV$ . The diameter of the mitral valve  $D$  was measured as the average of the diameters in the three-chamber view and perpendicular to the three-chamber view in the short-axis view. VFR was computed as  $VFR = 4/\pi \times EWV/D^3$ .

#### Results

The mixing fraction was significantly higher in the patients compared to the volunteers ( $35 \pm 7\%$  vs.  $19 \pm 8\%$ ,

$p=0.006$ ). In contrast to previous studies in water tanks, there was no significant correlation between VFR and the mixing ratio in either group (Figure 2B).

#### Conclusions

We found a higher mixing ratio in the patients compared to the healthy volunteers. The absence of a significant correlation between VFR and mixing fraction suggests that vortex ring formation in the left ventricle of the human heart is subject to additional complexity and asymmetry compared to experimental studies in water tanks.

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