

The Research on Biosynsphere Damage Analysis Based on 3D Vessel Bioprinter

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Keywords: Biosynsphere, Cell encapsulation, Mechanical properties, 3D vessel bioprinter.

Abstract. 3D bioprinter is an emerging interdisciplinary technology, which offers a new plan not only for the functional materials, (droplets, drug delivery, organ regeneration, tissue engineering), but also for the new artificial vessel called 3D vessel bioprinter. In this paper, we developed a theoretical proposal to analyze the biosynsphere mechanical propertie under the multilayer fluid based on the 3D bioprinter, further analyze the broken mechanism to verify the theoretical. Our investigation shows that the outer fluid and inner fluid have difference effect on droplet, with the increase pressure of outer fluid, the force of droplet becomes greater, which revealed that the better pressure plays an important role in protecting the droplet.

1. Introduction

3D bioprinter is an emerging interdisciplinary technology, which offers a new plan not only for the functional materials, (droplets, drug delivery, organ regeneration, tissue engineering), but also for the new artificial vessel called 3D vessel bioprinter.[1-3]

In the past few years, 3D vessel bioprinter has attracted extensive attentions due to its application in artificial blood vessel, the functional blood vessel can be produced in such bioprinter system under certain conditions, the formation of droplets with micro-fluidic has been widely investigated due to the application of drag delivery, organ regeneration, tissue engineering,[4] many devices with the different generating mechanism have were demanded. For example, Sujin Yeom et al.[15] show that the droplets form process in the T-junction through numerical simulation and analysis, and predicted size of drops formed by dripping at a micro T-junction. a new cross-junction microfluidic device was revealed by J. Tan et al.[17], this method can realize the controllable preparation of monodisperse O/W and W/O emulsions, the size of droplets arraied from 300 to 1800um, the mechanism droplets formation is because of the equilibrium between shear force of the continuous flow and interfacial tension; furthermore, to predict equation of the droplet length and prove the agreement between theoretical and experimental results. A microfluidic axisymmetric flow-focusing device was created by shoji takeuchi et al. [19], which could produce polymer-coated droplets with the more narrow size distributions.

The biosynsphere called droplet was a kind of particles formed by encapsulation material, and the gel like shell was a porous material, which aimed to entrap viable cells in the biosynsphere, it could realize the absorption of nutrients, oxygen and waste discharge.

It is well known that the cell activity plays an important role in the formation of vessel, the effectively measures were adopted to maintain cell activity; cell encapsulation is a new technology, which can control the fluids to realize accurate cell separation, with the increased technology development, a variety of cell encapsulation were adopted for experimental research such as T-junction, cross-junction, flow focusing, etc.

Recently, many attentions were paid on micro-device for the formation of droplets, S et al.[15] show that the droplets form process in the T-junction through numerical simulation and analysis, and predicted size of drops formed by dripping at a micro T-junction; Boruah, N. et al. [18]reported the study to simulate motion and deformation of droplets in a microfluidic cross-junction and highlight the three-dimensional effects of the asymmetric micro- fluidic geometry on the droplet deformation

and the dramatically different effects of the fluids viscosity ratio on the droplet's overall length scales and the local length scales at the droplet edges; Y. et al. [21] in flow-focusing microfluidic device by CFD simulation with VOF method, Found that the effect of the flow rate of the outer fluid is greater than middle fluid for the droplet formation mode as well as the generated droplet size, and the interfacial tension ratio shows greater influence on interface shapes of droplet than the droplet sizes, However, there has been little research on theoretical analysis of the droplets mechanical properties.

In this paper, we firstly presented a novel nozzle for fabricating the artificial vessel. Next, we summarized a theoretical proposal to analyzed the mechanical properties of the biosynsphere in the fluid. Nevertheless, we intended to simulate the force state of biosynsphere in the process of fluid flow, Based on the theory of biological print nozzle, further analysis and verification of the damage mechanism of the biosynsphere.

2. Design and fabrication

In order to analyze the mechanical properties, we designed the 3D vessel bioprinter nozzle, which is roughly compose of Inner cylinder, outer cylinder, joint, sealing ring etc, as shown in Fig. 1. The outer cylinder and the inner cylinder can meet the positioning requirement of the coaxial degree through the clearance fit between the outer cylinder and the inner cylinder. The fixing plate plays the role of fixing the inner cylinder, the sealing ring prevents the fluid from escaping, and the diameter can be changed by changing the inner cylinder.



