Additively manufactured implants with multifunctional surfaces

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Aging happily...

• Thanks to an orthopaedic implant
Additively manufactured implants

- Customised implants
- Enhanced porosity and surface area
Implant-associated infection

- Bacteria form biofilm and infect surrounding tissue
- 1-2% of implants become infected
Implant-associated infection

- 1-2% of implants become infected

Aseptic loosening

**TABLE** REASONS FOR REVISION OR RE-SURGERY IN PATIENTS WHO UNDERWENT A HIP REVISION ARTHROPLASTY IN THE NETHERLANDS IN 2016 (N=3,836).

<table>
<thead>
<tr>
<th>Reasons for revision</th>
<th>Proportion¹ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loosening of acetabulum component</td>
<td>22.4</td>
</tr>
<tr>
<td>Dislocation</td>
<td>19.3</td>
</tr>
<tr>
<td>Infection</td>
<td>19.3</td>
</tr>
<tr>
<td>Loosening of femur component</td>
<td>18.7</td>
</tr>
<tr>
<td>Inlay wear</td>
<td>18.5</td>
</tr>
<tr>
<td>Peri-prosthetic fracture</td>
<td>12.3</td>
</tr>
<tr>
<td>Girdlestone situation</td>
<td>6.1</td>
</tr>
<tr>
<td>Symptomatic MoM inlay</td>
<td>4.0</td>
</tr>
<tr>
<td>Peri-articular ossification</td>
<td>2.3</td>
</tr>
<tr>
<td>Other</td>
<td>10.6</td>
</tr>
</tbody>
</table>

¹ One patient may have more than one reason for revision or re-surgery. As such, the total proportion is over 100%.

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Revision surgeries

• 1.3% of total Dutch population

FIGURE  CUMULATIVE REVISION PERCENTAGE OF TOTAL HIP ARTHROPLASTIES IN THE NETHERLANDS IN 2007-2016 (N=227,301).
Aim

Synthesize bone implants to prevent infection and implant loosening
Experimental design

Additive Manufacturing

Surface Biofunctionalization

Multifunctional bone implants
Rational design
Rational design

<table>
<thead>
<tr>
<th>Aspect ratio</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area compared to solid wire</td>
<td>3.75</td>
<td>3.35</td>
<td>2.73</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>14.4</td>
<td>30.6</td>
<td>37.6</td>
</tr>
</tbody>
</table>

Van Hengel, *Biomaterials*, 2017
Selective Laser Melting (SLM)
Plasma electrolytic oxidation (PEO)

- Electrochemical surface treatment
- Silver, copper and zinc nanoparticles to create multifunctional surface

Additive manufacturing
PEO
Biomaterial characterisation

- Highly porous surface with nanoparticles
Phase composition: X-ray diffraction

- X-ray beam fired at biomaterial
- Sample rotates and intensity is collected at different angles
- Phases can be detected according to peaks
Phase composition

- Ca/P phases, including hydroxyapatite
- Addition of strontium in PEO electrolyte results in Sr/P/Ca phases
Silver ion release

- Increased Ag ion release from porous compared to solid implants
Antibacterial zone of inhibition

- Larger zone for porous compared to solid implants
Prevention biofilm formation

- Methicillin-resistant *Staphylococcus aureus* (MRSA) after 48 h
Selfdefending surface
Overview
Ex vivo bone infection model
Multifunctional implants reduce bacterial growth *ex vivo*

- MRSA after 24 h

Multifunctional implants are not cytotoxic

- Human Mesenchymal Stem Cells (MSCs) after 24 h
  - Alive
  - Dead

Van Hengel, *Biomaterials*, 2017
Multifunctional implants enhance cell activity

Van Hengel, *Biomaterials*, 2017
Discussion

• Duration of biological properties

• Explore PEO parameters

• Translate research into clinically relevant implants
Conclusion

Rationally designed, additively manufactured implants

Surface biofunctionalization with Ag, Cu and Zn nanoparticles

Multifunctional implants

Implant functioning and longevity↑
“Wat hebben Japanse origami en botimplantaten met elkaar gemeen”? 
With Sebastien Callens
Thank you!