SLA® AND SLActive® SURFACE ON ROXLID® AND TITANIUM DENTAL IMPLANTS

In the past decades, titanium was the first choice material for dental implants. This material is highly biocompatible, resistant to corrosion in the biological environment, and has excellent osseointegration properties. In recent years, implant surfaces such as Straumann® SLA® and SLActive® have been developed to further improve osseointegration of dental implants. Micro-rough surfaces on titanium implants have shown excellent performance in pre-clinical and clinical studies. These implant surfaces have demonstrated superior osseointegration properties compared to smooth or polished surfaces (Buser et al. 1991). Many studies show that the bone-to-implant contact increases significantly with a higher surface roughness (Shalabi et al. 2006). Optimal results are achieved in a narrow range for moderately rough surfaces with Ra/Sa1,2 values of 1.0 – 2.0 µm (Wennerberg et al. 2000). The Straumann® SLA® and SLActive® surfaces are moderately rough surfaces (Sa2 value of about 1.5 µm) which is optimal to enhance bone-to-implant contact according to a consensus paper (Lang et al. 2009).

Originally, SLA® and SLActive® have been exclusively developed for and applied to titanium implants. The alternative implant materials TAV (Ti-6Al-4V) or TAN (Ti-6Al-7Nb) have a different crystal structure. This crystal structure makes it impossible to create an SLA®- or SLActive®-like surface on TAV and TAN alloys. In contrast to these materials, SLA® and SLActive® surfaces can be created on Roxolid®. Roxolid® is a titanium-zirconium alloy containing about 13% – 18% zirconium. The crystal structure of Roxolid® is similar to the crystal structure of titanium and therefore, the SLA® and SLActive® surface can also be created on titanium.

It has been demonstrated that SLActive®, which had been created on Roxolid® and titanium, performed identically on both implant materials. The surfaces of both materials were characterized by microstructural analysis of the surface topography, cell culture experiments, hydrophilicity assessment as well as pre-clinical and clinical studies.

SURFACE ROUGHNESS AND SURFACE TOPOGRAPHY

The microstructures of the implant surfaces were analyzed by using a scanning electron microscope and by confocal microscopy. No relevant differences for any of the surface roughness and topography parameters for either implant materials were detected (Fig. 1 and Table 1).

Fig. 1: SEM images of the different implant surfaces

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>SEM Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roxolid® SLA®/SLActive®</td>
<td><img src="image1" alt="Roxolid® SEM Image" /></td>
</tr>
<tr>
<td>Titanium SLA®/SLActive®</td>
<td><img src="image2" alt="Titanium SEM Image" /></td>
</tr>
</tbody>
</table>

No relevant differences can be identified between SLA®/SLActive® on Roxolid® (A) or titanium (B) according to the SEM images.

\[ Ra = \text{profile roughness parameter} \]
\[ Sa = \text{area roughness parameter} \]
\[ SEM = \text{scanning electron microscope} \]
Surface roughness can be quantified by typical parameters. Only minor differences were detected between the different surfaces, and these differences are within the expected range of source material variability.

**Table 1:** Surface roughness parameters (Berner & Appert 2013)

<table>
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<tr>
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<tbody>
<tr>
<td>Sa</td>
<td>1.195 ±0.099</td>
<td>1.23 ±0.174</td>
<td>1.042 ±0.045</td>
<td>1.146 ±0.061</td>
</tr>
<tr>
<td>St</td>
<td>8.18 ±0.77</td>
<td>8.53 ±1.2</td>
<td>7.28 ±0.25</td>
<td>7.56 ±0.46</td>
</tr>
<tr>
<td>Ssk</td>
<td>0.289 ±0.044</td>
<td>0.165 ±0.064</td>
<td>0.227 ±0.055</td>
<td>0.382 ±0.047</td>
</tr>
</tbody>
</table>

Sa: arithmetic mean deviation
St: maximum peak-to-valley height
Ssk: skewness of the surface

The surface roughness of the surfaces on both implant materials is similar. The small difference is considered irrelevant for the biological behavior.

**SURFACE CHEMISTRY**

The chemical composition of the implant surface on both materials is very similar showing only minor differences. The element zirconium was detected on the surface of the Roxolid® implant but not on the titanium implant.

**Table 2:** XPS data of the implant surfaces measured in atomic percentage

<table>
<thead>
<tr>
<th></th>
<th>Roxolid® SLA® [%]</th>
<th>Titanium SLA® [%]</th>
<th>Roxolid® SLActive® [%]</th>
<th>Titanium SLActive® [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>58.3 ±1.6</td>
<td>54.6 ±1.4</td>
<td>61.4 ±1.2</td>
<td>62.4 ±1.3</td>
</tr>
<tr>
<td>C</td>
<td>20.2 ±3.1</td>
<td>21.0 ±2.2</td>
<td>15.2 ±1.5</td>
<td>14.4 ±1.3</td>
</tr>
<tr>
<td>N</td>
<td>1.3</td>
<td>2.7 ±0.4</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Si</td>
<td>–</td>
<td>2.4 ±0.3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ti</td>
<td>18.3 ±0.6</td>
<td>19.4 ±1.2</td>
<td>20.0 ±0.5</td>
<td>23.2 ±0.2</td>
</tr>
<tr>
<td>Zr</td>
<td>2.8 ±0.24</td>
<td>–</td>
<td>3.4 ±0.1</td>
<td>–</td>
</tr>
</tbody>
</table>

The chemical composition of both materials is similar except for the element zirconium which is only present in the Roxolid® material.

**MECHANICAL STABILITY**

Both implant materials are excellent for use in dental implants. The advantage of Roxolid® is the increased mechanical stability compared to titanium (Table 3). Analysis of the fatigue behavior indicated that the endurance level of Roxolid® implants was 13% – 42% higher compared to titanium implants with the same length, diameter and surface treatment (Bernhard et al. 2009). The ultimate tensile strength of Roxolid® is significantly higher than of titanium.

**Table 3:** Tensile strength of different implant materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength [MPa]</th>
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<tbody>
<tr>
<td>Titanium IV</td>
<td>~50%</td>
</tr>
<tr>
<td>Straumann®</td>
<td>~80%</td>
</tr>
<tr>
<td>Roxolid®</td>
<td>~120%</td>
</tr>
</tbody>
</table>

Roxolid® shows 20% higher tensile strength compared to cold worked titanium and 80% higher tensile strength compared to titanium grade IV.

The hydrophilic properties of the Roxolid® and titanium SLActive® surfaces showed no differences. The tensiometric contact angle on both surface materials was 0° on all implants (Bernhard et al. 2009).

Based on the surface characterization it can be concluded that the SLA® and SLActive® surfaces perform equally on titanium and Roxolid®, any small differences are within the expected variability of the source material.
CONCLUSION

Micro-rough surfaces such as SLA® and SLActive® can be applied to titanium and Roxolid® implant materials. The surface characteristics of both materials are similar and there is no relevant difference.

Pre-clinical and clinical data have shown that both surfaces have equally excellent osseointegration properties. In clinical studies both implant materials performed on the same high level.

The outstanding advantage of Roxolid® is the increased tensile strength compared to titanium.

CELL CULTURE EXPERIMENTS

Multiple cell culture studies documented the comparison of cell proliferation, cell differentiation and the expression of certain biochemical marker proteins on Roxolid® and titanium. Cell density on the Roxolid® surface was slightly higher than on titanium. The expression level of certain marker proteins like PGE2 and Osteocalcin showed no differences (Zhao et al. 2007).

Extensive in vitro and in vivo biocompatibility testing was performed. Both materials were tested to cover sensitivity, irritation and toxicity as well as genotoxicity and systemic toxicity. All tests confirm excellent biocompatibility properties in both materials; no differences were detected (Ikarashi et al. 2005).

CLINICAL AND PRE-CLINICAL STUDIES

The performance of Roxolid® SLActive® and titanium SLActive® has been assessed also in pre-clinical and clinical studies (Wen et al. 2013, Gottlow et al. 2012, Saulacic et al. 2012, Al-Nawas et al. 2012, Benic et al. 2013, Tolentino et al. 2013). In these studies, titanium SLActive® implants and Roxolid® implants were directly compared. It was demonstrated impressively that the performance of the Roxolid® SLActive® implants was at least as good as the titanium SLActive® implant’s performance. In some studies Roxolid® SLActive® implants performed even better than titanium SLActive® implants (Gottlow et al. 2012, Wen et al. 2013).
REFERENCES


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Saulacic N, Bosshardt DD, Bornstein MM, Berner S, Buser D.: Bone apposition to a titanium-zirconium alloy implant, as compared to two other titanium-containing implants. Eur Cell Mater. 2012 Apr 10;23:271–86


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