Peri-implant hard and soft tissue integration to dental implants made of titanium and gold

Ingemar Abrahamsson
Giuseppe Cardaropoli

Abstract

Objectives: The aim of the study is to compare the peri-implant hard and soft tissue integration around dental implants made of commercially pure (c.p.) titanium or a gold alloy but with the same shape and surface roughness.

Material and methods: In four beagle dogs, all mandibular premolars were extracted. Three months later, four experimental non-submerged implants were placed in each edentulous premolar region. Each implant comprised three different zones: zone A (coronal), zone B (central) and zone C (apical). Each zone was made of either c.p. titanium or a gold alloy. Four different combinations of metal and zone were used. A plaque control program was initiated and 6 months later, the animals were sacrificed and biopsies were obtained. The biopsies including the implant and the surrounding tissues were processed for ground sectioning.

Results: The height of the peri-implant mucosa and the length of the barrier epithelium were similar at the four experimental sites. The marginal bone level in the different metal combinations was located between 4.5 and 4.8 mm apical of the implant rim. The percent of mineralized bone that was in direct contact with the implant surface (BIC%) was consistently greater in the marginal than in the apical portion of the implants. The BIC% for the marginal and apical zone were consistently greater for implant portions made of titanium than for portions made of gold alloy (zone B: 42.7% vs. 36.5%, zone C: 33.2% vs. 19%).

Conclusions: Osseointegration was achieved to surfaces made of both c.p. titanium and a gold alloy. BIC% was higher at titanium than at gold surfaces. Moreover, the peri-implant soft tissue dimensions were not influenced by the metal used in the ‘marginal’ zone of the implant.

The function of modern dental implants depends on the presence of a direct bone anchorage, usually called ‘osseointegration,’ which was defined by Brånemark (1985) as ‘a direct structural and functional connection between living ordered bone and the surface of a load carrying implant.’ The process through which osseointegration is achieved depends on several factors, such as the biocompatibility of the metal used as well as the design and surface conditions of the implant, the condition of the host bed, the surgical technique used and the loading conditions applied (Albrektsson et al. 1981). One major implant-related factor for osseointegration is the biocompatibility of the metal used in the implant. In this respect, commercially
pure (c.p.) titanium is usually recognized as the gold standard. The unique biocompatibility of c.p. titanium is attributed to its stable, passive oxide surface and corrosion resistance (Johansson 1991; Steinemann 1996; Akagawa & Abe 2003; Albrektsson 2003).

In attempts to enhance esthetics and to facilitate technical processing, materials other than c.p. titanium have been used in the marginal, transmucosal part of the implant. The biocompatibility of several different metals and ceramics were studied in different models (for a review, see Johansson 1991). Gold, which is frequently used in dental reconstructions, was suggested as an alternative to titanium. There are, however, only a few studies presented in which gold was used as an implant material. Albrektsson et al. (1982) studied the bone–implant interface at plastic implants onto which a thin layer of titanium or gold was evaporated. Three months after insertion into the rabbit tibia, no bone contact had occurred to the gold-coated implants. The bone response to titanium, zirconium and gold implants placed in the rabbit tibia was studied by Thomsen et al. (1997). The hard tissue healing at all three implant materials presented with bone in contact with the implant material. Gold implants, however, demonstrated a lower degree of bone-to-implant contact (BIC%) than the titanium and zirconium implants.

Proper dimension and function of the soft tissue seal around dental implants is considered to be a pre-requisite for achieving long-term stable peri-implant conditions (Abrahamsson et al. 1997). The biocompatibility of the material used in the transmucosal part of the implant may therefore be a factor of importance for treatment success. In a study in the beagle dog, Abrahamsson et al. (1998) demonstrated that an apical shift of the marginal bone level and the soft tissue margin occurred when abutments of gold alloy were used in the transmucosal part of Bränemark implants. In other words, both hard and soft tissue response to gold as an implant material is still unclear. The aim of the present study was to compare the peri-implant hard and soft tissue integration around dental implants made of c.p. titanium or a gold alloy but with the same shape and surface roughness.

Material and methods

The study protocol was approved by the Regional Ethics Committee for Animal Research, Göteborg, Sweden. Four beagle dogs, about 1-year old, were included in the experiment.

