Biologic Interfaces in Esthetic Dentistry. Part II: The Peri-implant/ Restorative Interface*

****Arndt Happe,** Dr med dent, DDS
Private practice, Münster, Germany
Research Fellow, Department of Oral and Maxillofacial Plastic Surgery, University of Cologne

****Gerd Körner,** Dr med dent
Private dental practice, Bielefeld, Germany
Educational Board Member, Dresden International University (DIU)

* This article is Part II of a two-part review on biological interfaces in esthetic dentistry that took place at the European Association of Esthetic Dentistry (EAED) Active Members Meeting in October 2010 in Tremezzo, Italy. Please see Part I *(Eur J Esthet Dent 2011;6:206–224)* for discussion of the perio/restorative interface.

** Both authors contributed equally to this article.

Correspondence to: Arndt Happe
Schützenstr. 2; D-48143 Münster, Germany
tel: 0251 45057; fax: 0251 40271; e-mail: a.happe@dr-happe.de

Prologue

By Joerg Rudolf Strub

Many factors have been proposed to interact with the peri-implant tissue, thus influencing long-term stability and esthetic outcome such as quality of peri-implant tissue, implant abutment interface (microgap), material and design of implant abutment, and surgical and prosthetic procedures. Other factors are: presence of attached gingiva, type of provisional restorations, and oral hygiene procedures.

The design of the implant–abutment interface is important because it is one of the primary determinants of prosthetic stability. The nature of this interface makes it sensitive to mechanical overloading and bacterial contamination, giving rise to many problems such as micromovements, loosening of abutment screws, and microbial colonization, which result in peri-implant inflammation and marginal bone resorption. Many designs of implant abutments, including interface, have been introduced in an attempt to overcome these problems. One design concept is "platform switching" which refers to the use of a small diameter abutment on a larger diameter implant collar. Other implant abutment designs include scalloped implants and gingivally converging implants. Studies show many controversies concerning the effectiveness of these designs on preserving peri-implant tissues, and

recommendations for use must be based on clinical evidence that new designs are effective in accomplishing what is claimed.

Because of its well-documented biocompatibility and mechanical properties, implant abutments are mainly being fabricated out of commercially pure titanium. Nevertheless, the risk of metal components being visible, especially through thin peri-implant tissues, remain a risk. Today, aluminium oxide and zirconium oxide are being used to fabricate esthetic implant-supported restorations. Here, it is noteworthy to mention that mucosa thickness is a crucial factor in terms of discoloration, as it has been suggested that with a mucosa thickness of 3 mm, no change in color can be distinguished with any type of material.

Another factor that may affect the osseous and soft tissue stability is the surgical procedure. The original protocol for implant placement is the 2-stage procedure, in which the implant is placed in the first surgery, then after a healing period between 2 and 4 months, a second surgery is required to uncover the implant body and connect the abutment. This 2-stage technique was improved upon with a 1-stage procedure, which has the advantage of requiring only one surgery. Implant surgeries can also be classified according to the time of implant placement into “immediate,” “late,” or “delayed.” Several studies have been carried out in order to investigate whether the time of implant placement may affect the peri-implant tissues. Immediate implant placement has been suggested to be a possible solution for maintenance of soft and hard tissue architecture. In contrast, a number of studies showed that even with immediate implant placement, the process of bone resorption was not avoided.

Assessment of the quality of the peri-implant tissue is important for implant-supported restorations. Tissue scallop, defined as the distance between the mid-facial and interproximal facial height, has been categorized as either flat or scalloped. Tissue biotype, which is defined as the thickness of the soft tissue in the buccolingual dimension, has been classified as being either thick or thin. It has been reported that implant sites with a normal or pronounced tissue scallop and a thin biotype are more prone to recession.

Introduction

The peri-implant restorative interface is a highly relevant subject for scientific research, as it may be the key to longevity of implant restorations and sustainability of implant esthetics.

