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Investigation of impact dynamics of ionically crosslinking hydrogel droplets in mist-based 3D bioprinting systems

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1. ABSTRACT

3D bioprinting is a method of deposition of biomaterials and cells (bioinks) according to a computer design and has a wide range of applications, including tissue engineering and drug delivery. Among different deposition mechanisms, droplet-based bioprinting method provides a high level of versatility and control over the deposition of bioinks. However, printing ionically crosslinking hydrogels is challenging using the droplet-based printheads as the crosslinked hydrogel is too viscous. Previous studies have shown that printing in a crosslinker bath or using co-flow of crosslinker can address this issue. Our group has recently shown that introducing the crosslinker in mist form, and more importantly, removing the mist within the printhead is an excellent approach to crosslink the hydrogel droplets while printing. The dynamics of a droplet spreading after exposure to mist is an important factor in achieving high shape fidelity of printed constructs and must further be investigated.

In this study, the spreading factor of ionically crosslinking bioink droplets dispensed from a droplet-base bioprinter was investigated experimentally. The effects of exposure to and removal of the mist on spreading factor was investigated for hydrophobic and hydrophilic surfaces. Sodium alginate droplets of 2% w/v solution was printed using a 3D bioprinter (Cellink, BioX) with and without a custom-made mist-based printhead. Calcium chloride ($CaCl_2$) solution (10%-40% w/v) was atomized and delivered to the hydrogel droplets as crosslinker, and it was collected within the printhead using a vacuum pump. A hydrophobic printbed with a contact angle of 95° and a hydrophilic printbed with a contact angle of 17° was used in this study. High speed imaging (at 40 kfps) was used to study droplet impact on the printbed.

It was observed that introduction of mist decreases the spreading factor over time due to crosslinking of hydrogel and the consequent increase in the viscosity. Therefore, the degree of crosslinking has a significant impact on droplet spreading. This was further confirmed as the use of 40% mist solution led to a 12% decrease in spreading factor as compared to using 10% mist solution. Moreover, it was observed that the droplet impact velocity has a significant effect on the spreading factor: increasing the impact speed from 2.6 m/s to 4.8 m/s led to a 45% increase in spreading factor. Finally, it was observed that the surface properties play an important role in the spreading of droplets: droplets show lower spreading factor on hydrophobic surfaces as compared to hydrophilic surfaces. Fluctuation and bouncing of droplets that were observed on hydrophilic surfaces were damped faster using mist. Overall, this study enhances the fundamental understanding of the parameters affecting the droplet spreading and shape fidelity of bioprinted constructs for a wide range of applications.