Case Report

Histopathology of Microbially Induced Corrosion and Cluster Failure of Moderately Rough Surface Oral Implants in a Resident Bone Microbiota

[1]Stephen Nelson, [2,3]Helen Hu, [3]Anand Deva, [4]Andre John Viljoen and [3]Karen Vickery

[1]*Independent Researcher, 29 Old Princess Hwy, Batemans Bay, NSW, Australia*
[2]*Faculty of Medicine, Jinhua Institute of Zhejiang University, Jinhua, Zhejiang, China*
[3]*Faculty of Medicine, Health and Human Sciences, Macquarie University, NSW, Australia*
[4]*Independent Researcher, 7 Bayside Street, Broulee, NSW, Australia*

Abstract: This case report presents as a maxillary "cluster-failure", where six moderately rough-surface oral implants (1-2 microns) were installed to support a full-arch hybrid bridge. Understanding cluster failures requires the acknowledgment of biofilm science that recognizes the persistence of bacterial infection in bone following extraction and the need to bioremediate the bone-bed, by surgical debridement, before implant installation. The patient, a 54-year-old, non-smoking, female sought full-arch implant rehabilitation following the extraction of teeth with chronic endo/periodontal disease. Approximately six years after the fitting of a 12-tooth titanium hybrid prosthesis, the patient presented with a prosthesis that was mobile. All six moderately rough surface implants, (4 etched and 2 anodized), presented with destructive cupping bone loss that resulted in 100% circumferential loss of all previously integrated threaded surfaces. Further, the implant surfaces were corroded and blackened. Histopathology of bone samples taken from the surrounding maxillary bone and implant surfaces showed necrotic bone with associated inflammation, in keeping with osteomyelitis. The bone marrow showed evidence of fibrosis with mixed inflammation comprising neutrophils, plasma cells, and lymphocytes, the degree of which was more pronounced in bone sampled from the anodized implant surfaces. This finding supports the definition of biomaterial failure provided in orthopedics, where biofilm infection of the implant surface is accompanied by chronic osteomyelitic (biofilm) infection of the adjacent bone. Planktonic bacterial cells cannot corrode metal surfaces, however, the cumulative activity of live bacterial biofilm phenotype communities are capable of degrading complex substrate surfaces by robbing electrons and altering metal surfaces-Microbially Influenced Corrosion (MIC). Corrosion of metal surfaces correlates directly with significantly increased adhesive potential with increased surface area in the micrometer range, increasing bacterial biomass and pathogen adhesion for rough versus smooth surfaces. Increasing the surface roughness encourages bacterial adhesion, immunomodulation, quorum sensing, relapse infection, and the potential degradation of biotic and abiotic surfaces. Increasing biomaterial surface roughness also conflicts with the fundamental understanding of biofilm science which mandates the need to prevent or inhibit bacterial adhesion. Smooth and uniform (cell-like) surfaces evade pathogen adhesion and are accessible to cell-surface microfluid flow which prevents the adhesive retention and accumulation of autoinducers, which facilitate cell-to-cell communication quorum sensing and biofilm-mediated relapse infection.

Keywords: Microbially Influenced Corrosion, Resident Human Jawbone Microbiome, Moderately Roughened Dental Implants, Cluster Implant Failure, Destructive Bone Loss

