Measuring Porosity (Millimetre to Nanometre scale)

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Porosity and pore types

Open

Closed

Blind-end
The role of closed/open pores

<table>
<thead>
<tr>
<th>Open Pores</th>
<th>Closed Pores</th>
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<td>Cell ingress</td>
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<td>Nutrient supply/waste removal</td>
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<td>Mechanical performance</td>
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<td>Degradation behaviour</td>
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<td>Gas diffusion</td>
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Interconnectivity

Blind-end

Open

Closed
Different structures with the same porosity
Porosity and scaffold performance

- Porosity
- Pore geometry
- Permeability
- Open pore interconnectivity
- Open/Close

%
What is porosity?

- 80 definitions in ASTM terminology (some duplicates!!)
- Holes in a solid, not necessarily connected. (Standard: E7)
- That portion of a membrane filter volume which is open to fluid flow, also known as void volume. (D6161 Standard: D1129)
- Percentage of the total volume of a material occupied by both open and closed pores. ([D02.F0] C709 Standard: D4175)
Porosity and length scale

- Size of pores
- No of pores

Cell conduits?

‘Service’ conduits?
Porosity linked to resolution of technique
Porosity in a cell-seeded scaffold?

- In the absence of cells?
- In the presence of cells?
Links with pore volume?

~30\(\mu\text{m}\)
## Techniques for obtaining a porosity value

<table>
<thead>
<tr>
<th>Method</th>
<th>Closed Pores</th>
<th>Open Pores</th>
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<td>Mercury Porosimetry</td>
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<td>Density Measurements</td>
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<td>Gas Flow Porometry</td>
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<td>Permeability</td>
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<td>- X-ray Micro-CT</td>
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<td>- Confocal</td>
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Fibrin Gel (slush nitrogen/freeze dryer)
How is porosity reported?

- As a percentage e.g. 42.2%, often with no standard deviation and coupled with an average pore diameter e.g. 161.5 μm.

- “in which the pores are so open that it is difficult to distinguish what can be considered a pore from what is actually a pore window” Renghini et al. (J. Eur. Cer. Soc. 33 (2013) 1553)

- “….the total pores content assessed by micro_CT analysis is lower than that evaluated by weight-volume measurements …” Renghini et al. (J. Eur. Cer. Soc. 33 (2013) 1553)
Question

- What needs to be done to improve the practical use of a measured porosity?
Enhancing the value of the metric

- Identify one or more preferred methods that can be used for >95% of scaffolds
- Encourage investigators to report open and closed porosity where possible
- Encourage investigators to report range of length scales over which porosity has been determined
- Encourage reporting of pore size distributions (and volumes?)
- Evaluate the role that sub-micrometre pores have on scaffold performance
Thank you for your attention