Corrosion at the Marginal Gap of Implant-Supported Suprastructures and Implant Failure

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Purpose: *Late failure, which occurs after successful osseointegration, is usually attributed to prosthodontic determinants. Corrosion of metallic suprastructures and incorrectly handled materials are often primary causes of late implant failure. In this study, 6 implants whose failure was related to suprastructure metal corrosion and adjacent bone were investigated.* ***Materials and Methods:*** *Six implants as well as their suprastructures were analyzed for surface corrosion using light and scanning microscopy. Metal alloys and soldering compounds were analyzed using energy-dispersive x-ray analysis. Bone adhering to the implants was removed and analyzed for metal content using atom absorption spectroscopy.* ***Results:*** *Extensive corrosion lesions and areas of oxidation were detected on all 6 of the implants and inner crown surfaces. Bone tissue collected from 5 of the implants showed higher contents of metal ions in comparison to physiologic baseline values detected in healthy bone.* ***Discussion:*** *In spite of the high gold content of the suprastructure, corrosion occurred. Bonding oxides necessary for the process of fusing porcelain to gold will initiate corrosion. Apparently, once corrosion is initiated it rapidly progresses at the gap crevices, and toxic metal ions are released. These toxic ions diffuse into the peri-implant bone, causing bone structure breakdown and hastening osseodisintegration.* ***Conclusion:*** *Biocompatible metals, alloys, and ceramics should be used for implant-supported suprastructures. It is also essential that gaps between the implant and its suprastructure be avoided by cementing the suprastructure or sealing the gap.* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:826–831

Key words: *biocompatibility, corrosion, dental implant failure, osseodisintegration, oxidation*

Two basic types of implant failure have been repeatedly mentioned in the dental implant literature.[1–4] Early failure has been attributed to healing disruption and lack of osseointegration. Late failure, which occurs after successful osseointegration, has been attributed to infection, incorrect loading, and material incompatibility. A number of measures have been implemented to avoid failure at every stage of implant restorative treatment. However, it is still prudent to take material compatibility into consideration.

Material-induced pathology is generally the result of a corrosive process and may have chronic or acute courses. Metal surfaces and alloys become soluble in the intraoral medium (electrolyte), thus resulting in electron and/or ion exchange. This process lacks a conductor and therefore is not completed with electrical current as its final product. Nevertheless, electrochemical corrosion can result locally.[5–7] Ions from corroding metals and alloys may diffuse to adjacent soft and hard tissues, causing local toxic reactions.[8,9] The corrosion process is detected either when the adjacent oral tissue manifests signs of biologic stress or when corrosion near the gap between the implant and the suprastructure is observed on the surfaces of the metals used.

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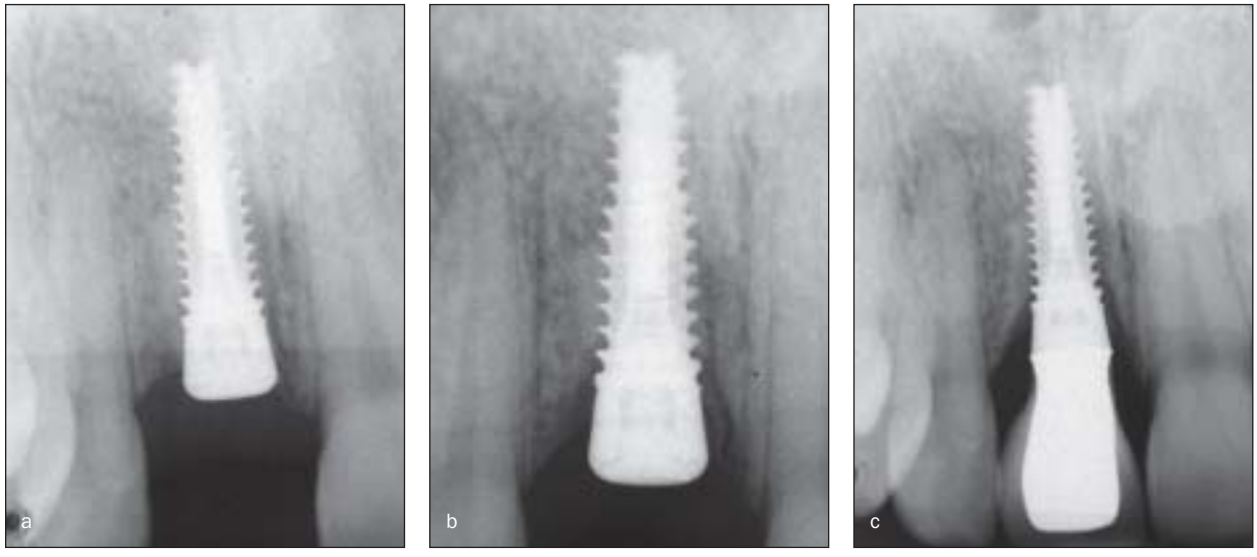

Fig 1 Radiographs showing the course leading to osseodisintegration of the implant in patient 6: *(a)* immediately after placement; *(b)* at reentry, immediately before abutment connection, and *(c)* after failure, immediately before removal.