Introduction

The gold standard in enduring osseointegration remains the smooth, turned implant (Nobelpharma Gothenburg, Sweden) in Fig. 1. Ensuring patient safety and welfare is at the heart of ethical healthcare and this philosophy is encapsulated by the phrase "first, do no harm" (primum non nocere). In the context of implant dentistry, this means that if an implanted device fails, it should fail in such a benign manner that the patient is no worse off than if they had not received treatment in the first place (Brånemark *et al.*, 1985). This case report will illustrate that our observations do not support the benign failure of some modified or roughened surface endosseous dental implants. Chrcanovic *et al.* (2017) defined cluster failure as at least three implant failures in one patient. In a study with 8337 patients, 56.8% of all implant failures exhibited cluster behavior. While several systemic and local factors were discussed including intake of antidepressants and bruxism, a causal relationship was not identified. Jemt and Häger (2006) historically presented cluster failure in full arch hybrid cases and were confident of a significant contribution made to cluster failure by bone quality. However, they made no intellectual or radiographic connection between the cluster failure and the health/disease status of the pre-existing failed dentition, or microbial pathology. The sterile bone model prevailed even when it was not supported by a methodology suited to the detection of bacterial biofilms (Tipton *et al.*, 2017). We have established that bone quality is directly linked to the supported, resident, microbial ecological populations (Nelson, 2015; Nelson *et al.*, 2023a-b). As a result, the site-specific resident bacterial biofilm phenotype (Ciofu *et al.*, 2022) becomes the determinant of microbial ecological health and disease and bone quality.

Any implanted device can fail, however, there appears to be a significant difference in the mode of failure of modified surface dental implants, when compared to smooth (Sa < 1micron) surface implants (Nobelpharma Gothenburg, Sweden); moderately roughened suffering significantly greater peri-implant bone destruction, than smooth (Fig. 2).

Case Report

This case study highlights the relationship that exists between the resident bacterial biofilms in the human jawbone, Microbially Influenced Corrosion (MIC), and the resultant destructive peri-implant bone loss.

Patient Presentation and Initial Treatment

Previous papers (Nelson, 2015; Viljoen, 2019; Nelson *et al.*, 2023a-b) discuss the need to return the bone bed to homeostatic health before implant installation. This case presentation discusses the adverse outcome that can potentially occur when modified surface implants, both etched and anodized, are placed into a bone bed that has not been returned to homeostatic, microbial, and radiographic ecologic health.
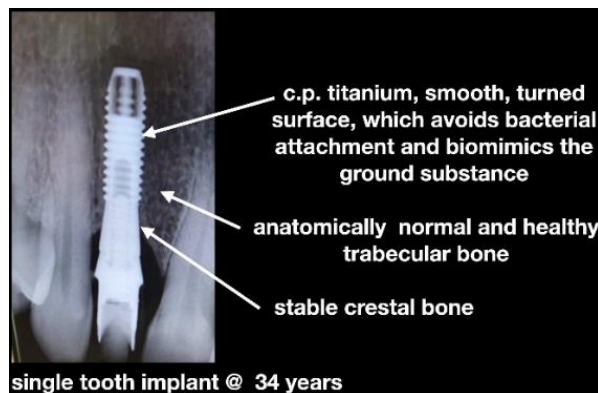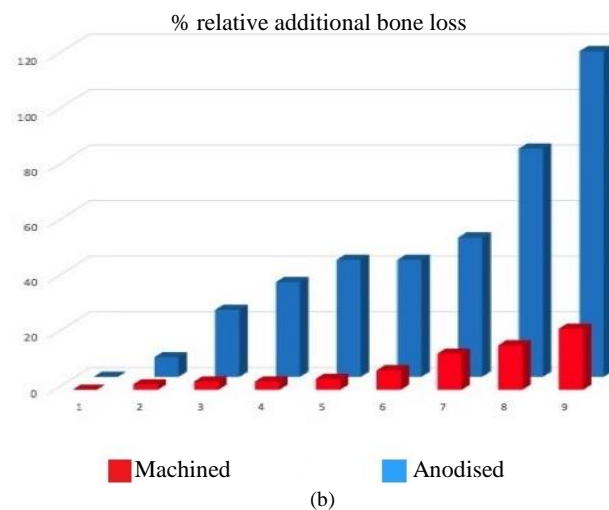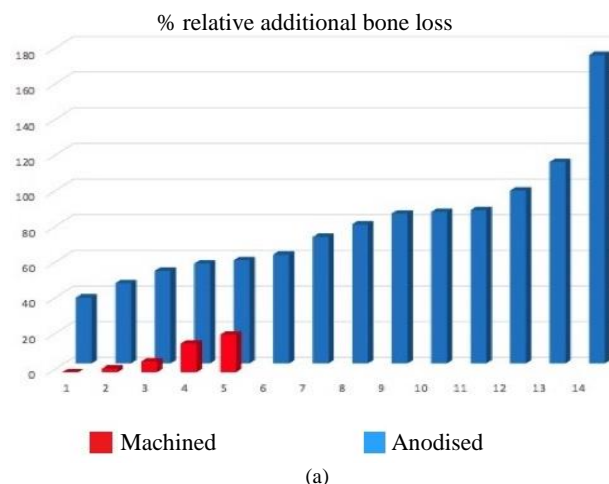

