Osseoconduction of an Airborne Particle–Abraded and Etched Titanium Alloy Surface in Type IV Bone: A Human Histologic and Micro-CT Evaluation

The present study aimed to evaluate the osseoconduction ability of an airborne particle–abraded and etched (SAE) titanium alloy surface when placed in humans with poor bone quality. Four patients scheduled to receive an implant-supported full-arch prosthesis received two additional reduced-diameter implants to be harvested after 6 months of submerged healing. Undecalcified vestibulopalatal/vestibulolingual histologic sections were prepared after the micro-computerized tomography (µCT) examination. Six implant sides from four biopsied implants displayed a type IV bone environment and were included in the present study. Bone-to-implant contact (BIC) was first measured on each implant side. The estimated initial BIC (E-iBIC) was evaluated by superimposing the implant profile 0.25 mm away from its actual position. The µCT provided information about the local and adjacent bony architecture. The mean BIC was 62.5% ± 10.6%, while the mean E-iBIC was 33.1% ± 4.4%. The E-iBIC/BIC ratio was 1.81 ± 0.38. The 3D µCT sections showed the thin bone trabeculae covering the implant surface; although they seemed to be separated from the rest of the bony scaffold, they were much more interconnected than what appeared to be on the 2D histologic preparations. This limited number of human histologic samples document, for the first time, that the SAE titanium alloy implant surface is apparently osseoconductive when placed in poor human bone quality. The average BIC was 1.81 times higher than the E-iBIC. This high osseoconductivity may explain the predictable clinical behavior of implants with this type of SAE textured surface in type IV bone.


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the end of the healing period, when osseointegration is achieved, a conductive bone surface should see its BIC superior to the iBIC (BIC > iBIC). A bone-neutral or a not-bone-conductive surface either does not increase the initial BIC (BIC = iBIC) or leads to a reduction of it (BIC < iBIC). The BIC delivers a picture of the interaction between the implant surface and the surrounding bone at a given time; however, it does not provide information on the iBIC at the time of implant placement. Trisi et al9 proposed a way to estimate the iBIC from a histologic section after osseointegration is completed. The method relies on the fact that an implant alters the new local bone architecture up to approximately 1 mm away from the implant surface, depending on the local bone quality and the implant surface.10–13 The extent and magnitude of the alterations of the local bone architecture following implant placement depends on the surface condition. A machined surface leads to a reaction of bone corticalization, in which a thick cortical shell is formed all around the implant surface.11–13 In contrast, a roughened surface that allows micro-mechanical anchorage with bone leads to a reaction of bone trabeculization, in which trabeculae of limited thickness adjacent or perpendicular to the implant surface are formed instead.11–14 The extent of the disruption of the local bone architecture surrounding an implant is broader for a machined-surface implant than a textured one.12–14

To estimate the iBIC at implant placement from a histologic section, Trisi et al9 proposed moving the implant’s external envelope from its actual position up to a distance where it appears that the presence of the implant did not alter the local bone architecture. Next, the implant profile’s interception with the local bone architecture is measured and serves as the estimated iBIC (E-iBIC). Consequently, every histologic section can simultaneously provide both a BIC and an E-iBIC value; it is then possible to appraise the osseoconductive properties of an implant surface in a given bone environment. Trisi et al9 placed mini implants (one side machined-surface, one side dual–acid-etched) in the human posterior maxilla (poor bone density), and allowed them to heal for 6 months in a submerged fashion prior to biopsy. The machined surface was bone-neutral or not bone-conductive (average BIC/E-iBIC = 0.72 < 1), while the etched surface was bone-conductive because the average BIC/E-iBIC was 1.58, which is higher than 1.

