Electro-mechanical control of Plateau-Rayleigh instability for homogenous multi-cellular production

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In the BioImaging & Optofluidics team we have developed a micro-fluidic encapsulation technique enabling high-throughput production of multi-cellular systems. These assemblies, such as organoids that recapitulate certain organ functions, are of great interest and have numerous applications in fields such as tissue engineering, oncology and regenerative medicine [1]. The encapsulation technique is based on Rayleigh-Plateau instability that explains how a falling stream of fluid breaks up into smaller droplets with the same volume but reduced surface area [2]. In our configuration, our system typically produces droplets of around 300-500 µm in diameter at a rate of 5000 capsules per second. Yet, without external control of the instability several modes develop and coalescence occurs. The resulting diameter distribution is relatively broad.
As we are seeking to achieve homogenous aggregate production for biological applications, it is pivotal to control the fragmentation of the jet with an external excitation.

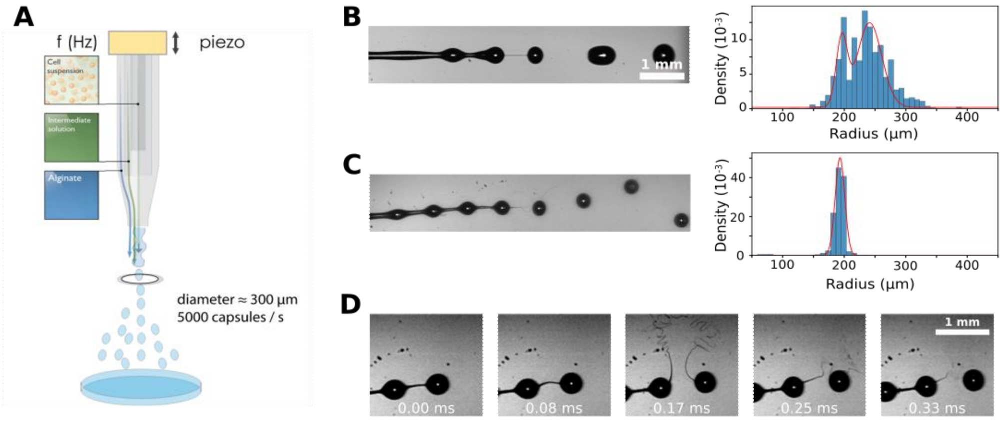

Figure 1: (A) Sketch of the microfluidic encapsulation system. (B)Image of the instability without external excitation and the resulting droplet diameter distribution. (C) Same as (B) but with a piezoelectric excitation at 1500 Hz and a voltage of 5000V. (D) Whipping instability in the filament connecting the drops due to the application of a 5000V voltage.

In the past, several strategies had been developed to perform an external control of the Plateau-Rayleigh instability including electric field, acoustic waves or mechanical vibrations [3]. We show that the simultaneous use of a piezoelectric actuator and the application of voltage to the jet results in various phenomena, such as reduced coalescence between drops, the formation of small satellite drops, and the onset of whipping instability. We demonstrate that a judicious choice of the excitation frequency-voltage combination (f, V) enables the production of uniform drops and capsules over a wide range of radii (150 - 250 µm) using the same injector. Employing a fixed voltage value, as commonly practiced, would only provide access to a limited range of radii. The composite nature of our jet and the necessity to form capsules that retain the core-shell structure present an additional challenge. This must be overcome through appropriate selection of voltage and other experimental parameters, such as the flow rate ratio of the core and shell fluids.

[1] Alessandri, et al. (2013). *Proceedings of the National Academy of Sciences*, *110*(37), 14843-14848.
[2] Eggers, J. (1997). *Reviews of modern physics*, *69*(3), 865.
[3] Doméjean, H. (2014). (Doctoral dissertation, Paris 6).