Fig. 1: The gold standard in implant dentistry - enduring osseointegration after 34 years of continuous function

(a)

(b)

% relative additional bone loss
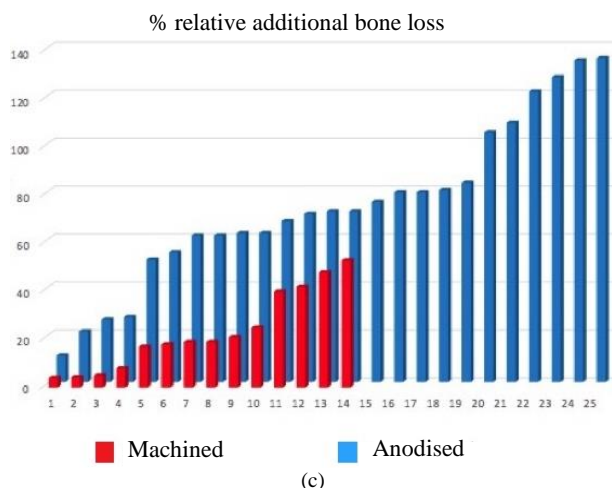
■ Machined   ■ Anodised

(c)

Fig. 2: 2D volumetric analysis of peri-implant bone loss around smooth (machined) versus anodized (roughened) dental implants (Nobel Biocare, Kloten, Switzerland), taken from three private practices (clinics a, b and c). Note the bone loss in anodized implants (Sa >1) (blue) is significantly greater than about smooth (Sa <1) (red) implants (Viljoen, 2019)
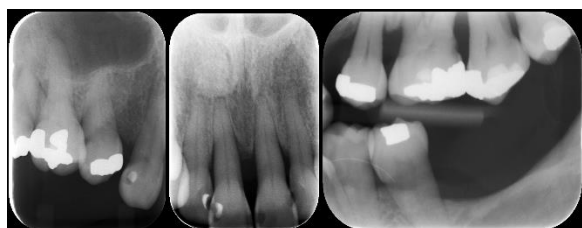

Fig. 3: Terminal maxillary dentition with severe periodontal involvement of the maxillary dentition
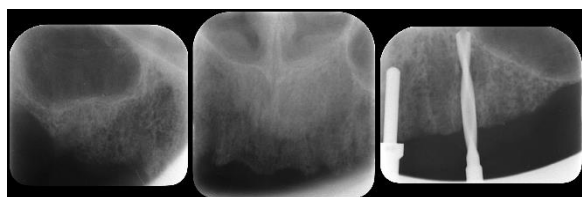

Fig. 4: 7 Months post-extraction. Clinical and radiographic examination showed a residual maxillary ridge suitable for the installation of 6 endosseous dental implants

A 54-year-old non-smoking female patient presented with a periodontally terminal dentition and requested treatment options (Fig. 3).

The patient had undergone several periodontal interventions and was reluctant to undergo further treatment. Ultimately, it was decided that her most practical option was a maxillary clearance and, initially, the fitting of an immediate Full Upper Denture (FUD).

Treatment was carried out in November 2012 under local anaesthetic and an immediate full upper denture was fitted. No regenerative surgical debridement was carried out and a 6-month healing period was allowed, during which several soft relines of the full upper denture were carried out. Healing was uneventful. This healing period allowed the patient to decide whether she could accept and adapt to the FUD, or whether further treatment using dental implants was required.

