# On Osseointegration: The Healing Adaptation Principle in the Context of Osseosufficiency, Osseoseparation, and Dental Implant Failure

Sreenivas Koka, DDS, MS, PhDª/George Zarb, BChD, DDS, MS, MS, FRCD(C)<sup>b</sup>

The host-implant interface is remarkably enduring given the functional and biologic challenges it faces, and our success in assisting patients to lead better lives because of implant biotechnology is the envy of many other health care practitioners. It is therefore vital that dentists accept that clinically significant marginal bone loss is uncommon and that implant failure is rare. In this paper, important elements regarding why implants experience marginal bone loss, why implants may fail as a result of such bone loss, and how to describe the continuum of bone loss with respect to patient-mediated outcomes are outlined. *Int J Prosthodont 2012;25:48–52.* 

ental implant failure as a result of progressive Dmarginal bone loss is an infrequent occurrence. The work of Laurell and Lundgren<sup>1</sup> provides clear and compelling evidence that a significant majority of dental implants, from diverse implant systems and placed in a vast number of patients, experience little marginal bone loss. However, despite its remote occurrence, the risk of implant failure confronts all of us practitioners, since such failure may have catastrophic consequences for both our patients and our psyches. Although it is the implant that fails, we clinicians are prone to personify the failure and make it our own, regardless of our inability to prevent it. It may even be tempting to rationalize implant failures as "varying degrees of success," or even dismiss their occurrence as "stuff happens." Hence, there is a need to remove emotional biases and remain objective as we ask, "Why do implants fail?"

We propose a rational theory wherein host biology and implant characteristics are viewed as two separate entities expected to interface and coexist over decades. We suggest that if the host and implant each bring enough ingredients to the recipe, a successful interface will form and be maintained. We assign the term *osseosufficiency* to this concept of "enough," with the understanding that the desired osseointegration outcome results. We assign the term *osseoseparation* to the state of insufficiency or suboptimal osseointegration that is manifested as a progressively compromised interface with loss of marginal, or indeed interfacial, bone around an implant. We also propose degrees of osseoseparation indicative of the extent of marginal bone loss.

# The Healing Adaptation Principle in the Context of Osseosufficiency

In general terms, the healing adaptation principle suggests that a host site that receives a dental implant must meet all challenges related to the initial healing and long-term function if the implant is to survive. A site that is unable to heal will manifest early implant failure, and a site that heals initially but does not maintain integration will fail later. Put another way, the healing phase can be considered as the "promotion" of integration, and successful adaptation as its "perpetuation."

It is recognized that these are broad statements about the general interfacial healing phenomenon. Nevertheless, the theory is proposed to offer, in conceptual terms, a much-needed widespread view of the host-implant interface since the majority of discussions focus on a microappraisal of the interface, yielding a forest (of host and implant) indistinguishable from the constituent trees (of cells, proteins, genes, polymorphisms, surface treatments, platform, smoking, diabetes, bisphosphonate use, titanium, hydroxyapatite, and so on).<sup>2</sup>

The best and perhaps only way to deduce the importance of specific variables that we think might be important regulators of the host-implant interface is through long-term clinical observation. Short-term observation periods, animal models, and in vitro work may give us clues, but long-term human observation is the ultimate arbiter. To that end, numerous centers such as the University of Toronto and Mayo

<sup>&</sup>lt;sup>a</sup>Professor of Dentistry, Division of Prosthodontics, Mayo Clinic, Rochester, Minnesota, USA.

<sup>&</sup>lt;sup>b</sup>Professor Emeritus, University of Toronto, Toronto, Ontario, Canada.

**Correspondence to:** Dr Sreenivas Koka, 200 First Street SW, Rochester, MN 55905. Fax: 507-284-8082. Email: koka.sreenivas@ mayo.edu



**Fig 1** Effect of smoking status on implant survival. (Reprinted from Holahan et al<sup>5</sup> with permission.)

Clinic have provided resources of invaluable information regarding treatment outcomes. The Toronto prospective studies were initiated in the late 1970s as an integral part of a competitively achieved Canadian government grant, subsequently sustained by funding from Nobel Biocare,<sup>3,4</sup> and carried out by clinical specialty graduate students under staff supervision. The Mayo Clinic practice, on the other hand, represents one of the longest-running private group prosthodontic and surgical practices in the world, and none of the relevant papers cited were supported by industry. We refer to three published human clinical observation papers from the Mayo Clinic database of over 15,000 implants placed in over 6,000 patients dating back to 1983.5-7 So, how do these studies shed light on hostand implant-directed osseosufficiency?

Holahan et al<sup>5</sup> showed the effect of smoking on implant failure in postmenopausal women. The Kaplan-Meier curve demonstrates that implants in smokers fail at a higher rate in the first year after placement and that an implant that survives 1 year in a smoker has a similar survival pattern as an implant that survives 1 year placed in a nonsmoker (Fig 1). Application of the healing adaptation principle would conclude that smoking affects healing (promotion of integration) but does not affect adaptation (perpetuation of integration). Indeed, it is apparent that in some patients, smoking renders the host insufficient to support initial osseointegration. Interestingly, however, implants that do integrate in smokers attain a level of sufficiency indistinguishable from successful implants in nonsmokers.