Different factors have been identified and reported to interact with the peri-implant tissues, respectively influence the vertical localization of the crestal bone and the dimension and localization of the peri-implant soft tissues. These are the individual morphotype,[1] the peri-implant tissue quality,[2] the restorative environment,[3] and the property of the abutment,[4] including nature of the abutment connection.[5]

Quality of the peri-implant soft tissue seems to influence the implant success in the long run, especially when implant esthetics are concerned. All two-piece implant systems share the problem of leakage and contaminations of peri-


Fig 1-1a and 1-1b Although these implants survived many years and are still in function, these patients do not consider these results successful and asked for a retreatment.

implant tissues. There is no evidence that individual abutments made of gold alloy bear a risk for crestal bone loss and soft tissue recession. Ceramic abutment materials are superior to metal abutments in terms of esthetics, and CAD/CAM technology has a great potential for individual full ceramic abutment design for the esthetic zone. The clinical performance of zirconium dioxide as an abutment material is comparable to the gold standard titanium and even better in terms of biology and tissue integration, but surface properties such as surface roughness have to be taken into account. Platform-switching shows encouraging results, but is a multi-factorial phenomenon with some still unexplained mechanisms.

The intention of this article is to give a survey of the current findings in related literature addressing these factors. Moreover, the clinical interpretation of these findings as it affects the clinical protocols – especially in the esthetic zone – will be discussed.

Essay 1: Quality of peri-implant tissues, long-term stability and longevity. Is there a correlation?

Soft tissue interface

To be functionally useful, oral implants have to pierce the gingiva or oral mucosa and enter the oral cavity, thus establishing a transmucosal connection between the external environment and the inner parts of the body.

In order to avoid bacterial penetration that could jeopardize either initial healing or long-term success of implants, the formation of an early and long-standing effective barrier is a critical part of tissue integration and has to lead to an effective interface between living tissues and a foreign body. Besides osseointegration, this soft tissue integration is a key factor for implant success.[6]

The soft tissue interface has been histologically assessed in animals and has a

Fig 1-2 Lip line exposing papillae.

Fig 1-3 Failing tooth 11 due to root fracture.

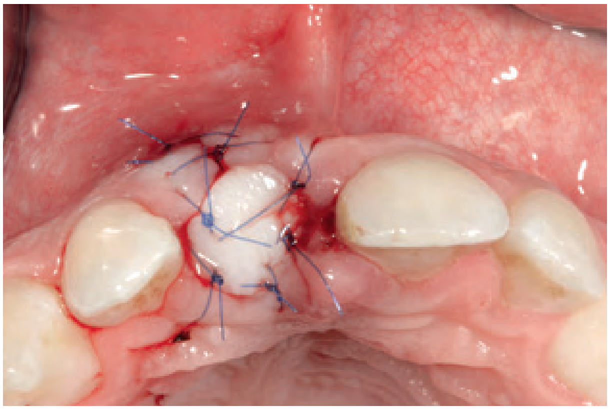


Fig 1-4 Post-extraction soft tissue management with free gingival graft. Buccal lamella not present. A xenograft serves as a temporary filler in the socket.

Fig 1-5 Uneventful healing after 6 weeks. The contour of the ridge was preserved and provides a natural soft tissue envelope for bone augmentation.

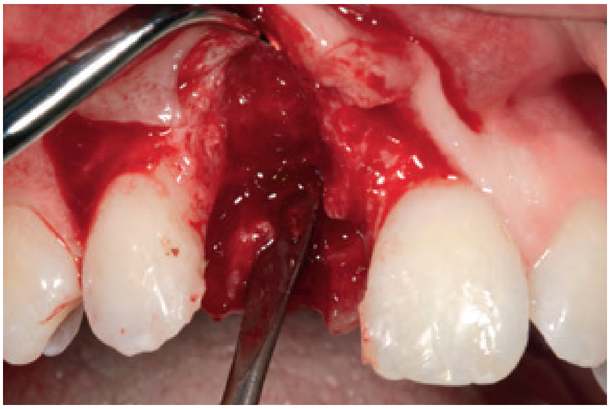


Fig 1-6 Flap reflection reveals the three-dimensional ridge defect after removing the filler.