The patient had considerable difficulty adapting to the FUD and after several months, requested a transition to an implant-supported, fixed prosthesis. Clinical and radiographic examination of the bone bed indicated sufficient hard tissue support for a 6-implant hybrid-type prosthesis. Based on sterile bone teaching at that time, the bone bed was presumed to have spontaneously healed and returned to sterility (Fig. 4).

However, closer examination of the radiographs, clearly shows residual areas of lysis, confined by sclerosis, both in the posterior and anterior maxilla. Lysis surrounded by sclerosis is a known biomarker of bone disease (Parfitt, 1962) (Fig. 5).

At the time, the authors were unaware that the bone exhibiting these biomarkers needed to be surgically debrided before implant installation, as our subsequent research showed that this bone type supported pathological biofilm communities and implant installation was contra-indicated without first returning the bone microbial ecology to health, through regenerative surgical debridement.

Implant Treatment

Two-stage implant installation was carried out in June 2013 under local anesthetic, using a sterile surgical technique and modem Brånemark. recovery was uneventful and the implants were uncovered 6 months later and healing abutment attached. All 6 implants exhibited excellent primary stability, although one implant had lost a few threads of bone coronally (Fig. 6). A twelve-unit titanium and acrylic bridge was constructed and issued in February 2014.

The patient was recalled at twelve months and the prosthesis was removed and all implants were firmly integrated. The bridge was cleaned and re-fitted and the occlusion checked.
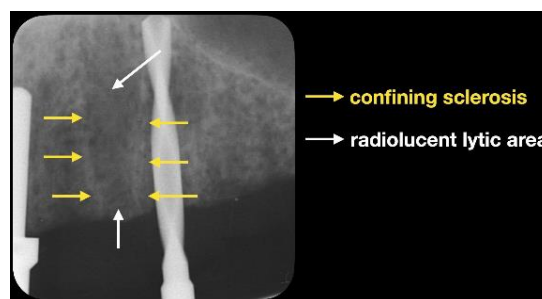

→ confining sclerosis
→ radiolucent lytic area

Fig. 5: Note areas of lytic and sclerotic bone that remain, even after several months of tooth removal, harboring pathologic biofilm niduses
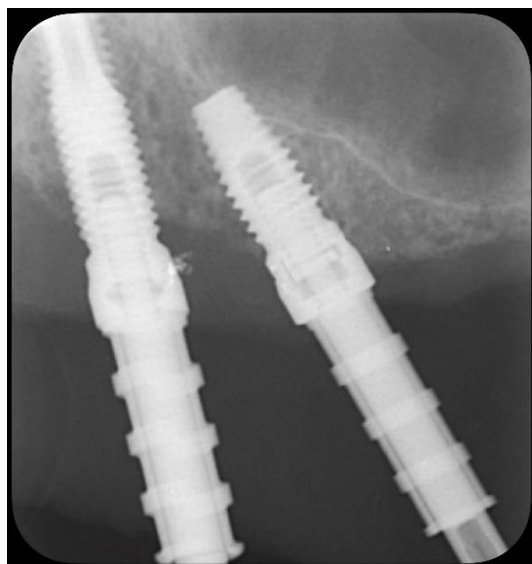
Fig. 6: Implants at the time of impression taking. Note the implant in the canine region has lost a few threads of bone

Fig. 7: Hybrid bridge complex immediately after removal. 6-year "cluster" failure of 6 moderately roughened (1-2 micron) maxillary implants with corrosion of all surfaces. Histopathology of failed maxillary osteotomy sites and bone removed from implant surfaces was the same: Chronic osteomyelitic bone, confirming Zimmeli's (2014) observation that biomaterial failure is a biofilm infection of implant surface accompanied by chronic osteomyelitis in the supporting bone
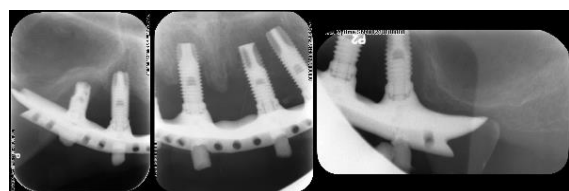