The implants used were custom made, had a solid screw design and were prepared with a machined and polished surface (3.3 x 12 mm, Straumann AG, Waldenburg, Switzerland). Each implant comprised three different zones: zone A (coronal, 4 mm), zone B (central, 3 mm) and zone C (apical, 5 mm; Fig. 1). Each zone was made of either c.p. titanium (grade 4) or a gold alloy [Au, 60%; Pt, 19%; Pd, 20% and Ir, 1%]. Four different combinations of metal and zone were used, namely (coronal/central/apical) Ti/Ti/Ti, Ti/Au/Au, Au/Au/Au and Au/Ti/Ti. The different metal combinations were connected to each other by laser welding before the final surface treatment was performed.

During all surgical procedures, general anesthesia was induced with intravenously injected propofol (10 mg/ml, 0.6 ml/kg) and was sustained with N2O:O2 (1:1.5–2) and isoflurane using entotraceal intubation. All mandibular premolars and the first, second and third maxillary premolars were extracted. Three months later, bilateral crestal incisions were made in the edentulous mandibular premolar regions. Buccal and lingual mucoperiosteal flaps were raised and the implants were placed. In each dog, eight implants were installed in a randomized order. Following installation, the bone crest coincided with a reference that was present on the implants at a distance 3 mm from their margin. Cover screws were placed and flaps were adjusted and sutured to allow non-submerged healing. Radiographs were obtained from all sites. After 2 weeks, the sutures were

![Fig. 1. Schematic drawing illustrating an experimental implant. Left: each implant has three different zones: zone A (coronal, 4 mm), zone B (central, 3 mm) and zone C (apical, 5 mm). Right: the landmarks used for the histometric measurements: PM, the margin of the peri-implant mucosa; B, the marginal level of bone to implant contact; aBE, the apical extension of the barrier epithelium; I, the rim of the implant.](image-url)
removed and a 6-month period of plaque control was initiated. The plaque control program included cleaning of the exposed portions of the implants and the adjacent teeth with the use of a toothbrush and dentifrice. The cleaning procedure was repeated 5 days/week.

After 6 months of healing, a new set of radiographs was obtained. The animals were sacrificed by an overdose of sodium pentothal and perfused through the carotid arteries with a fixative. The fixative consisted of a mixture of 5% glutaraldehyde and 4% formaldehyde buffered to pH 7.2 [Karnovsky 1965]. The mandibles were removed and placed in the fixative. Each implant site was dissected using a diamond saw [Exakt®, Kulzer, Germany] and further processed for ground sectioning. The tissue samples, comprising the implant and the surrounding soft and hard peri-implant tissues, were dehydrated in serial steps of alcohol concentrations and subsequently embedded in a methyl-methacrylate resin [Technovit® 7200 VLC, Exakt®]. Using a cutting–grinding unit [Exakt®, Apparatebau, Norderstedt, Germany] and a micro-grinding system [Exakt®, Apparatebau] and starting from the lingual aspect, the blocks were cut and ground in a mesio-distal plane until two central sections from each implant had been reduced to a final thickness of approximately 20 μm. The remaining buccal part of the tissue block [about 40–45% of the implant and the surrounding tissues] was, subsequently, rotated 90° and one section of the buccal tissues was prepared in a similar manner. The sections were stained in toluidine blue [Donath 1993].

Histological analysis
The histological examination was performed in a Leica DM-RBE microscope [Leica, Heidelberg, Germany] equipped with an image system Q-500 MC® (Leica).

In each section, the following landmarks were used for linear measurements [Fig. 1]: PM – the margin of the peri-implant mucosa, B – the marginal level of BIC, aBE – the apical extension of the barrier epithelium and I – the rim of the implant. The distances between the landmarks were determined.

The BIC% measurements, i.e. the length fraction [%] of mineralized bone that was in direct contact with the implant surface, were performed separately for each zone at magnification × 100.

Statistical analysis
Descriptive statistics including mean values and standard deviations were calculated for each variable. The animal was used as the statistical unit (N = 4).

Results
Healing following implant installation was uneventful in all dogs and for all 32 implant sites. At the end of the plaque control period, the exposed implant surfaces and the neighboring teeth were free from visible plaque and the peri-implant mucosa showed no clinical signs of inflammation [Fig. 2].

