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Experimental Investigation of the Flow Dynamics in a Left Ventricle during a Blunt Chest Trauma

Dorian Sweidy[a, b*], Kowsar Teimouri[c], Wael Saleh[c], Ghassan Maraouch[c], Lyes Kadem[c], Morgane Evin[a, b]

a Laboratoire de Biomécanique Appliquée, Marseille, France
b Gustave Eiffel University, France
c Laboratory of Cardiovascular Fluid Dynamics, Montreal, Canada
* Corresponding author: dorian.sweidy@univ-eiffel.fr

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1. Introduction

Blunt trauma is a significant complication arising from high-speed Motor Vehicle Crashes (MVCs). It often leads to a wide spectrum of injuries with varying severity and emergency state (Pruitt & Titus, 2007). Cardiac injuries following Blunt Chest Trauma (BCT) can range from minor myocardial contusions, occurring in an estimated 16 % to 76 % of MVC (Tochii et al., 2022), to life-threatening cardiac ruptures (Verma et al., 2018). With its higher ventricular pressure compared to the right one, the left ventricle (LV) could be prone to more damage in some accidents (Tochii et al., 2022). However, investigations into ventricular and blood flow responses during BCT remain relatively scarce, and the approaches are limited by the impossibility to measure the blood flow, or to reproduce the hemodynamic conditions of the patient or to get the real behavior of living tissues. The objective of this study is to develop an in vitro cardiac simulator of the left heart subjected to a direct compression and to explore the flow dynamics using time-resolved Particle Image Velocimetry (PIV).

2. Methods

2.1 The experimental simulator

The setup consists of a left heart simulator, combining elastic silicone models of the left atrium, the left ventricle and the aorta. The silicone used for the ventricle is optically transparent and compatible with PIV measurements. It was applied manually layer by layer on a 3D-printed LV model to reach the desired thickness (1.5 mm ± 0.5 mm). The mitral valve and the aortic valve used were both bioprosthetic valves with a diameter of 23 mm and 25 mm respectively. The working fluid was a mixture of distilled water and glycerol (60-40% by volume) with a dynamic viscosity (4.2 cP) and a density (1100 kg/m^3) relatively similar to the blood's characteristics. The higher compartment of the box contained the left atrium, passively filled by an upper container linked to the four pulmonary veins. The lower compartment encased the LV in a hydraulic chamber filled with the same fluid to minimize the optical distortion. A plexiglass wall was added at the back of the ventricle to limit its motion after the impact, simulating the presence of the spine (Figure 1.a).

2.2 The activation system

A piston-cylinder assembly activated the contraction and relaxation of the ventricle, through an electromagnetically driven precision linear motor (Di Labbio et al., 2018). Two syringes of 10 mL each were inserted perpendicularly to the lower compartment's wall, linked from one side to a 3D printed impactor facing the LV, and from the other side to another linear motor inducing a 150 ms impact at 0.4 m/s. The velocity did not replicate real crash scenarios but presented a feasibility study to simulate such incidences. The flow inside the circulatory system was seeded with polyamide particles with a 50 µm mean diameter. A double-pulsed Nd:YLF laser illuminated the particles in

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a plane formed between the center of the apex and the center of the valves. A high-speed camera captured the LV flow domain with double-framed images. The recording rate was 200 Hz and the frames were 2500 µs apart. With the hypothesis of the post-traumatic ventricular septal defect occurring during end-diastole or iso-volumetric systole (Pruitt & Titus, 2007; Tochii et al., 2022), where both mitral and aortic valves are closed and the ventricle starts to contract, the impact was programmed to occur right before the systole of the second cycle.

2.3 Post-processing

Data was filtered using the Proper Orthogonal Decomposition (POD). Five modes were selected.

3. Results and discussion

The results compared the flow dynamics during three consecutive cycles: the pre-impact cycle, the impact cycle and the post-impact cycle. Velocity vectors inside the LV translated a healthy intraventricular vortex before the impact and after it (Pedrizzetti & Domenichini, 2005). At the moment of the impact, the vortex was lost and the vortex center got dispatched (Figure 1.b). Two rectangular zones delimited the mitral and aortic blood flow inside the LV. For the three cycles, the mitral blood flow velocity values remained identical with an average peak of 0.45 m/s (± 0.05 m/s). These values reflect the physiological flow values in a normal state (Di Labbio et al., 2018). The aortic blood flow velocity tremendously increased at the moment of impact, reaching a peak 2.5 times higher than the other peaks in both cycles and the normal state. As for the vortex formation, Lambda 2 values replicated an uncommon vortex during the impact cycle compared to the pre- and post-impact cycles. The combination of anterior and posterior forces applied to the thorax would cause several damages to the tissue and flow (Pruitt & Titus, 2007). Disrupted fluid dynamics inside the LV with the increasing pressure during impact could be the reason behind a ventricular septal defect (Tochii et al., 2022).