Crevices near gap spaces seem to be particularly vulnerable to corrosive processes because of the reduction of pH within the immediate vicinity of the metal. In the oral cavity this phenomenon can be attributed to the decrease in or complete elimination of oxygen flow. A second factor contributing to pH reduction is the production of bacterial metabolites by the bacteria that colonize the marginal gap spaces. Studies have shown that bacteria colonize internal surfaces and spaces of implants and implant-supported suprastructures soon after placement.[10–14]

Studies aimed at the elimination of bacterial colonization by means of a gap-sealing antibacterial varnish have shown promising results in the short term.[12] However, these studies have not been followed long enough to determine whether the gaps will be colonized after the varnish has dissolved and been washed out. It is assumed that gap sealing or definitive cementing may somehow reduce the amount of corrosion or slow the corrosion process. However, gap sealing will not eliminate the need to use biocompatible metals and alloys for implant-supported suprastructures.[15,16]

In this clinical case study, 6 cases are presented in which lack of biocompatibility between implants and their suprastructures led to implant failure. The implants and surrounding bone tissue were examined for evidence of corrosion.

MATERIALS AND METHODS

Between 1996 and 1997, 6 implants that failed after achievement of osseointegration and loading, the bone adhering to the failed implants after removal, and the suprastructures they had supported were obtained, with the informed consent of the patients, so that they could be studied to determine the possible causes of implant failure (Figs 1a to 1c). The implants were placed at different sites by different oral surgeons, and the suprastructures were seated by different prosthodontists. The implants were identical in design; all had been acquired from the same manufacturer (HaTi Dental, Bettlach, Switzerland). The diameter and length of each implant varied depending on the available bone and suprastructure requirements. The suprastructures were produced by the same dental technician and were made of porcelain fused to gold. Creation 98 porcelain (Willi Geller, Baar, Switzerland) and V-Supergold (Metalor, Neuchâtel, Switzerland) were used for all suprastructures. The declared contents of the high-grade gold alloy were 86% gold, 7% platinum, 4% palladium, and 1% silver. The remaining 2% comprised undetectably small amounts of cobalt, indium, and tin.

A brief history of each patient and implant can be found in Table 1. At the time of removal all implants were mobile enough to make removal using tooth-extraction forceps feasible. The implants were preserved in physiologic saline solution and immediately delivered to the laboratory for bone removal and incorporated metal ion analysis. Bone adhering to the implants was removed using a ceramic scalpel or scaler. It was necessary to obtain 20 mg of bone (dry weight) for each of the atomic absorption spectroscopy (AAS) analyses.[15] The collected bone was first digested in pure nitric acid and

Table 1 Summary of Treatment From Placement to Explantation

Patent no.	Gender	Age (y)	Implant position	Implant size (mm)	Date of implant placement	Time elapsed (mo)			
						Between placement and abutment connection	Between abutment connection and loading	Between loading and failure	Between failure and explantation
1	F	33	Maxillary right central incisor	5.0 × 17 (short neck)	4/1995	6	1	6	1
2	M	53	Maxillary left central incisor	6.0 × 14 (short neck)	12/1993	6	1	15	6
3	F	41	Mandibular left first molar	7.0 × 11 (short neck)	2/1996	7	1	1	2
4	M	18	Maxillary right lateral incisor	4.5 × 17 (short neck)	12/1993	4	2	21	1
5	M	17	Maxillary left central incisor	5.0 × 17 (short neck)	5/1995	6	1	< 1	16
6	M	20	Maxillary right central incisor	5.0 × 17 (long neck)	10/1992	7	< 1	39	< 1

HaTi implants (HaTi Dental, Bettlach, Switzerland) were used for all patients.