Fig. 8: Radiographs showing complete loss of osseointegration, with significant destruction of the hard tissues, in the form of (destructive) cupping bone loss, quite unlike the benign failure of smooth surface implants

Final Outcome

The patient was a poor attender, even though she lived only an hour's drive away. Despite being sent an annual recall, her next attendance was 5 years later and the hybrid bridge was mobile. The prosthesis and its associated implants were easily removed by hand without local anesthetic (Fig. 7).

The maxilla was then anesthetized with local anesthetic and bone samples were taken from within the cupping bone loss defects (Fig. 8).

Note the black (corroded) maxillary implants in Fig. 7. Costerton and Boivin (1991) stated "that this very deleterious process is the cumulative activity of biofilm communities that rob electrons and alter metals. Corrosion control is now increasingly based on the detection and control of biofilm populations". Significantly increased adhesive potential with increased surface area in the micrometer range (Berne *et al*., 2018) increases bacterial biomass and pathogen adhesion on rough versus smooth implants (Bermejo *et al*., 2019).

The histopathology of the bone spicules on the blackened implants and infected bone ridges were all similarly osteomyelitic. Significantly, this was not a foreign body reaction; this was a living biofilm infection resulting in the MIC of the metal surfaces. Zimmerli (2014) stated that "indwelling medical devices fail by biofilm infection of the surface, accompanied by biofilm infection of the bone, in the form of chronic osteomyelitis".

Pathology Report (09/07/19) (Lab Reference: 19-18584231)

Macroscopic Examination

Specimen 1: Bone spicules removed from the surface of failed anodized implants
Specimen 2: Bone spicules removed from the surface of failed etched implants
Specimen 3: Bone fragments removed from infected bone osteotomies, left maxilla
Specimen 4: Bone fragments removed from infected bone osteotomies, right maxilla

Microscopic Examination

The histologic report stated that "All of the specimens are relatively similar and comprise fragments of mature lamellar bone, many of which are necrotic. The bone marrow surrounding these bony trabeculae show evidence of fibrosis together with mixed inflammation comprising of neutrophils, plasma cells, and lymphocytes, the degree of which is more pronounced in specimen 1" (bone spicules removed from the surface of the anodized failed implants). "The overall features are in keeping with an infected bone osteomyelitis".

Discussion

The new understanding that human jawbone may support resident biofilm populations (Kassolis *et al.*, 2010; Nelson and Thomas 2010; Nelson, 2015; Viljoen, 2019, Nelson *et al.*, 2023a-b), requires implant dentists to re-assess the supposed benefits of using implantable devices with surfaces attractive to the formation of bacterial biofilms, both with regards to post-osseointegration infection and corrosion (Nagay *et al.*, 2022). Kudo *et al.* (1987) showed that biofilm formation enables metabolically cooperative bacteria to form stable, multi-species consortia which are essential in the degradation of complex substrates, and that biofilm communities are inherently much more active than planktonic populations. Similarly, it became apparent that planktonic cells cannot corrode metal surfaces, but rather that this very deleterious process is the cumulative activity of biofilm communities that rob electrons and alter metals (Costerton and Bovin, 1991). In contrast to the infective failure of modified surface implants (Fig. 9c), failure of turned implants does not present with visually corroded surfaces and when removed and along with a thin, non-destructive, peri-fixtural fibrous capsule, rather, they look "like new", that is, there is no evidence of corrosion or alteration of the implant surface because of MIC (Fig. 9b).