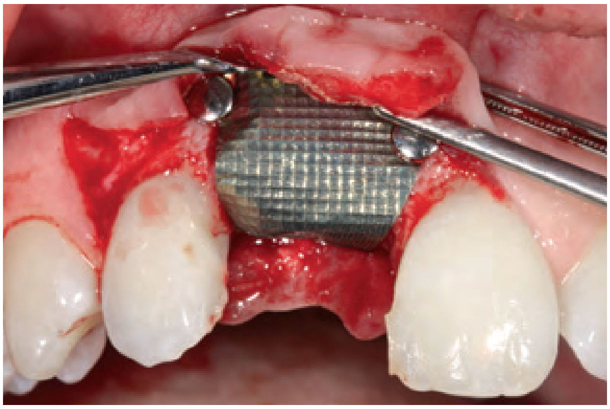


Fig 1-7 A titanium foil protects particulated autogenous bone grafts.

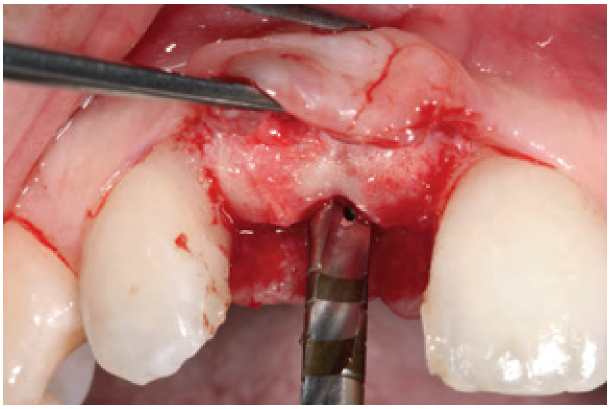


Fig 1-8 Four months after augmentation the bony ridge is reconstructed...

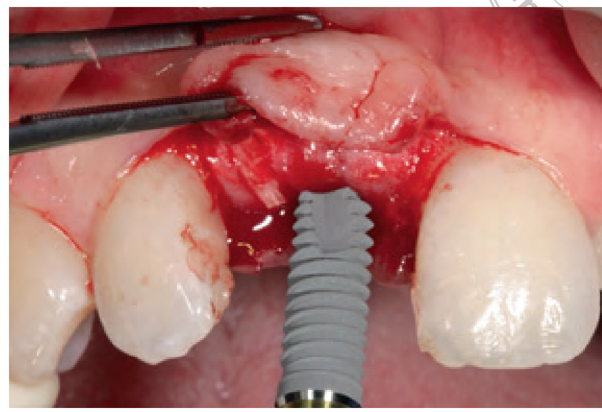


Fig 1-9 ... and allows for restoratively driven implant installation with sufficient buccal bone plate.

Fig 1-10 Minimally invasive second stage surgery and placement of a healing abutment.

Fig 1-11 Final all-ceramic restoration shortly after finalization with a surplus of soft tissue (dental technician: Andreas Nolte, Münster, Germany).

Fig 1-12 Smile of the patient after treatment.

Fig 1-13 Smile of the patient 1 year after restoration.

dimension of 3 to 4 mm in the apico-coronal direction called "biological width." The interface consists of two zones, one of epithelium, which covers about 2 mm of the surface, while the rest is covered with connective tissue adhesion.[7–9]

Junctional epithelium

At early phases of the healing process, the quality and stability of the fibrin clot adhesion to the surface of the transmucosal components most probably plays a role in the formation and positioning of the junctional epithelium.[10] The fibrin clot forms rapidly after implant/abutment installation and the epithelium found at the border of the incision proliferates over this bridge towards the surface. Once it reaches the surface, it moves in the coronal-apical direction and the former oral epithelium is transformed, due to several influences, into a junctional epithelium about 2 mm long.[11] The attachment of the junctional epithelium can be formed after 2 to 3 days of healing via the formation of hemidesmosomes and a basal lamina.[12] The role of the underlining connective tissue in preventing epithelium down-growth has been clearly demonstrated in animal models.[13]

Connective tissue attachment

In the early healing of the connective tissue wound, the formation and adhesion of the fibrin to the implant or abutment surface clot leads to connective tissue cells on the implant's surface, transforming the clot into granulation tissue.[14] After tissue maturation, the connective tissue portion, located between the barrier epithelium and the marginal bone, has been found to be poor in cells and in vascular structures but rich in collagen fibers. These fibers run more or less parallel to the surface of the implant. Apart from the orientation of the fibers, the major difference between the connective tissue around teeth and around artificial abutments is related to their connection to the natural or artificial root surface. In natural teeth, the dento-gingival collagen fibers firmly insert into the cementum and the bone, and are oriented perpendicular or oblique to the tooth surface, serving as a barrier to epithelial migration and invasion.[15]

In contrast, implants lack cementum. The orientation of the supracrestal soft tissue compartment is parallel with the implant surface and does not insert in the implant surface.[7] Therefore the connective tissue adhesion at implants has a poor mechanical resistance compared to that of natural teeth.[16] This lack of mechanical resistance can potentially endanger the prognosis of oral implants. Tearing at the connective tissue/implant interface could occur due to lack of soft tissue stability, which could induce the apical migration of the junctional epithelium, accompanied by gingival recession or pocket formation and by bone resorption.[6]

Peri-implant tissue stability

Peri-implant tissues are constantly challenged by various hazards. Bacterial plaque formation,[17] loading,[18] and prosthetic manipulation[19] are factors that can have an adverse effect on implant success.

Research in the 1980s has shown that bone loss of up to 1.5 mm after the first year and 0.2 mm in subsequent years with mucosal recession are inevitable in implant restorative treatment with joint implant designs.[20]

Apse et al looked at peri-implant tissues over a 4- to 9-year period. The study examined plaque, keratinized mucosa, gingival indices, probing depth, and the height of the abutment above the peri-implant mucosa. The authors reported a decrease in probing depth, from 4.27 mm in the first year to 2.51 mm in the ninth year. Abutment height above the peri-implant mucosa increased over the 9-year period, indicating approximately 1.75 mm of tissue shrinkage over 9 years.[21] These results are similar to those reported previously by Adell et al (1.7 mm).[22]

Influence of presence of keratinized mucosa

As the mechanical stability of peri-implant soft tissue is increased in keratinized mucosa, this should have a positive influence on the sealing of the peri-implant interface, and thus play a role in maintenance of dental implants.

In a prospective study, Bengazi et al evaluated peri-implant tissues longitudinally for a 2-year period following prosthesis placement. They measured plaque, mucositis, probing depth, bleeding upon probing, marginal soft tissue level, width of masticatory mucosa, and marginal soft tissue mobility in 163 implants in 41 patients. Though they did not publish an overall mean value for the recession, it appeared to be approximately 0.5 mm. All of the recession occurred within the first 6 months after prosthesis placement, and mandibular lingual sites showed the greatest tendency toward recession. A recession over 1 mm was recorded in 38% of implants placed in keratinized tissue, versus 57% in non-keratinized.[23]

Chung et al did research on this issue and conducted a longitudinal clinical study involving 339 implants in a follow-up of 8 years. Implants where the zone of fixed or keratinized mucosa was absent or very small, displayed statistically significantly higher plaque accumulation and signs of inflammation and the mean bone loss per year was higher in these compromised sites.[24]

Another longitudinal survey with 218 patients and a follow up of 9 to 14 years showed a correlation between the absence of fixed keratinized mucosa and peri-implant mucositis (defined as bleeding on probing, combined with probing depth of more than 4 mm) that was significant.[25]

Esthetic region

All these studies involve measurements of soft tissue levels at the time of prosthesis placement. Recession after placement of suprastructures may be a problem in the esthetic region and lead to an esthetic compromise.

Tarnow and co-workers published a longitudinal study, which measured the soft tissue around implants following second-stage surgery, to determine if a predictable pattern of soft tissue changes could be identified. This study evaluated 63 implants in 11 patients. Baseline measurements were recorded at stage 2 surgery in 2-stage implant systems, and at stage 1 surgery in 1-stage systems. Subsequent measurements were recorded at 1 week, 1 month, 3 months, 6 months, 9 months and 1 year after baseline measurements. From 1 week to 1 year, the total mean recession on the midfacial (midbuccal) was greater than 1 mm (1.05 mm). Most of the recession occurred during the first 3 months following abutment connection surgery. For this reason, clinical protocols should take into account at least 1 mm of total recession. Therefore, in an esthetically demanding area, abutment selection and final impressions should be performed after at least 3 months of healing.[26]

Grunder published 1-year results of 10 patients that had received implant borne single-tooth restorations. His surgical protocol employed guided bone regeneration and soft tissue grafts. Measurements were taken at the day of crown placement, and once again 1 year later. After 1 year, 7 of the 10 implants showed a recession of 0.5 mm on the buccal side. The mean overall recession of the 10 implants amounted to 0.6 mm. At the same time the papilla height increased by 0.375 mm on average. None of the 20 papillae lost volume. The distance between the contact points of the crowns and the bone level on the tooth side was in all cases 5 mm or less after 1 year.[27]

Kan and Kois stated that the peri-implant soft tissue dimensions are also related to the present biotype of tissue. In a study with 45 patients and 45 implants in the anterior maxilla, they performed measurements and proved this hypothesis.[1] The outcome and stability of the peri-implant soft tissue situation seem to be related to the individual healing patterns and tissue dimensions determined by the biotype.

A problem that is commonly seen is a missing papilla between adjacent implants, especially when it comes to bone augmentation prior to implant placement. Tymstra et al[28] published data from 10 patients with two adjacent implants that needed a separate augmentation prior to implantation. They assessed the outcome radiographically and clinically. They also recorded the esthetic result with the Implant Crown Aesthetic Index and documented the patients' satisfaction (scoring from 0–10). Although many patients were satisfied, it was difficult to establish an acceptable esthetic result with two adjacent implant-supported restorations with patients who needed a separate augmentation procedure.

The group headed by Tarnow[29] published data of a multicenter study with 33 patients that received adjacent implants. Under local anesthesia, a sounding with a standardized probe was performed in order to measure the inter-implant papillary height. Mean height was 3.4 mm with a range from 1 to 7 mm. The most frequently occurring results they found were 2 mm (16.9%), 3 mm (35.3%), and 4 mm (37.5%).

A recent critical review of the literature addressed the question of whether there is evidence that the presence of masticatory mucosa plays an important role in the longevity of implants.[2] A total of 29 articles could be identified; including animal studies, and prospective and retrospective clinical trials. The survival rates ranged from 90.1%–95.4% after 5 years, to 82.1%–92.8% after 10 years. The authors pointed out clearly that there was a significant difference between implant survival and implant success. Implant success is very much connected to biological, functional, and esthetic criteria, which may be individually defined by patient and clinician demands. They concluded that the presence or absence of masticatory mucosa seems not to have a major influence on the statistical survival rate of implants, but the influence on the success rate is discussed controversially in the literature. They stated that the presence of a fixed keratinized (hence masticatory) mucosa is a key factor for the sustainability of an esthetic appearance and peri-implant soft tissue stability in the esthetic zone.

Clinical interpretation

Taking all the information of the present literature into account, it may be concluded that effort has to be taken to provide fixed and keratinized peri-implant soft tissue, respectively the masticatory mucosa around dental implants. A stabile – immobile – soft tissue situation seems to have a positive influence on the sealing of the peri-implant interface, playing a leading role in the maintenance of dental implants. The described properties are imperative to yield long-term stability of the soft tissue and also sustainability of the esthetic outcome.

Establishing a papilla between two adjacent implants, especially when ridge defects have to be regenerated, is a procedure of limited predictability.

As the peri-implant interface always undergoes changes after abutment connection, clinical protocols – especially in the esthetic zone – should take into account at least 1 mm of midfacial recession, but also an increase in papillae volume in single-tooth implant restorations. As the changes seem to be related to the biotype of the patient, they are not predictable. Therefore, in an esthetically demanding area, abutment selection and final impressions should be performed after at least 3 months or more of healing. The use of interim restorations is recommended in the esthetic zone of thin biotypes and in questionable situations to allow the changes to occur, before a stabile peri-implant interface is established and the final restoration can be placed.

References

1. Kan JY, Rungcharasseng K, Umezu K, Kois JC. Dimensions of peri-implant mucosa: an evaluation of maxillary anterior single implants in humans. J Periodontol 2003;74:557–562.
2. Bühler-Frey C, Burkhardt R. Evidenz für die Bedeutung mastikatorischer Mukosa um enossale Implantate – eine kritische Literaturübersicht. Implantologie 2008;16:155–169.
3. Salama H, Salama MA, Garber D, Adar P. The interproximal height of bone: a guidepost to predictable aesthetic strategies and soft tissue contours in anterior tooth replacement. Pract Periodontics Aesthet Dent 1998;10:1131–1141.
4. Linkevicius T, Apse P. Influence of abutment material on stability of peri-implant tissues: a systematic review. Int J Oral Maxillofac Implants 2008;23:449–456.
5. Steinebrunner L, Wolfart S, Bössmann K, Kern M. *In vitro* evaluation of bacterial leakage along the implant-abutment interface of different implant systems. Int J Maxillofac Implants 2005;20:875–881.
6. Rompen E, Domken O, Degidi M, Pontes AEF,

Piatelli A. The effect of material characteristics, of surface topography and of implant components and connections on soft tissue integration: a literature review. Clin Oral Implants Res 2006;17:55–67.
7. Berglundh T, Lindhe J, Ericsson I, Marinello CP, Liljenberg B, Thomson P. The soft tissue barrier at implants and teeth. Clin Oral Implants Res 1991;2:81–90.
8. Berglundh T, Lindhe J. Dimension of the periimplant mucosa. Biological width revisited. J Clin Periodontol 1996:23:971–973.
9. Abrahamson I, Berglundh T, Moon IS, Lindhe J. Periimplant tissues at submerged and non-submerged titanium implants. J Clin Periodontol 1999;26:600–607.
10. Lowenguth RA, Polson AM, Caton JG. Oriented cell and fiber attachment systems *in vivo*. J Periodontol 1993;64:300–342.
11. Listgarten, MA. Soft and hard tissue response to endosseous dental implants. Anat Rec 1996;245,410–425.
12. Swope EM, James RA. A longitudinal study on hemidesmosome formation at the dental implant-tissue overflow. J Oral Implantol 1981;9:412–422.
13. Chehroudi B, Gould T, Brunette DM. A light and electron microscopic study of the effects of surface topography and the behaviour of cells attached to titanium-coated percutaneous implants. J Biomed Mater Res 1991;25:387–405.
14. Meyle J. Cell adhesion and spreading on different implant surfaces. In: Lang NP, Karring T, Lindhe J. Proceedings of the 3rd European Workshop on Periodontology: Implant Dentistry. Berlin: Quintessence 1999:55–72.
15. Gargiulo AW, Wentz FM, Orban B. Mitiotic activity of human oral epithelium exposed to 30 per cent hydrogen peroxide. Oral Surg Oral Med Oral Pathol 1961;14:474–492.
16. Hermann JS, Buser D, Schenk RK, Schoolfield JD, Cochran DL. Biological width around one- and two-piece titanium implants. A histometric evaluation of unloaded non-submerged and submerged implants in the canine mandible. Clin Oral Implants Res 2001:12:559–571.
17. Barboza EP, Caula AL, Carvalho WR. Crestal bone loss around submerged and exposed unloaded dental implants: a radiographic and microbiological descriptive study. Implant Dent 2002;11:162–169.
18. Misch CE, Dietsch-Misch F, Hoar J, Beck G, Hazen R, Misch CM. A bone quality-based implant system: First year of prosthetic loading. J Oral Implantol 1999;25:185–197.
19. Abrahamson I, Berglundh T, Lindhe J. The mucosal barrier following abutment dis/reconnection. An experimental study in dogs. J Clin Periodontol 1997;24:568-572.
20. Albrektson T, Zarb G, Worthington P, Eriksson RA. The longterm efficacy of currently used dental implants. A review and proposed criteria for success. Int J Oral Maxillofac Implants 1986; 1:11–25.
21. Apse P, Zarb GA, Schmitt A, Lewis DW. The longitudinal effectiveness of osseotintegrated dental implants. The Toronto study: Peri-implant mucosal response. Int J Periodontics Restorative Dent 1991;11:94–111.
22. Adell R, Lekholm U, Rockler B et al. Marginal tissue reactions at osseointegrated titanium fixtures. (I). A 3-year longitudinal prospective study. Int J Oral Maxillofac Surg 1986;15:39–52.
23. Bengazi F, Wennström JL, Lekholm U. Recession of the soft tissue margin at oral implants. A 2-year longitudinal prospective study. Clin Oral Implants Res 1996;7:303–310.
24. Chung DM, Shotwell JL, Misch CE, Wang H. Significance of keratinized mucosa in maintenance of dental implants with different surfaces. J Periodontol 2006;77:1410–1420.
25. Roos-Jansaker A, Renvert H, Lindahl C, Renvert S. Nine-to fourteen-year follow-up of implant treatment. Part III: factors associated with peri-implant lesions. J Clin Periodontol 2006;33:296–301.
26. Small PN, Tarnow DP. Gingival recession around implants: a 1-year longitudinal prospective study. Int J Oral Maxillofac Implants 2000;15;527–532.
27. Grunder U. Stability of the mucosal topography around single-tooth implants and adjacent teeth: 1-year results. Int J Periodontics Restorative Dent 2000;20:11–17.
28. Tymstra N, Meijer H, Stellingsma K, Raghoebar M, Vissink A. Treatment outcome and patient satisfaction with two adjacent implant-supported restorations in the esthetic zone. Int J Periodontics Restorative Dent 2010;30:307–316.
29. Tarnow D, Elian N, Fletcher P et al. Vertical distance from the crest of the bone to the height of the interproximal papilla between adjacent implants. Journal of Periodontology 2003;74:1785–1788.

Essay 2: Properties of the trans-mucosal abutment restorative material for the ideal peri-implant soft tissue biologic response and esthetic outcome

The abutment represents the transmucosal connection between the implant and the suprastructure. It serves as the three-dimensional transition from the geometric implant diameter to the anatomical emergence profile of the crown. As the diameter of the implant most of the time is smaller than the emergence of the restoration, the abutment must be progressively flared to achieve proper morphology. Industrial components often fail in establishing an anatomical emergence profile. Early efforts in creating anatomical abutments from the University of California employed a refractory gold alloy base that allowed for the manufacture of an individual abutment made of gold.[1] Current concepts involve CAD/CAM-derived zirconium abutments. Computer designed and generated implant abutments fundamentally changed the earlier restorative protocols for implant dentistry. Individual abutments can be ground very precisely[2] and zirconium proved its clinical reliability in several *in vitro* experiments and clinical studies.

Peri-implant soft tissue biologic response

Titanium, gold alloys, and zirconium or aluminium oxide ceramics are available for prosthetic implant abutment fabrication. A number of clinical and animal studies address the influence of abutment material and peri-implant tissues.[3,4] Titanium served as the gold standard most of the time, but as indications for implants were not anymore limited to edentulous patients and suprastructures became more and more demanding, gold and ceramic abutments started playing a leading role and have now been available for many years. Zirconium dioxide is the latest material to complete the choice of abutments and shows significantly less accumulation of bacteria in the oral cavity.[5]

Animal studies

Abrahamson et al[6] compared the reaction of peri-implant tissues on titanium, gold alloy, and aluminium oxide abutments and abutments individualized with dental porcelain. Thirty 2-piece titanium implants were placed in five dogs. Abutments of different materials were placed. Histometric observations showed that bone loss was 0.78 mm around titanium abutments (control), 0.80 mm around aluminum oxide abutments, 1.80 mm around gold alloy abutments, and 1.26 mm around dental porcelain abutments. Clinical assessment showed marked soft tissue recession around gold alloy abutments.

The same group published data in 2008 of another animal study[7] with six Labrador dogs, where four Astra Tech implants were connected to two titanium (Ti) abutments, plus one zirconium (ZrO_2) abutment and one abutment made of a gold-platinum-alloy (AuPt-alloy), 1 month after implant placement. Three months after the first side implant placement and subsequent abutment shift were repeated in the contralateral side. Two months later the dogs were sacrificed and histologically assessed. The histological results showed an apical shift of the barrier epithelium and the marginal bone between the second and fifth month of healing. Soft tissue dimensions at Ti and ZrO_2 abutments remained stable between 2 and 5 months of healing. The 80 µm-wide connective tissue zone lateral of the gold alloy abutment contained lower amounts of collagen and fibroblasts and larger fractions of leukocytes than the corresponding zone at Ti and ZrO_2 abutments.