Machined-surface implants placed in type IV bone are at a higher risk of failure than implants placed in normal or dense bone quality.7,15,16 On the other hand, implants that are made of commercially pure titanium with either a dual–acid-etched textured surface17 or a textured surface that is airborne particle–abraded and etched (SAE)14,18–20 placed in a poor bone quality environment have been documented to be as successful as implants placed in normal and dense bone.21–24 This results from their advantageous bone-conductive properties in sites of poor bone density.9,14,17,25,26

Human histologic evidence of successfully osseointegrated implants is rare in the literature because opportunities to retrieve them are limited.27,28 This scarcity is even more pronounced when dealing with biopsy samples obtained from specific sites, like sites of poor bone quality. In a previous study,29 eight implant biopsy samples with an SAE titanium alloy surface (V3 implants, MIS Implants Technologies) were obtained from humans after 6 months of submerged healing. The detailed histologic qualitative and quantitative data of these human implant biopsy samples were reported.29 The present study focuses on the implant sections found in contact with poor bone density. The aim was to evaluate the osseoconduction capacity of the SAE titanium alloy surface in type IV bone. For this purpose, the E-iBIC was considered and was compared to the actual BIC. The objective was to determine whether this surface was bone-neutral (BIC/E-iBIC ≈ 1) or bone-conductive (BIC/E-iBIC > 1).

A micro-computerized tomography (µCT) examination of the biopsy samples was performed to assess the 3D bone architecture around the implants prior to histomorphometric analysis.

Materials and Methods

Implant Surgery and Biopsy

Details of both implant surgery and biopsy techniques are discussed in a previous publication.29 In brief, four patients presenting with either an edentulous mandible or eden-
tulous maxilla were scheduled to receive implants (C1 implants, MIS Implants Technologies) supporting a full-arch prosthesis. They agreed to receive two additional customized, reduced-diameter implants (V3 implants; 3.5 × 8 mm with a triangular neck) to be harvested after submerged healing in exchange for free dental treatment. The patients signed an informed consent form based on the Declaration of Helsinki of 1975, as revised in 2000.

The four patients each received two study implants planned to be harvested for biopsy sampling, resulting in eight study implants (four in the maxilla, four in the mandible). After 6 months of healing, they were retrieved with the surrounding bone and were immediately fixed in formaldehyde 4%. The samples were scanned for µCT and then processed for undecalcified histology.

µCT Analysis

Before undergoing the histologic process, the fixed biopsy samples were scanned using a high-resolution µCT system (SkyScan 1276, Bruker). The samples remained immobile, and the radiation source and the detectors were rotated around it. A sample holder was designed to maintain the long axis of the implant perpendicular to the x-ray source. Scan parameters were: 80 kV x-ray source voltage combined with an Al/Cu filter; 65 μA source current; 2,700-millisecond exposure time/projection, acquiring two projections/position; and a voxel size of 12 μm. The scanning was performed over a 360-degree rotation, acquiring images every 0.25 degrees. The images were reconstructed using the Nrecon software (Bruker) and evaluated with the DataViewer software (Bruker).

This examination aimed to obtain simultaneous information about the bone-implant interface from the sagittal, coronal, and axial planes. The objective was to acquire a 3D overview of the bony arrangement from the immediate vicinity of the implant surface and away, up to the adjacent cortical tables. Specific axial planes taken from three different levels alongside the implant were analyzed with regard to implant bone coverage (percentage of BIC) and its interconnectivity to the surrounding bone architecture.

Histologic Processing and Inclusion Criteria for Selected Samples

The eight implant biopsies with the neighboring hard tissue were fixed, dehydrated in a graded series of ethanol solutions, and embedded in a light-curing resin (Technovit 7200 VLC, Heraeus-Kulzer). A central buccolingual section, passing through the long axis of each implant, was obtained. The sections were then thinned down to approximately 50 μm and stained following Lackó and Lévai.30 Images were captured using a motorized light microscope (BX51, Olympus) and a digital camera (DP71, Olympus) connected to a PC-based image capture system.

The bony environment of each of the eight implant sites was assessed histologically. The sides that displayed a local arrangement of poor bone density adjacent to the implant surface were included in the present study (Fig 1).