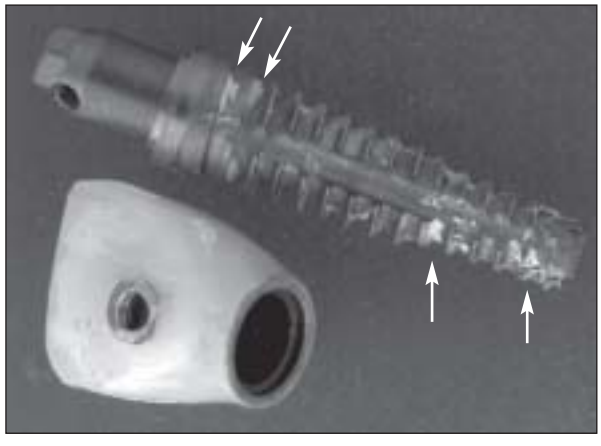

Fig 2 An implant with its porcelain-fused-to-ceramic crown (patient 1). The arrows show bone fragments still adhering to the implant surface.

heated in a microwave oven as described by Nadharni.[17] Graphite furnace atomic absorption spectrophotometry (GFAAS) (Perkin Elmer HGA 600; Perkin Elmer, Waldenburg, Switzerland) was then used to determine trace metal content. GFAAS was calibrated with matrix base and pure standard solution. Gold, palladium, silver, copper, indium, gallium, cadmium, cobalt, and nickel were analyzed.

The metal surfaces of the implant, abutment, and suprastructure were inspected with a light microscope and a scanning electron microscope for evidence of corrosion as described by Wirz.[16] The metal alloys and soldering compounds used in the suprastructures were analyzed using energy-dispersive x-ray analysis (REM Philips XL30, EDAX CDU LEAP; Philips, Eindhoven, The Netherlands).[18] The parameters used were 20 kV beam, 500× magnification, 10 mm sample distance, and 80 minutes' detection time.

RESULTS

All suprastructure crowns were made of a high-grade gold alloy that contained cobalt and indium as well as oxide layer–forming elements necessary for the process of fusing porcelain to gold. The surfaces of all of the crowns and implants showed extensive corrosion lesions and areas of oxidation (Figs 2 and 3). These corrosion lesions (crevice corrosion) were found exclusively at the crevice surfaces of the inside of the crowns. The bone tissue collected from 5 of the implants showed the incorporation of metal ions from gold, copper, cobalt, indium, palladium, and silver. Not enough bone could be collected from the sixth implant for an AAS analysis (Table 2). The bone samples collected showed different degrees of metal ion incorporation (Table 3).

DISCUSSION

Although initial osseointegration of the implants was confirmed in the 6 cases presented, signs of failure were detected soon after seating the suprastructure (crown). The crown-implant contact surfaces showed extensive corrosion lesions and areas of oxidation. Furthermore, bone tissue collected from the implants showed the incorporation of metal ions, an apparent result of the corrosion process. One could

Fig 3 Scanning electron micrographs of the corroded crowns and implants.

Fig 3a *(Left)* The porous layer of the inner surface of a crown (original magnification ×20).

Fig 3b *(Right)* A corrosion-altered alloy surface in the region of the implant shoulder (original magnification ×1,250).

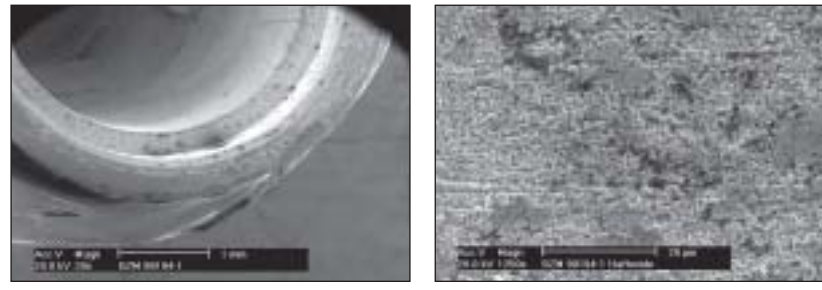

Fig 3c *(Left)* Corroded inner surface of the alloy (original magnification ×500).

Fig 3d *(Right)* Severe corrosion lesions, surrounded by bonding oxide residue (original magnification ×1,000).

