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Pulsatile Jet Characteristics of Mitral Regurgitation Flow Using Particle Image Velocimetry

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Cardiovascular diseases are a common cause of death worldwide. Mitral valve insufficiency, also referred to as mitral regurgitation, represents the second most prevalent valvular heart disease. This condition is characterized by a backflow from the left ventricle (heart chamber) into the left atrium during systolic phase of the cardiac cycle, resulting in a so-called regurgitation jet into the atrium of usually several millilitres per heartbeat. Clinical assessments of its severity and therapeutic decisions often rely on qualitative or semi-quantitative measures.

The present work therefore systematically compares and classifies the pulsatile jet flows originating from different regurgitation orifices using particle image velocimetry (PIV) in a controlled in-vitro environment[1]. Special emphasis is laid on the fluid mechanic structures of the pulsatile jet, like the role of the vena contracta, which leads to saddle-back velocity profiles[2], the strength and evolution of the starting vortex, and the instability mechanisms which might potentially lead to turbulent regions. Circular orifice shapes with diameters ranging from 5 to 12 mm are systematically compared.

The investigation of the flow is conducted with an *ILA.PIV.sCMOS* camera (16 bit dynamic range, 6.5 µm pixel size) equipped with a 50 mm *Zeiss Makro Planar* lens, yielding a magnification factor of $M = 0.2$ (reproduction scale $s^{xy} = 33.3$ µm/px; FOV size: 85×72 mm^2). Illumination was provided by a double-pulsed *Quantel Evergreen* Nd:YAG laser (210 mJ, $\lambda = 532$ nm, maximum repetition rate: 15 Hz) with a pulse width of 80 µs.

Figure 1 illustrates the experimental setup, including the optical arrangement and camera positioning. Figure 2 shows the instantaneous velocity field for the 12 mm orifice as vector plot for a time instance, where the jet almost covers the entire atrium (normalised time $t^* = 0.327$). The underlying colour depicts the occurring vortical structures by means of the Q criterion, where positive values, coloured in red, illustrate regions with high rotation, while negative values, coloured in blue, show regions with high strain. The orifice of the regurgitation jet is located on the left at $x = 0$. Interestingly, Kelvin-Helmholtz instabilities

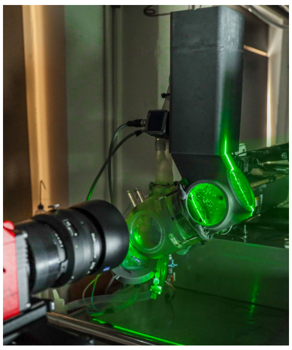

Figure 1: Experimental test facility with optical setup

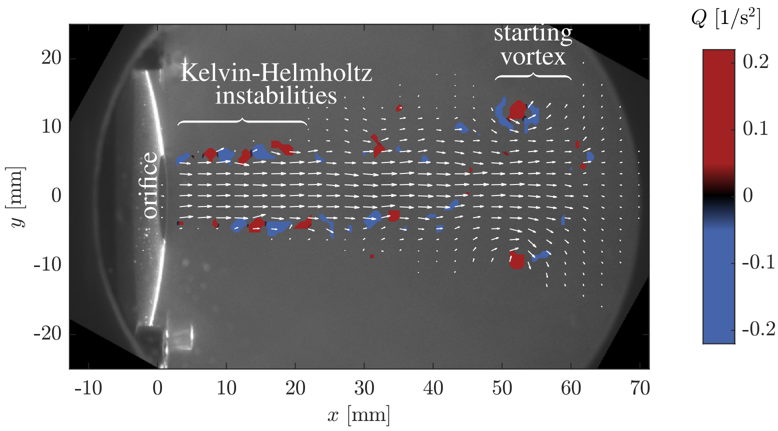

Figure 2: Flow field of the regurgitation jet at $t = 245$ ms with underlying vortex Q criterion highlighting vortical structures (adapted from [2])

observed at the jet boundaries are weakly-pronounced as coherent structures and dissipate approximately 20 mm downstream from the orifice. We aim to discuss the influence of individual fluid mechanical phenomena in the context of existing literature and explore potential interactions between identified structures. Insights gained from this investigation aim to enhance the understanding of mitral regurgitation flows and inform their application in clinical practice.

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[1]Karl et al., *Int J CARS*, **15** 411–421 (2024) **DOI**: 10.1007/s11548-023-03036-4
[2]Leister and Karl et al., *Cardiovasc Eng Tech*, (2025) **DOI**: 10.1007/s13239-024-00763-w