Histomorphometric Measurements of BIC and E-iBIC

Histomorphometric measurements were performed using an image analysis program (ImageJ, National Institutes of Health). The percentage of mineralized bone along the analyzed implant side (vestibular or palatal) was calculated first; this was considered as the actual BIC. After this first measurement, the implant external envelope was displaced 0.25 mm away from the implant surface in both the vestibular and the buccal directions (Fig 2). Care was taken to assess that the shifted implant profile was positioned in a place where the implant’s presence did not alter the local bone architecture. The percentage of BIC intercepted by the implant profile was calculated; this was considered the E-iBIC. Subsequently, the BIC/E-iBIC fraction was calculated. The same methodology was applied to measure the BIC amount on three axial sections obtained from the µCT analysis.

Results

Histologic Observation

From the 16 vestibular and buccal sites of the eight biopsy samples,
6 sites met the inclusion criteria. They were the vestibular and palatal sides of two implants placed in the maxilla in positions 12 (FDI tooth-numbering system; Fig 1a) and 22 (Fig 1b); the palatal side of another maxillary implant in position 24 (Fig 1c); and the vestibular side of a mandibular implant in position 34 (Fig 1d). These histologic slides displayed poor bone density with a limited number of trabeculae of various thicknesses at a close distance from the implant surface. At the implant surface, continuous bone trabeculae of distinct thicknesses covered the implant surface over several threads (Fig 3). Table 1 lists the BIC and the E-iBIC of the six sites in contact with type IV bone. The mean BIC was 62.5% ± 12.2% (range: 45.4% to 77.1%), and the mean E-iBIC was 33.1% ± 5.2% (range: 26.5% to 40.9%). Every measured BIC was superior to its corresponding E-iBIC; the mean E-iBIC/BIC ratio was 1.81 ± 0.45 (range: 1.33 to 2.51).

**µCT Observation**

The µCT examination provided images from three different perpendicular planes: sagittal, coronal, and axial. Figure 4 shows the bony architectural arrangement of the implant at site 24. There is some continuity between the thin bone trabeculae covering the implant surface observed in the 2D histologic sections (Figs 2 and 3) and the adjacent supporting cortical tables. Figure 4a shows struts of bone running from the implant surface toward the adjacent bony scaffold. The same feature appears on the corresponding axial plane (Fig 4b), while the related coronal plane (Figs 4c and 5a) suggests the existence of only isolated
Table 1 Determining the BIC, the E-iBIC, and the Corresponding Ratio

<table>
<thead>
<tr>
<th>Implant site</th>
<th>Side</th>
<th>BIC</th>
<th>E-iBIC</th>
<th>BIC/E-iBIC ratio</th>
</tr>
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<tr>
<td>12</td>
<td>Palatal</td>
<td>62.48</td>
<td>40.92</td>
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<td>22</td>
<td>Vestibular</td>
<td>45.43</td>
<td>34.20</td>
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<td></td>
<td>Palatal</td>
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<td>32.96</td>
<td>1.45</td>
</tr>
<tr>
<td>24</td>
<td>Vestibular</td>
<td>75.22</td>
<td>37.42</td>
<td>2.01</td>
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<tr>
<td></td>
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<td>26.82</td>
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<td>Vestibular</td>
<td>66.79</td>
<td>26.51</td>
<td>2.51</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>62.47</td>
<td>33.14</td>
<td>1.81</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>12.25</td>
<td>5.23</td>
<td>0.45</td>
</tr>
</tbody>
</table>

BIC = bone-to-implant contact; E-iBIC = estimated initial BIC.

*FDI tooth-numbering system.

Fig 2 Illustration of the protocol leading to the determination of the E-iBIC (estimated initial bone-to-implant contact). (a) Histologic section from site 22 showing an implant placed in an environment with poor bone quality. (b) The implant’s envelope was displaced 0.25 mm away from its position on the vestibular and palatal sides (in green). The intercept between the envelope and the bone determined the E-iBIC on each side.