Fig. 1. 3D bioprinter nozzle

In this experiment, the diameter of biosynsphere is 200um, which is obtained through the micro capsule granulation instrument b-395pro, and the particle size range of the equipment is 0.15-2mm. the fluids velocity in the cylinder and the outer cylinder are controlled by the corresponding pneumatic device. In the propose test, the inner pressure is kept in 0.2MPa, the pressure of the outlet cylinder is set to 0.2, 0.3, 0.4, 0.5, 0.6, 0.7MPa.

The Coaxial device fixed inner tubes which can be changed, the continuous phase1 fluid flow inside the inner tube, and continuous phase2 fluid flow between the inner and outer tubes. These fluids flow separately until they reach the end of the inner tube, which is the biosynsphere force area.

3. Theory

Fig .2 shows schematic diagram of the fluid velocity in the channel, in which R_1 , R_2 , L , a , respectively denote the diameter of the inner channel, the diameter of the outer channel, the length of the force region, the radius of biosynsphere. Biosynsphere flows through inner channel, external package materials under pressure from outside of the pipe extrusion under different pressure, Bio-brick in from internal pipe extrusion, and external package materials under pressure from outside

of the pipe extrusion, in this case, inner and external fluid will simultaneously produce the biosynsphere pressure, shear force, and so on.

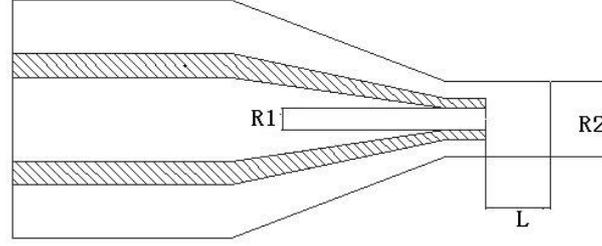


Fig. 2 3D bioprinter nozzle

In the propose device, Fig .2 shows the velocity profile of fluid motion in the channel, the fluid itself has a viscosity, there is a certain relationship between the change of speed, the speed relationship is calculated by the following equations:

$$V_x(y, z) = \frac{\Delta p}{4\eta L} (a^2 - z^2 - y^2) \quad (1)$$

Where, $V_x(y, z)$ denotes the velocity of each point in the circular area, a denotes the biosynsphere diameter, Δp is inlet and outlet pressure difference, L is length of force area. η is viscosity of fluid, fluid shear thinning did not occur, the viscosity was not changed.

The drag force applied to the biosynsphere surface exposed to the continuous phase in inner channel can be given as

$$F_{drag1} = 6\pi\eta a(v-u) \quad (2)$$

Where v is initial velocity, u is outlet velocity. The drag force applied to the biosynsphere surface exposed to the continuous phase in external channel can be given as[9]

$$F_{drag2} = \frac{6uaQ}{C} [(a^2 + A - B - A \ln a) \cos \theta_0 - \frac{a^2}{3} \cos^3 \theta_0 - A \cos \theta_0 \ln(\sin \theta_0) - \frac{A}{2} \ln(\frac{1 - \cos \theta_0}{1 + \cos \theta_0})] \quad (3)$$

$$\frac{a^2}{3} \cos^3 \theta_0 - A \cos \theta_0 \ln(\sin \theta_0) - \frac{A}{2} \ln(\frac{1 - \cos \theta_0}{1 + \cos \theta_0})]$$

$$F_{drag3} = \frac{6uaQ}{R_1^4} (R_1^2 - \frac{2}{3} a^2) \quad (4)$$

$$F_{drag} = \eta(F_{drag1} + F_{drag2} + F_{drag3}) \quad (5)$$

Substituting Eqs. (2)-(4) into Eq.(5), we will finally obtain the equation, which can predicted the biosynsphere force.

4. Simulation procedure

In order to research the droplets force in the fluid and analyze cell, we simulated the situation of droplets by fluent, in this case, the droplets in the inner tube was squeezed out under the pressure of 0.2Mpa, meanwhile, the bio-material was squeezed out under the pressure of 0.2,0.3,0.4,0.5,0.6,0.7Mpa, we can draw the regulation of the destiny between inner fluid and outer fluid, as shown in the Fig. 4.