In contrast, an example of successful promotion and unsuccessful perpetuation was presented in the study by Buddula et al,<sup>6</sup> wherein implants placed in irradiated bone showed outstanding early implant survival rates only to have significantly higher failure rates



**Fig 2** Kaplain-Meier curves for implant survival by type of implant and smoking status. (Reprinted from Balshe et al<sup>7</sup> with permission.)

at 10 years post-implant placement. Here, radiation did not render the host insufficient to support initial osseointegration. Instead, the host was unable to provide long-term sufficiency.

The importance of osseosufficiency is apparent at the implant level as much as at the host level. A potentially insufficient state provided by the host can be overcome by implant characteristics to provide osseosufficiency as a result of the net contributions of the host and implant. An excellent example of an implant characteristic that overcomes host insufficiency is seen in the work of Balshe et al.7 This study offers clear evidence that the increased risk of implant failure in smokers who present an insufficient state is abrogated by use of implants with a modified implant surface, in this case, an anodized, rough surface (Fig 2). Indeed, it appears that whereas the combination of a smoker host and a smoothsurfaced machined titanium surface is more frequently insufficient, the combination of a smoker host and a modified titanium surface is just as likely to be sufficient as the combination of a nonsmoker host and a modified titanium surface. The important conclusion is that host insufficiency can be mitigated by an implant's microsurface morphology.

Taken together, these data offer scientific evidence that implant survival over the short and long term is influenced by properties of both the host and implant. As long as the combined effect of the properties promotes and perpetuates osseointegration, an implant will survive. Should either the host or implant present with suboptimal properties, implants may not integrate or, once integrated, may not maintain optimal supporting bone.

Diagnostic measures should be undertaken with the intent of determining host sufficiency so that potential insufficiency can be considered. If insufficiency cannot be overcome by implant characteristics, the patient should be informed of the higher risk for implant failure (short or long term). Well-conducted clinical outcome trials are certainly needed to establish the risk factors associated with osseosufficient and osseoinsufficient states with greater clarity and confidence.

# The Healing Adaptation Principle in the Context of Osseoseparation

Fortunately, marginal bone loss around implants is a slow, progressive condition. This affords clinical scholars the opportunity to study the long-term behavior of edentulous bone (see Zarb and Koka editorial in this issue, page 11) and the accompanying manifestation of marginal bone loss. However, flawed clinical decisions regarding selection of unfavorable host sites' bone dimensions for implant placement remain a frequent cause of dramatic and regrettably predictable marginal bone loss. This is encountered all too frequently in the anterior maxilla when implant volume "overwhelms" that of the available host site, and the engaged labial or buccal bone plates become inadvertently programmed for rapid vertical reduction.8 A similar situation is encountered in the posterior bone quadrants, which probably accounts for the higher degree of failure in wide-bodied implants.9 The availability of optimal pretreatment radiographic imaging should preclude this additional challenge to osseosufficiency and resultant secondary surgical interventions that seek to camouflage such surgically induced esthetic and even functional mishaps.

The degree of marginal bone loss can have minor or significant consequences when viewed from such functional and esthetic standpoints, especially when favorable circumoral labial morphology is present. Therefore, conceptualizing marginal bone loss with an appreciation for patient-mediated expectations is crucial to understanding the importance of such bone loss and any possible need for therapeutic measures. We propose the concept of osseoseparation to describe stages of marginal bone loss and provide simple-to-use but profoundly important guidelines for clinicians to assess, and where feasible select, the best management options over the long-term.

# Osseointegration, stage 0 osseoseparation (Figs 3a to 3e):

- · Implant is asymptomatic and immobile.
- "Nuisance gingivitis" may or may not be present and easily rectified.

- Marginal bone loss is minimal.
- Eligible for prosthodontic abutment service with a predictable esthetic outcome.

#### Stage I osseoseparation (Figs 4a and 4b):

- Implant is asymptomatic and immobile.
- Gingivitis may or may not be present.
- Eligible for prosthodontic abutment service, although marginal bone loss and minimal accompanying implant material exposure may preclude a satisfactory esthetic outcome.
- Readily managed with routine debridement and oral hygiene protocols.
- Additional clinical intervention is not required because of noncompromising site location, eg, favorable circumoral lip morphology. Alternatively, minor prosthetic design alterations may be indicated.

#### Stage II osseoseparation (Fig 5):

- Implant is asymptomatic and immobile.
- Gingivitis is often present.
- Frequently precludes esthetically satisfactory prosthodontic outcome since the amount of marginal bone loss also exposes implant threads.
- Favorable oral hygiene considerations or a satisfactory esthetic outcome cannot be achieved without secondary changes in prosthesis design or attempting secondary plastic gingival surgical interventions.