Fig 3 Neoformation of thin bone trabeculae on the implant surface. (a) Vestibular and (b) palatal sides of the implant biopsy sample taken from site 24. Note the continuous trabeculae covering several threads and the poor bone quality away from the implant surface. (c) Vestibular side of the implant biopsy sample taken from site 12. Note the newly formed bone and the poor bone density away from the implant.
trabeculae around the implant surface. The bone arrangement was further observed on three distinct axial sections (Fig 5a): The first encompassed a thread level with little surrounding bone tissue (Figs 5a and 5b); the second passed through a between-thread area at the apical portion of the implant (Figs 5a and 5c); and the third was at the level of the implant apex (Figs 5a and 5d). The bone architecture of each section revealed connectivity between the bone that tightly enclosed the implant surface and the adjacent mineralized tissue. From the most coronal aspect toward the most apical aspect, the BIC of each axial plane was 62.07%, 63.70%, and 60.58%, respectively.

Discussion

This limited number of human histologic samples document, for the first time, that the present SAE titanium alloy implant surface was bone-conductive when placed in human bone of poor density. The mean BIC of these implants was on average 1.81 times higher than the
E-iBIC. In similar poor bone conditions, the BIC/E-iBIC ratio measured for machined surfaces was 0.72 (< 1), and that surface was not identified as bone-conductive in poor bone quality. In a study by Trisi et al, a BIC/E-iBIC ratio of 1.58 was measured for the Osseotite surface, which is a minimally rough etched surface with roughness parameters (Ra/Sa) < 1 µm, The mean BIC/E-iBIC ratio of the present SAE surface with a mean roughness parameter (Sa) of 1.22 µm (according to Pimenta et al) was 1.81. This was higher than the Osseotite surface ratio, which is only etched, without prior airborne-particle abrasion, which adds roughness to the etching process and increases implant anchorage in the bone.

The bone reaction to implant placement in this poor bone density environment was “bone trabeculization.” The hard tissue response did not aim to shape-up a cortical bony shell that characterizes the bony response to machined surfaces. This means that the living bone tissue identified this SAE textured surface as a rough surface. In contrast to implants with a machined surface, implants with textured surfaces display shorter healing periods, lower failure rates during the osseointegration period, and higher success rates for smokers, for short implants (≤ 10 mm), and for implants placed in poor bone quality. The ample bone coverage (45.4% to 77.1%) of this rough surface may explain the positive clinical prognosis of rough implants placed in poor bone quality, which has been thoroughly reported in the literature.

The present histologic sections showed thin bone trabeculae covering most of the implant surface. This neoformation of mineralized tissue seems to alter only moderately the pristine adjacent poor bone architecture away from the bone-implant interface. On the 2D histologic sections, the implants were bordered by a thin shell of bone, and they appeared hanging in the middle of a space devoid of efficient bone support. A mere look at the histologic sections might cast some doubt on how this weak bone arrangement can provide sufficient implant stability in bone with such poor density, especially under loading conditions. On the other hand, observation of the corresponding 3D µCT data provides simultaneous insight into the sagittal, coronal, and axial planes, offering a more reassuring picture of the bone disposition. The thin web of bone trabeculae that tightly encloses the implant surface is linked to the solid adjacent cortical tables by a network of interconnected struts and trabeculae. This bone architecture appears strong enough to ensure implant stability even under the heavy loads exerted in the posterior area of the oral cavity, where type IV bone is usually found. The similar failure rates prove this resistance capacity for rough-surface implants placed in poor and normal bone densities.

Finally, the present combination of histologic and µCT data suggest that evaluating the bony arrangement around an implant that relies on only one or more central 2D histologic sections may be misleading. A supplementary µCT examination provides a more accurate picture of the actual bone organization in the implant surface’s immediate vicinity and the adjacent bone architecture.

Conclusions

This limited number of human histologic samples document that the present SAE titanium alloy implant surface appears to be osseoconductive, even when placed in poor human bone quality. The average BIC was 1.81 times higher than the E-iBIC. This may explain the predictable clinical behavior of implants with an SAE textured surface in type IV bone. Lastly, the combination of histologic observation and 3D data generated by µCT provides a more accurate picture of the local bone architecture at the implant surface and its relation to the adjacent bony scaffold.

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References