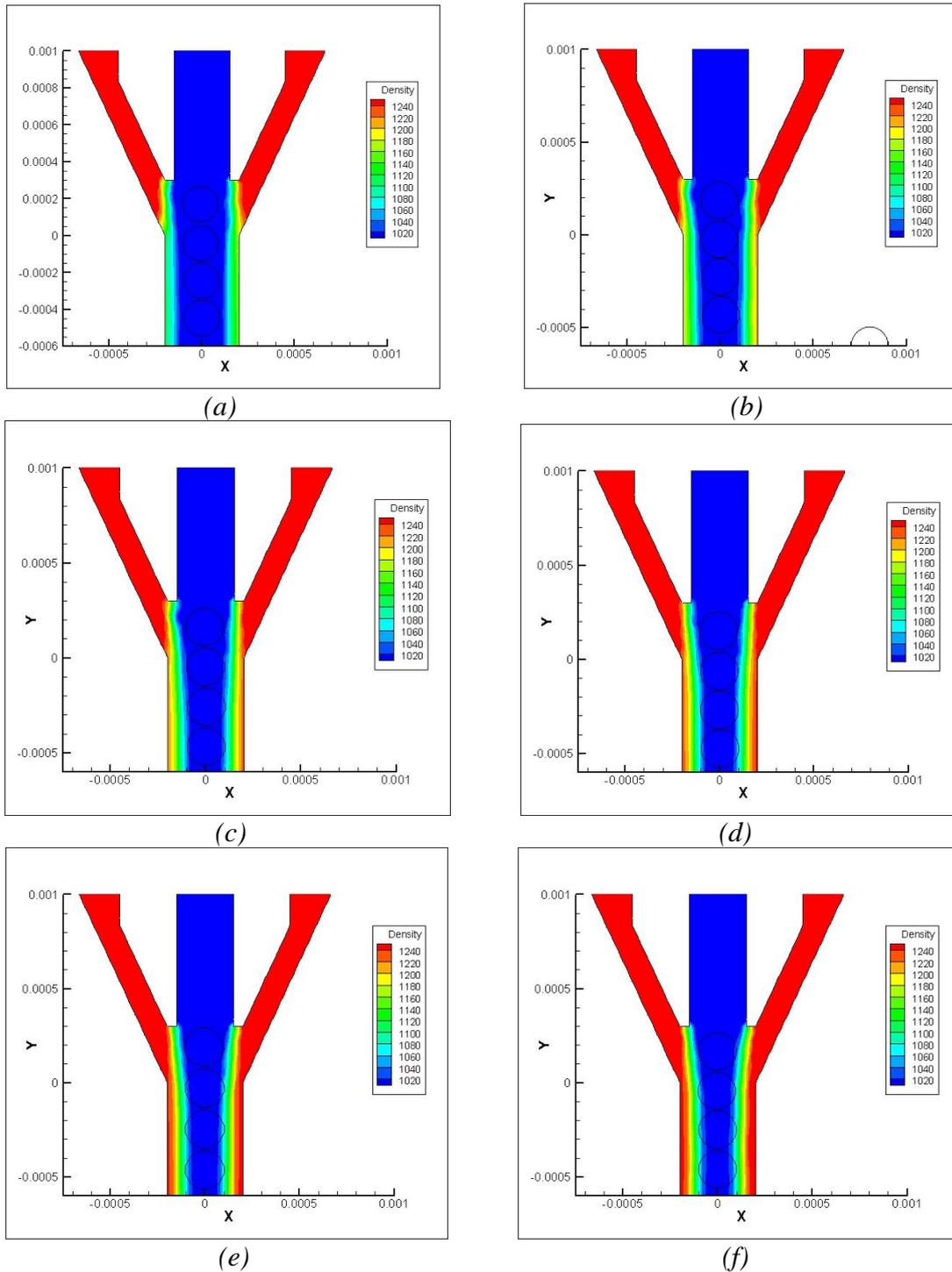


Fig .5 The regulation of destiny between inner fluid and outer fluid under the pressure of 0.2,0.3,0.4,0.5,0.6,0.7Mpa

From the fig. 5, we can draw a conclusion that when the pressure difference between inner fluid and out fluid was little, the force of droplets known as F_{drag} was mainly caused by the inner fluid, with the increasing of pressure, the influence of outer fluid played an important role in the inner fluid, biosynspheres appear large deformation, which lead to Cells' activity decreased.

5. Conclusion

In a word, we designed the 3D biprinter nozzle, which is used as the coaxial model for theoretical analysis, the propose device mainly include two parts to construct the 3D coaxial structure, several simulation procedures were conducted to verity the biosynsphere force under the various conditions. The simulation results shown that the force of biosynsphere become greater with the increase of

pressure, the pressure of outer fluid played an integral role in protecting biosynsphere from damage, which indicated that the biosynsphere mechanical in the coaxial model can be predicted by theoretical analysis, the effect of pressure for biosynsphere can be simulated through the regulation of destiny between inner fluid and outer fluid.

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