Histological observations
Peri-implant mucosa (Table 1)
The height of the peri-implant mucosa [PM–B] was similar at the four experimental sites, and the mean height varied only between 3.44 and 3.71 mm [Table 1]. Also, the length of the barrier epithelium appeared to be similar in the different sites. Hence, the mean value of distance PM–aBE varied between 1.5 and 1.71 mm. The marginal level of BIC in the four different metal combinations was consistently located between 4.52 and 4.8 mm apical of the rim of the implant [I–B].

<table>
<thead>
<tr>
<th>Zone</th>
<th>A–B</th>
<th>Au–Au</th>
<th>Ti–Au</th>
<th>Au–Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>I–B</td>
<td>4.71 (0.26)</td>
<td>4.72 (0.32)</td>
<td>4.8 (0.41)</td>
<td>4.52 (0.45)</td>
</tr>
<tr>
<td>PM–B</td>
<td>3.44 (0.34)</td>
<td>3.71 (0.70)</td>
<td>3.71 (0.27)</td>
<td>3.46 (0.09)</td>
</tr>
<tr>
<td>PM–aBE</td>
<td>1.5 (0.34)</td>
<td>1.69 (0.28)</td>
<td>1.71 (0.41)</td>
<td>1.65 (0.24)</td>
</tr>
</tbody>
</table>

Mean values (mm) and standard deviations (SDs).
I, rim of the implant; B, level of marginal bone in direct contact with the implant surface; PM, margin of the peri-implant mucosa; aBE, apical level of barrier epithelium; zone A, coronal region; zone B, central region.
Discussion

In this animal experiment, it was demonstrated that osseointegration (BIC%) was achieved on surfaces made of both c.p. titanium and a gold alloy. BIC% was higher at titanium than at gold surfaces. Furthermore, this study demonstrated that peri-implant soft tissue dimensions and the level of the marginal bone were

<table>
<thead>
<tr>
<th>Animal</th>
<th>Zone B Titanium</th>
<th>Gold</th>
<th>Zone C Titanium</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.97</td>
<td>28.53</td>
<td>29.19</td>
<td>17.85</td>
</tr>
<tr>
<td>2</td>
<td>45.36</td>
<td>34.28</td>
<td>33.39</td>
<td>13.31</td>
</tr>
<tr>
<td>3</td>
<td>37.83</td>
<td>37.21</td>
<td>26.47</td>
<td>19.9</td>
</tr>
<tr>
<td>4</td>
<td>54.51</td>
<td>45.79</td>
<td>43.91</td>
<td>24.8</td>
</tr>
<tr>
<td>Mean</td>
<td>42.7 (9.4)</td>
<td>36.5 (7.19)</td>
<td>33.2 (7.66)</td>
<td>19 (4.76)</td>
</tr>
</tbody>
</table>

BIC, bone-to-implant contact.

---

**Table 2.** BIC% in different zones of the experimental implants; zone B: central, zone C: apical. BIC% presented for each dog and as mean values with standard deviations (SDs)

---

**Fig. 3.** (a) Mesiodistal cross section showing the osseointegrated part of an experimental implant made of titanium in zones B and C. Ground section. Original magnification ×16. (b) Detail of (a): mesiodistal cross section showing zone B of a titanium implant. Ground section. Original magnification ×25. (c) Detail of (a): mesiodistal cross section showing zone C of a titanium implant. Ground section. Original magnification ×25.

---

**Fig. 4.** (a) Mesiodistal cross section showing the osseointegrated part of an experimental implant made of gold in zones B and C. Ground section. Original magnification ×16. (b) Detail of (a): mesiodistal cross section showing zone B of a gold alloy implant. Ground section. Original magnification ×25. (c) Detail of (a): mesiodistal cross section showing zone C of a gold alloy implant. Ground section. Original magnification ×25.
not influenced by the metal used in the ‘marginal’ zone of the implant.

**Hard tissue integration**

C.p. titanium was, due to its unique properties for integration with living tissue, considered as the implant material of choice [for a review, see Steinemann 1998]. The finding of the present study, that osseointegration may occur to both titanium and gold alloy, is in conflict with the results from a previous experiment on rabbits [Albrektsson et al. 1982]. The investigators studied the bone-implant interface at plastic plug implants onto which a thin layer of titanium or gold was evaporated. Three months after implant insertion into the rabbit tibia, the surrounding bone appeared to be in contact with the titanium coating, while no bony contact was seen to the gold-coated implants. On the other hand, data in agreement with the results of the present investigation were reported in an experiment by Thomsen et al. (1997). They analyzed BIC% and the amount of bone within the threads at solid screw-shaped titanium, zirconium and pure gold implants placed in the tibia of rabbits. The authors reported BIC% values varying between 36% and 40% after 1 and 6 months of healing at titanium and zirconium implants, while the corresponding BIC% values at gold implants were 18% and 24%.