#### Stage III osseoseparation (Fig 6):

- Bone loss location may be variable and often substantial, although the implant(s) remain(s) asymptomatic and immobile.
- Gingivitis almost invariably present.
- Only eligible for prosthodontic abutment service if resultant esthetic and oral hygiene concerns can be rectified by additional interventions.
- Treatment outcome and prognostic considerations (both patient- and dentist-mediated ones) frequently demand change(s) in the original treatment plan, including removal of the implant(s) and surgical site development.

#### Stage IV osseoseparation (Fig 7):

- Implant is usually symptomatic, and slight mobility is almost invariably present.
- Bone loss may present as either inconsequential or substantially so.

Figs 3a to 3e Clinical examples of Stage O separation.











**Figs 4a and 4b** Clinical example of stage I osseoseparation with minimal bone loss accompanying gingival recession and good oral hygiene. Circumoral morphology readily camouflages so-called "black triangles."

- Gingivitis may or may not be present.
- Biologic failure of the osseointegration process has occurred (early failure) or has developed gradually on an osseoinsufficiency/time-dependent basis (late failure).



## The Elephant in the Room

The concepts of healing adaptation, osseosufficiency, and osseoseparation are merely starting points for a discussion on how an implant interfaces with host bone over time either in optimal or suboptimal states. But what leads to insufficiency and osseoseparation? Some factors that predispose an insufficient state create little controversy, eg, the uncontrolled diabetic. Other factors, such as parafunctional habits and occlusal overloading, medications (eg, history of bisphosphonate use), or bacterial insult (eg, periodontopathogens) are speculative and controversial. Disappointingly, for a profession in search of evidence-based practice, our fragile emotions override our ability to acknowledge that there is a difference between cause and effect and association. The biases evident in experimental design and data interpretation are compounded by the risk of human weakness of being subjectively influenced when conducting industry-sponsored research.<sup>10,11</sup> The unwillingness to acknowledge these

© 2011 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART OF MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER



Fig 5 Clinical example of stage II osseoseparation.



Fig 6 Clinical example of stage III osseoseparation.

**Fig 7** *(left)* Radiographic example of stage IV osseoseparation. (Courtesy of Drs Daniel Assad and Eddie Morales, Mayo Clinic, Rochester, Minnesota.)



influences threatens our credibility as stewards of our patients' oral health. We hope that clinicians will utilize the osseoseparation staging system with the intent of keeping intervention to a minimum and not as an excuse for costly therapies undertaken on an unwitting and trusting patient population. Our concerns are also readily reconcilable with emerging evidence from bone regeneration and tissue-engineering research to provide a scientific context for therapeutic intervention.<sup>12</sup> The lack of basic analyses of harm, outcome, benefit, risk, patient-centeredness, and costeffectiveness before embarking on unjustifiable therapies is easy to understand but impossible to defend.

### References

- Laurell L, Lundgren D. Marginal bone level changes at dental implants after 5 years in function: A meta-analysis. Clin Implant Dent Relat Res 2011;13:19–28.
- Cooper LF. Is the tissue-integrated interface a periodontium analogue: Myth or metaphor? Int J Prosthodont 2003;16(suppl): 32–34.
- Attard NJ, Zarb GA. Long-term treatment outcomes in edentulous patients treated with overdentures: The Toronto study. Int J Prosthodont 2004;17:425–433.

- Attard NJ, Zarb GA. Long-term treatment outcomes in edentulous patients with implant-fixed prostheses: The Toronto study. Int J Prosthodont 2004;17:417–424.
- Holahan CM, Koka S, Kennel KA, et al. Effect of osteoporotic status on the survival of titanium dental implants. Int J Oral Maxillofac Implants 2008;23:905–910.
- Buddula A, Assad DA, Salinas TJ, Garces YI, Volz JE, Weaver AL. Survival of turned and roughened dental implants in irradiated head and neck cancer patients: A retrospective analysis. J Prosthet Dent 2011;106:290–296.
- Balshe AA, Eckert SE, Koka S, Assad DA, Weaver AL. The effects of smoking on the survival of smooth- and rough-surface dental implants. Int J Oral Maxillofac Implants 2008;23:1117–1122.
- Hartman GA, Cochran DL. Initial implant position determines the magnitude of crestal bone remodeling. J Periodontol 2004;75:572–577.
- Shin SW, Bryant SR, Zarb GA. A retrospective study on the treatment outcome of wide-bodied implants. Int J Prosthodont 2004;17:52–58.
- Balevi B. Industry sponsored research may report more favourable outcomes. Evid Based Dent 2011;12:5–6.
- Popelut A, Valet F, Fromentin O, Thomas A, Bouchard P. Relationship between sponsorship and failure rate of dental implants: A systematic approach. PLoS One 2010;5:e10274.
- Giannobile WV, Nevins M (eds). Osteology Guidelines for Oral and Maxillofacial Regeneration: Preclinical Models for Translational Research. Chicago: Quintessence, 2011.

© 2011 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART OF MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER

Copyright of International Journal of Prosthodontics is the property of Quintessence Publishing Company Inc. and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.