Transition to turbulence of pulsatile flow in flexible pipes

T. Zeugin[ab], D. Morón[c], M. Avila[c] and M. Holzner[bd]

The presence of irregular flows and turbulence in the blood flow has been linked to various cardiovascular diseases. Nevertheless, *in vivo* and *in vitro* experiments have demonstrated that turbulence and complex flow patterns may also occur in healthy aortic conditions[1]. Investigating the root of turbulent blood flows is inherently difficult due to the complex nature of cardiovascular flows as they are governed by Reynolds number, Womersley number as well as pulsation amplitude and further impacted by complex geometries and fluid structure interactions. Recently, big strides have been made towards understanding the transition to turbulence of pulsatile flows in the simplified case of straight, rigid pipes[2,3]. In this work, we now study the onset of turbulence of pulsatile flows in a straight, flexible pipe segment experimentally. Leveraging highly sensitive pressure measurements for turbulence detection, we map out the parameter space where instabilities and turbulence occur. Further, we elucidate the different transition scenarios using optical velocimetry measurements. This study marks the first effort to systematically investigate the transition to turbulence of pulsatile flows in flexible vessels and thus contributes to our understanding of irregular cardiovascular flows.

---

[a] Institute of Environmental Engineering, Dept. of Civil, Environmental and Geomatic Engineering, ETH Zürich, Zürich, Switzerland

[b] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland

[c] Center of Applied Space Technology & Microgravity ZARM, University Bremen, Bremen, Germany

[d] Swiss Federal Institute for Water Science and Technology EAWAG, Dübendorf, Switzerland

[1] Ha et al., *Front. Physiol.* **9**, 36 (2018).

[2] Xu et al., *PNAS.* **117**, 11233 (2020).

[3] Morón et al., *JFM.* **948**, A20 (2022).

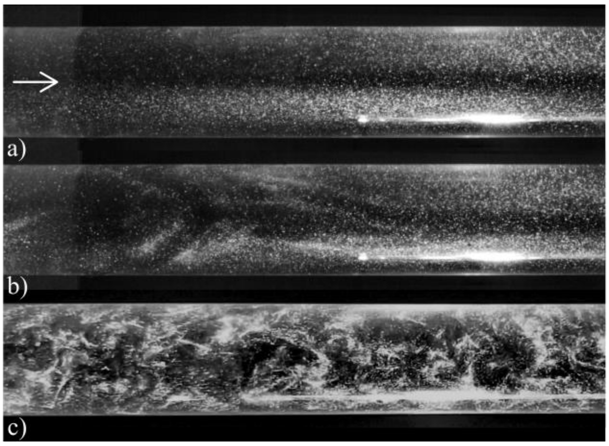

Figure 1: Flow patterns of pulsatile flow immediately downstream of a flexible pipe segment at the same time instance of the pulse showing a) laminar flow (Re = 700, Wo = 2.5), b) helical instability (Re = 900, Wo = 7) and c) fully developed turbulence (Re = 1300, Wo = 12).