4. Conclusions

This study simulates and shows the effect of an acute cardiac compression during a blunt chest trauma on the flow dynamics inside a model of a left ventricle. This represents an important step toward a better understanding of the causes that might lead to some cardiac injuries during car crashes.

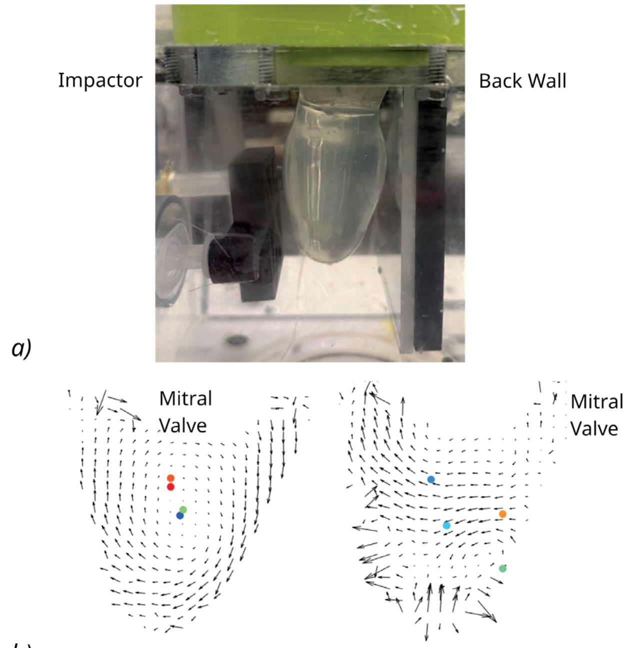

Figure 1. (a) Left ventricle model inside the box with the impact simulator and the back wall (b) Blood flow velocity vectors and vortex centers inside the LV during the systole of the pre-impact cycle (left) and impact cycle (right).

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Conflict of Interest Statement

The authors report no conflict of interest for this project.

Contributor Roles

DS: Conceptualization, Methodology, Experimental design, Data analysis, Writing original draft, Funding acquisition; KT: Conceptualization, Experimental design; WS: Conceptualization, Experimental design; GM: Conceptualization, Data analysis; LK: Conceptualization, Supervision, Writing- review & editing; ME: Conceptualization, Validation, Data analysis, Supervision, Writing- review & editing, Funding acquisition.

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Data, software, code availability

https://github.com/dilabbiog/matfluids

References

Di Labbio, G., Vétel, J., & Kadem, L. (2018). Material transport in the left ventricle with aortic valve regurgitation. *Physical Review Fluids*, *3*(11), 113101. https://doi.org/10.1103/PhysRevFluids.3.113101

Pedrizzetti, G., & Domenichini, F. (2005). Nature optimizes the swirling flow in the human left ventricle. *Physical Review Letters*, *95*(10), 108101. https://doi.org/10.1103/PhysRevLett.95.108101

Pruitt, C. M., & Titus, M. O. (2007). Ventricular septal defect secondary to a unique mechanism of blunt trauma: A case report. *Pediatric Emergency Care*, *23*(1), 31–32. https://doi.org/10.1097/PEC.0b013e31802c61c3

Tochii, M., Watanuki, H., Sugiyama, K., Futamura, Y., Ishikawa, H., & Matsuyama, K. (2022). Ventricular septal rupture after blunt chest trauma: A case report. *Surgical Case Reports*, *8*(1), 94. https://doi.org/10.1186/s40792-022-01448-z

Verma, K., Mukherjee, S., Gaur, P., Chawla, A., Malhotra, R., & Lalwani, S. (2018). High strain rate compressive behaviour of human heart. *International Journal of Experimental and Computational Biomechanics*, *4*(2/3), 152. https://doi.org/10.1504/IJECB.2018.092276