Commercially pure (c.p.) titanium was chosen as a suitable metal for implantation because of its mechanical strength, machinability, modulus of elasticity, and chemical properties, one of which is a high corrosion resistance. The thin layer of Titanium Oxide (TiO, Ti_2O_3, and TiO_2) that coats the metal is stable, inert, and highly corrosion-resistant when the surface roughness is < 1 micron. From 1965 to the early 2000s, the international benchmark oral implant producer, Nobelpharma/Nobel Biocare, used turned, smooth surface implants with a Sa value of <1 micron. However, as corporate competition increased, with other producers promoting the advantages of modified surfaces, both additive and subtractive, Nobel Biocare introduced an additive, porous, anodized surface. None of these new, modified surfaces were subjected to long-term, pre-market trials, although initial short-term results appeared favorable. The implant bone bed was thought to return to sterility following the extraction of an infected tooth and variations in histologic and radiographic anatomy (Lekholm, 1985) were deemed to be simply variations of normal, healthy bone. The bone-bed was regarded as sterile (Brånemark *et al.*, 1985).
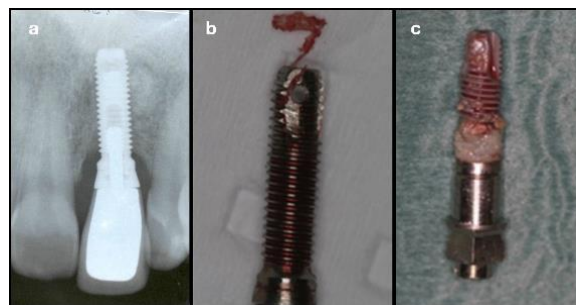

Fig. 9: (a) Failed smooth surface implant at ten years. Note super-eruption of implant crown and minimal peri-implant bone loss; (b) Implant at the time of removal; there is no corrosion and the implant surface remains smooth and shiny. The implant was held in place by a vital bone bridge through the apical hole; (c) Compare the biofilm-evading-surface of the turned implant in; (b) To the biofilm-encrusted surface of the failed anodized implant in (c)

Conclusion

This case presentation reinforces previous research supporting the argument that:

i. The human jawbone supports resident, living, biofilm communities, even after infected tooth removal and an extended healing period

ii. C.p. titanium is a preferred material for use in dental implants because, amongst other properties, it is highly corrosion resistant. However, when its surface is roughened, either by subtractive or additive methods and it is subjected to sustained bacterial biofilm attack, it can corrode

iii. If the pre-implant bone-bed harbors communities of pathologic biofilm, then without regenerative surgical debridement, a return to microbial ecological and anatomical health (H_2 and H_3 Nelson and Viljoen) will not occur spontaneously and subsequent implant installation will not result in enduring osseointegration

iv. The human jawbone needs to be returned to health and microbial ecological homeostasis before implant installation

v. Implant surfaces with a Sa value greater than 1 micron are at much greater risk of planktonic bacterial attachment and biofilm formation, (either metabolically active or a persister phenotype), with quorum sensing, loss of microfluid cleansing, endotoxin production, and ultimately, abiotic and biotic bone loss and implant-complex failure, than smooth surface implants

vi. Smooth implant surfaces have the advantage over roughened surfaces in that they biomimic the human

cell surface, are resistant to the formation of sessile biofilm communities of any phenotype, are resistant to MIC, and have been shown by multiple long-term studies to provide enduring osseointegration

The Brånemark turned or machined implant surface is the benchmark reference with regard to optimal surface topography. Its Sa value of <1 micron, biomimics the surface topography and microarchitecture of the ground substance and evades bacterial attachment and biofilm formation. Brånemark *et al.* (1985) observed no immunobiological event (immunomodulation), no surface corrosion, and minimal levels of host tissue destruction even in infective failure, without destructive (sometimes maiming) cupping bone loss seen with modified surfaces.

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Author Contributions

Stephen Nelson: Conception and designed, acquisition of data, interpretation of data, drafted and critically reviewed for significant intellectual content, final approval given for submission.

Helen Hu, Anand Deva, Andre John Viljoen and Karen Vickery: Analysis and interpretation of data critically reviewed for significant intellectual content final approval given for submission.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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