Spreading performance in 3D printed scaffolds for bone tissue engineering

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Introduction and Aims

The potential to grow cells in vitro could drastically expand the horizons of regenerative medicine, as more tissues and potentially organs would be available. The aim of this study is to first produce a porous scaffold with precise pore morphologies via computer aided design (CAD) and 3D printing technology, and to then subject these scaffolds to spreading tests. As well as this the scaffolds will have parameters such as porosity measured, via using a pycnometer, scanning electronic microscopy (SEM) image processing and calculated based on the design parameters. Permeability is measured by KRUSS Drop shape analyser and precise measurements for pore diameters and scaffold thickness are completed with image J. The uniform regularity of the scaffolds produced will accurately allow for interactions with cell culture medium.

Materials and Methods

1. CAD scaffold design

Various scaffolds were designed using the software Siemens NX® (Siemens, UK). First, the scaffold was specified in the programme, with dimensions of 10 mm x 10 mm and thicknesses between 0.5 mm – 2 mm. The pattern feature is shown in table 1.

Table 1 the physical properties of the produced porous scaffolds 3D printing

<table>
<thead>
<tr>
<th>Scaffolds No.</th>
<th>Scaffolds thickness (mm)</th>
<th>Pore diameter/length (mm)</th>
<th>Distance between pores (mm)</th>
<th>Pore shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>Circle</td>
</tr>
<tr>
<td>S2</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
<td>Circle</td>
</tr>
<tr>
<td>S3</td>
<td>0.50</td>
<td>0.50</td>
<td>2.00</td>
<td>Circle</td>
</tr>
<tr>
<td>S4</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>Circle</td>
</tr>
<tr>
<td>S5</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>Circle</td>
</tr>
<tr>
<td>S6</td>
<td>1.00</td>
<td>0.50</td>
<td>2.00</td>
<td>Circle</td>
</tr>
<tr>
<td>S7</td>
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<td>1.00</td>
<td>Circle</td>
</tr>
<tr>
<td>S8</td>
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<td>1.00</td>
<td>Circle</td>
</tr>
<tr>
<td>S9</td>
<td>0.39</td>
<td>0.50</td>
<td>1.00</td>
<td>Square</td>
</tr>
<tr>
<td>S10</td>
<td>0.78</td>
<td>0.50</td>
<td>1.00</td>
<td>Square</td>
</tr>
</tbody>
</table>

2. Porosity measurements

The porosity is measured using a pycnometer method, image processing and calculation based on design parameters. Pycnometer method is based on equation 1.

\[ \varepsilon = \frac{m_1 - m_2}{\rho_w} \]

where:
- \( m_1 \) - the mass of the water solution
- \( m_2 \) - the mass of the water solution and scaffold
- \( \rho_w \) - the density of water.

Image processing was done by uploading SEM images to the prepared MATLAB® file® to calculate what areas of the scaffold were porous or not. The porosity of the scaffolds was also calculated from the design specifications based on equation 2.

\[ \varepsilon = \frac{V_p}{V_s} \]

where:
- \( V_p \) - the volume of the designed scaffold with completely unblocked pores all with equal, constant diameters
- \( V_s \) - the total volume of the scaffold block without any pores.

3. Spreading experiments

KRUSS DSA100 drop shape analyzer is used to monitor the water (as reference) and CCM spreading process on the 3D printed scaffolds surface. 10 ul water/CCM drop is placed on the scaffold surface by pipette. The time evolution of volume of CCM and water droplets were recorded and calculated using the recorded images. The camera would record as the CCM or water droplet touched the scaffold and finished recording after the spreading had completed, or after a period of 30 minutes.

Results and Discussion

Figure 1 reveals that scaffolds made with pores of 0.5 mm in diameter were often blocked with support material, which subsequently affected porosity and spreading characteristics. Data in table 2 also suggests that dimensions specified on CAD are smaller after fabrication and cooling.

![Figure 1](image.png)

In this work, scaffolds have been designed using a CAD package and 3D printing. These scaffolds have undergone testing of physical properties such as pore size, thickness and porosity. As well as this, spreading behaviour of CCM on these porous scaffolds has been analysed. Pores of 0.5 mm in diameter and less, become blocked by the support material used in 3D printing, which usually results in lower porosity values than expected. The spreading experiments show that spreading occurs much quicker with scaffolds that have larger pores, than the scaffolds with smaller pores. Furthermore, due to multi-components in CCM, it shows better wettabillity than water.

Conclusions

In this study, scaffolds have been designed using a CAD package and 3D printing. These scaffolds have undergone testing of physical properties such as pore size, thickness and porosity. As well as this, spreading behaviour of CCM on these porous scaffolds has been analysed. Pores of 0.5 mm in diameter and less, become blocked by the support material used in 3D printing, which usually results in lower porosity values than expected. The spreading experiments show that spreading occurs much quicker with scaffolds that have larger pores, than the scaffolds with smaller pores. Furthermore, due to multi-components in CCM, it shows better wettabillity than water.

Reference: