The technology behind the solid-state hydrated ProActive surface

Fredrik Engman

1 Neoss Ltd, Gothenburg, Sweden

This article describes the techniques applied on a relatively smooth surface to enhance early healing response while still assuring predictable long term clinical success. In particular, it describes how a superhydrophilic surface can be achieved using a completely unique and novel method to deposit hydrated ions onto an implant surface, effectively creating a solid-state water surface.

INTRODUCTION

The biological behavior and clinical performance of a dental implant is dependent on the correlation between implant design, drilling protocol and implant surface properties. The key to a successful implant treatment is mechanical stability (primary stability) until the healing process has established the osseointegration (secondary stability) in order to minimize the stability dip normally occurs after 2-4 weeks of healing (Figure 1).

Implant design and drilling protocol mainly influence the primary stability, whereas the implant surface properties mainly influence the secondary stability. All three properties can be optimized such that the primary stability can be retained for a longer period and secondary stability can be achieved faster. This way, the dip in combined stability can be minimized or even eliminated.

SURFACE PROPERTIES AND OSSEOINTEGRATION

Surface roughness

The introduction of moderately rough modified implant surfaces improved the clinical success in implant dentistry compared to the original machined surface. There are several underlying factors in why clinical advantages are seen. The modified surfaces are normally sharper and mechanically create a higher friction and retention than a machined surface, thus increasing the primary stability. There is also evidence that these sharp features create bone debris as the implant is inserted and the debris acts as a nucleus for new bone formation.1 Furthermore, if the surface has varying roughness and/or machined features such as grooves, the debris can be collected and the remodeling can be even further enhanced. There is also evidence that cells have an increased affinity to topographic features such as grooves and ridges if they are roughly the same size or slightly smaller than the cells. These factors result in osteoconductive properties of the surface, meaning that bone cells are in direct contact with
and can develop from the implant surface.²

Excessive surface roughness may increase the likelihood of certain risks as it can be more prone for contamination and more difficult to clean. This could be one reason why there has been increased reporting of infection-related issues around dental implants in recent years and where a correlation to the rough surface has been shown.³ An excessively rough surface can also lead to release of wear particles and crack initiation leading to mechanical failures.

**Hydrophilicity**

The importance of implant surface cleanliness has been recognized for a long time. In recent years, the significance of hydrophilic properties to enhance the early biological healing process has been highlighted. A prerequisite for achieving a hydrophilic surface is that the underlying surface is ultraclean with minimal carbon content. Manufacturing, storage, packaging and handling all contribute to surface contamination of a dental implant. Carbon adsorption reduces surface energy and wettability, thereby impairing healing and bone formation.

Maintaining the hydrophilicity from time of manufacture to clinical use normally requires the implant to be immersed in a liquid as part of the packaging. This leads to more complex packaging containers and additional costs.

**THE PROACTIVE SURFACE**

The ProActive surface was developed 10 years ago. It is characterized by a dual surface roughness to optimize biological functions: The collar has a surface roughness with an Sa-value comparable to a polished surface (0.2-0.4 μm), while the micro- and macro-roughened threaded portion have an Sa-value around 1 μm. This addresses the need both to provide an osteoconductive surface during healing and to minimize bacteria adhesion in regions where the implant can be exposed to the oral environment after long term function.

Through a series of processes, an osteoconductive and superhydrophilic implant surface with different roughnesses on collar and threads is formed.

The ProActive surface is manufactured using the following steps:
- Blasting - to create the surface macro-roughness
- Etching - to create the surface micro-roughness
- Treatment with hydrated magnesium ions to make the surface superhydrophilic.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sa (μm)</th>
<th>Sdr (%)</th>
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<tbody>
<tr>
<td>ProActive</td>
<td>Collar: 0.3-0.4 Thread: 0.8-1.0</td>
<td>Collar: 50 Thread: 103</td>
</tr>
<tr>
<td>SLActive</td>
<td>1.75</td>
<td>143</td>
</tr>
<tr>
<td>TiUnite</td>
<td>1.1</td>
<td>37</td>
</tr>
<tr>
<td>OsseoSpeed</td>
<td>1.4</td>
<td>37</td>
</tr>
</tbody>
</table>

*Table 1: Surface roughness – a comparison of Sa and Sdr values for a number of commercially available dental implant surfaces: (A) ProActive, Neoss, (B) SLActive, Straumann, (C) TiUnite, Nobel Biocare, (D) OsseoSpeed, Dentsply Implants.*

*Figure 2: SEM images of a number of commercially available dental implant surfaces: (A) ProActive, Neoss (B) SLActive, Straumann, (C) TiUnite, Nobel Biocare, (D) TiOblast, Dentsply Implants.*
**Blasting - creating the macro-roughness**

After machining and cleaning, the Neoss ProActive implant threads are carefully blasted with a process that leaves no chemical residue on the surface and creates a macro-roughness while maintaining the self-cutting features of the implant. The collar is not blasted, resulting in the dual surface roughness.

**Etching - creating the micro-roughness**

After blasting, the complete implant – thread and collar – is etched to receive a superimposed micro-roughened surface. At this point the actual Neoss ProActive surface has been created.

The ProActive etching process generates a honeycomb micro structure with fine ridges and small pits at sub-micron level. Compared to other implant surfaces, the ProActive micro morphology structure is similar to SLActive (Straumann) while completely different to TiUnite (Nobel Biocare) and OsseoSpeed (Dentsply Sirona Implants) as demonstrated by SEM (Figure 2).

The ProActive surface has been designed with lower surface roughness than most competitor surfaces (Table 1). The design rationale behind the lower roughness is to achieve a balance between initial stability and long-term predictability without having the attraction of bacteria that rougher surfaces can exhibit. Once a machined surface has integrated, the long-term success is high. The issue is the failure rate during the first year. The ProActive implant design, in combination with the drilling protocol, creates a high and predictable initial stability that allows for a slightly smoother surface with micro pits and still provides predictable means for fast and strong healing. This is shown in animal models in comparison with other implant surfaces as well as in a vast number of clinical studies.

**Superhydrophilicity treatment**

After etching, the implants are subjected to the superhydrophilicity treatment which enables the implant to achieve an exceptionally high level of wettability without altering the blasted and etched surface.

A thin layer of ultra-clean hydrated Mg$^{2+}$ (magnesium) ions is deposited onto the surface. A hydrated Mg$^{2+}$ ion is an Mg$^{2+}$ ion that binds six water molecules. The hydrated ions create bonds with each other and the implant surface to form a stable, solid-state, water-rich film on the implant. The film has a solid, transparent and glossy appearance similar to ice and is stable on the implant surface at temperatures as high as $60^\circ$C.

This treatment is what makes the ProActive surface superhydrophilic, as demonstrated in surgical practice (Figure 3) and by the immeasurable low contact angle compared to other dental implant surfaces (Figure 4).

The Mg$^{2+}$ ions used in the superhydrophilicity treat-
ment are highly soluble which means that there is no Mg$^{2+}$ bound to the implant surface once the implant is implanted. Mg$^{2+}$ is abundant in the human body. It has also been shown to be an important substance for bone formation, but any direct correlation for ProActive still needs to be explored.

Even though the deposited water and Mg$^{2+}$ ions are highly soluble, they are highly stable on the surface which enables the implants to be delivered in conventional packages. This eliminates the need for the implant to be packaged in a liquid solution like other hydrophilic implants.

The ProActive production process uses non-contaminating blasting particles and an ultra-clean water supply. In addition, the implant packages are made of glass. This maintains the low carbon content on the implant surface, thereby maximizing surface energy.

Compared to other dental implant surfaces with carbon levels in the 30-50% range, the levels of surface contamination on the ProActive surface is very low with carbon levels generally below 20% and minimal levels of the trace elements P, S, Ca and Cl (Table 2). The data also shows that the ProActive superhydrophilicity treatment does not leave any Mg$^{2+}$ remnants.

### CONCLUSION

By applying a superhydrophilicity treatment to a carefully designed implant geometry and implant surface, the ProActive implants offer high initial stability and allow for predictable and safe use in challenging indications such as immediate loading and in compromised bone, and for patients with poor hygiene or pathological issues.

It is also suggested that the dip in stability during the remodeling process between initial stability and osseointegration, an effect seen for all well researched implant systems of today, is minimized with the ProActive implants. One reason for this can be the ability of the implant body to achieve high initial stability in combination with the very potent surface that enhances early bone formation, thus considerably minimizing or in some cases even eliminating the crucial and sensitive time where the initial stability is declining before the osseointegration is fully in place (Figure 1).

It is clear that an implant with a surface roughness on the lower end of the scale for moderately rough implants (1-2 µm), in combination with an implant design that achieves high initial stability, can perform very well also in challenging indications.

### REFERENCES

9. Neoss Internal Report 11899_0 AES Analysis ProActive Implants