In contrast to titanium, which is a metal that is normally covered by a thin layer of oxide, gold is a precious metal that does not form surface oxides but exposes the pure metal surface to the surrounding tissues. The gold surface and the titanium oxide layer are, however, similar in the sense that they are both chemically stable and have high corrosion resistance. Therefore, the tissue response following implant placement should not be influenced by products released from any of the two metals. Furthermore, while gold is an inactive metal from a chemical point of view, the oxide layer of titanium is active and has the ability to interact with many different molecules [Descouts & Aronsson 1999]. Titanium is also catalytically active in a number of organic reactions [Thomsen et al. 1997]. Indeed, it was argued that a true chemical bonding may occur between hydroxyles of the titanium dioxide and various ligands of organic matter (Steinemann 1996).

In the current animal experiment, BIC% was higher adjacent to surfaces comprised of c.p. titanium than to the gold alloy surfaces. The difference was more pronounced in the apical (zone C) than in the central region of the bone to implant contact (zone B). In addition, BIC% was consistently higher at titanium sites than at gold sites in all regions and all dogs (Table 2).

Data from previous experimental studies indicated that osseointegration is enhanced at titanium surfaces that have a certain surface roughness (Gottfredsen et al. 1992; Klokkevold et al. 1997; Wennerberg et al. 1997; Buser et al. 1998; Abrahamsson et al. 2001, 2004). Abrahamsson et al. (2001, 2004) used BIC% values to express the degree of osseointegration and reported higher BIC% values for implants with a moderately rough surface [according to the guidelines for surface topography classification suggested by Albrektsson & Wennerberg 2004] than for implants with smooth surfaces in the two animal experiments. Higher values of osseointegration to rough than to smooth implant surfaces were also reported in several experiments where removal torque measurements were used for the analysis (Gottfredsen et al. 1992; Klokkevold et al. 1997; Wennerberg et al. 1997; Buser et al. 1998). In the present study, all implants received the same type of surface treatment (machined and polished) as the experimental implants used in a previous study from our laboratory [Sannerby et al. 2005]. Thus, the $S_2$ value was about 0.35 $\mu$m, which indicates that the surface is comparatively smooth. Implants with such smooth surfaces are considered less favorable for osseointegration (Hämmle et al. 1996; Novaes et al. 2002). This may explain the relatively low BIC% found at both titanium and gold surfaces in the current experiment.

**Soft tissue integration**

In a previous animal experiment, gold alloy abutments were connected to implants of the Bränemark System [Nobel Biocare AB, Göteborg, Sweden] during the second-stage surgery [Abrahamsson et al. 1998]. It was reported that soft tissue dimensions at sites with such abutments were smaller after a 6-month healing period compared with sites where titanium abutments [Bränemark System, Nobel Biocare AB] were used. Soft tissue recession and increased bone level height reductions also occurred at the gold abutments. These findings are in contrast with the histometric results of this experiment, where both soft tissue dimensions and marginal bone level were similar at implants designed with the transmucosal part made of gold or titanium. In this context, it must be recognized, however, that there are major methodological differences between the two experiments and also that different brands of implant were used.

The results of the soft tissue assessments in this study are supported by previous in vitro findings. It was demonstrated that the adherence and spreading of epithelial cells on metallic surfaces, such as titanium and gold alloy, are good, especially if the surface is smooth [electropolished; Chehroudi et al. 1990; Hormia et al. 1991; Rååsåen et al. 2000]. The smooth surface texture is also important for how fibroblasts adhere and spread on metallic surfaces such as titanium and titanium alloy [Könnönen et al. 1992; Hormia & Könnönen 1994; Eisenbarth et al. 1996].
References


Donath, K. [1993] Preparation of Histologic Sections (by the Cutting-Grinding Technique for Hard Tissue and Other Material Not Suitable to be Sectioned by Routine Methods) – Equipment and Methodical Performance. Kulzer: EXAKT.