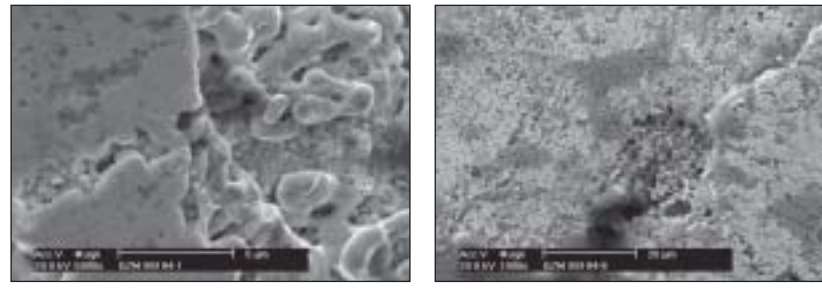

Table 2 Qualitative Analysis of the Suprastructure Alloy and Bone Residue After Detection of Extensive Corrosion Lesions on the Crown Inner Surface

	Composition of the corroded suprastructure (%)*							
Patient	Au	Pt	Pd	Ag	Co	In	Sn	Metals incorporated into the bone tissue
1	68	4	1	0	4	7	8	Au, Co, Cu, In
2	66	6	4	0	8	8	2	In
3	78	7	1	0	3	3	0	Au, Co, Cu
4	79	6	3	0	1	5	0	Ag, Au, Co, Cu, In
5	66	6	2	0	5	11	2	Ag, Au, Co, Cu, In, Pd
6	69	5	2	0	3	7	2	†

Ag = silver, Au = gold, Co = cobalt, Cu = copper, In = indium, Pt = platinum, Pd = palladium, Sn = tin
*Traces of carbon, silicon, aluminum, and potassium were also found in each sample.
†Not enough bone tissue (< .1 mg) could be collected for analysis.

Table 3 Metal Content of the Bone Residue in Comparison to Metal Content of Normal Jawbone

Patient	Bone collected (mg)*	Au	Co	In	Cu	Ag	Pd
1	1.5	174	14	ND	22	ND	ND
2	0.2	ND	ND	13	ND	ND	ND
3	4.1	99	15	ND	40	ND	ND
4	0.8	8	240	7	290	26	ND
5	16.4	150	250	0.2	15	2	5
Physiologic metal content of normal jawbone[15]		0.2 ± 0.9	0.07 ± 0.3	ND	4.1 ± 5.4	0.2 ± 0.38	ND

Au = gold, Co = cobalt, In = indium, Cu = copper, Ag = silver, Pd = palladium; ND = not detectable.
*Dry weight.
All values detectable are shown in micrograms per gram of bone.

argue that corrosion may not have been the sole cause of these implants' loss; other factors, such as unfavorable occlusion or peri-implantitis, could have played a role. However, we must still wonder why other cases of unfavorable occlusion or peri-implantitis appear to progress much slower.

Albrektsson and Albrektsson[19] presented 6 factors that would determine tissue response to a bone implant. First among these factors was biocompatibility of the implant material. Possibly the authors had not foreseen that this biocompatibility should be extended to the suprastructure to assure the survival of the implant.

The corrosion of a material such as gold alloy elicits a bioreaction similar to the bioreaction to bacterial toxins. Clinical symptoms such as pain, swelling, inflammation, lyses, and necroses are common responses to these local toxic reactions.[20] Obviously, if these reactions are not eliminated, the process, which would ultimately end with implant failure, is accelerated. It is not clear how a corrosion process can be slowed or halted once it has started. However, one could act prophylactically to seal the gap between the implant and its suprastructure, thus eliminating bacterial colonization, which contributes to local pH reduction and either initiates or accelerates the corrosion process. A number of studies have sought to increase the degree of precision fit of suprastructure components, but this also has not guaranteed protection against microorganism colonization of marginal gaps.[10,21] All these measures seem to be ineffective if biocompatible materials have not been used.

Studies have shown that submerging implants in the initial healing phase may not be necessary.[22–25] In this context one could refrain from using an abutment altogether and place an implant that would emerge through the soft tissue (ie, a 1-stage implant), thus eliminating the implant-abutment gap. This single-unit implant-abutment could be made of a homogeneous, biocompatible titanium. Temporary crowns to maintain esthetics could be placed on these implants and ground out of occlusion to avoid immediate loading of the implants if deemed necessary. In yet a further simplification of the restorative suprastructure, biocompatible prefabricated titanium crowns or crown components could be produced to fit over the 1-stage implants. This would enhance precision fit as well as biocompatibility.

Late failure may be avoided if implant-supported suprastructures are produced exclusively from biocompatible materials such as titanium or niobium. If alloys are used, they should be of high gold content, without toxic bonding oxides such as indium, cobalt, or any cobalt-based alloy; they should also be free of gallium (although gallium is not a bonding oxide). Metal-free materials such as ceramics could also be used. All conditionally removable suprastructures should be cemented or sealed to avoid bacterial colonization and possible crevice corrosion.

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