The study group headed by Strub compared zirconium oxide and titanium abutments: Kohal et al published a study with 12 implants made of zirconium and titanium, which were placed in six monkeys. Later zirconium and titanium abutments were cemented on the implants. Histologic assessment found effective formation of a mucosal attachment at both implant materials. The results did not reveal any statistically significant differences between the materials. The mean height of soft peri-implant tissues was 5 mm around the titanium implants and 4.5 mm around the zirconium implants.[8]

In 2007, Abrahamson and Cardaropoli[9] tested 1-piece implants made of gold alloy or titanium, and their ability to develop stable peri-implant tissues. Thirty-two implants were placed in four dogs. Histologic findings showed similar results for the vertical dimensions of the soft tissues.

Human histological studies

A histological study by Degidi et al[10] compared soft tissue responses to titanium and zirconium healing abutments in five patients. After a healing period of 6 months, a histologic analysis of specimens revealed that inflammatory infiltrate was more pronounced and there was a higher expression of a vascular endothelial growth factor (VEGF) around the titanium abutments compared to zirconium.

Clinical studies

Vigolo et al[11] performed a prospective controlled randomized 4-year study with a split-mouth design. Twenty patients received two implants and subsequently two abutments, one gold alloy and one titanium abutment each. Following up after 4 years, peri-implant tissues showed no difference in response to the different materials.

In a clinical randomized controlled multi-center study, aluminum oxide abutments were compared to titanium abutments.[12] A first group of 60 patients received 34 test aluminum oxide abutments and 35 control titanium abutments. This group was observed for 1 year. Results after 1 year showed no bone loss around the ceramic abutments.

The second group of patients consisted of 15 individuals who received 10 test and 10 control abutments with a follow-up period of 3 years. Results in this group showed 0.3 mm loss after 1 year and 0.1 mm gain of bone after 3 years of follow-up. Regarding soft tissue reactions, no significant differences were found in the first and second group.

The same author published results of an ongoing prospective 2-year multicenter study.[13] Thirty-two patients received a total of 103 implants for the support of 36 partial dentures. Fifty-three aluminum oxide ceramic and 50 titanium abutments were connected. The peri-implant soft tissue level was relatively stable. No differences were recorded between ceramic and titanium abutments regarding bleeding of the peri-implant mucosa. Marginal bone loss after 1 year was a little higher at titanium (0.4 mm) than at ceramic (0.2 mm) abutments.

The 5-year results of the same clinical study were published in 2003.[14] Results from 30 patients and 29 fixed partial dentures at that time revealed the average marginal bone loss around ceramic abutments after 1, 3, and 5 years as 0.3 mm (0.4 mm around titanium abutments). There were no significant differences between test and control abutments regarding bleeding on probing and plaque accumulation. However, the ceramic abutments showed more frequent soft tissue recessions.

Peri-implant soft tissue esthetic outcome

In the maxillary anterior area, the esthetic outcome is a critical determinant in the overall success of implant therapy and yet remains a challenge. Though the esthetic outcome is of major concern for patients,[15] in scientific research the esthetic result is usually poorly documented and not included in the success criteria.[16] That is the reason why indices for the documentation of the so-called white and red esthetic have been proposed. Fürhauser et al recommend the "pink esthetic score" to evaluate the soft tissue outcome around single-tooth implant crowns.[17] Meijer et al developed an index to judge both the crown and the adjacent soft tissues: the "Implant Crown Aesthetic Index."[18]

The restorative materials have an influence on the esthetic appearance of implant-borne restorations and differences appear to be most striking near the peri-implant soft tissue margin.[19] Jung et al[20] performed research on the *in vitro* color changes of soft tissues caused by restorative materials in pig jaws. Titanium, and zirconium with and without dental porcelain were tested beneath tissues of different thickness. The color changes of the tissue were analyzed with a spectrophotometer. The results showed that titanium causes significant color changes, even at a tissue dimension of 3 mm, whereas zirconium does not affect the tissue color any more beyond a thickness of 2 mm. It may be concluded that full ceramic restorations allow better esthetic results, especially in patients with thin facial soft tissues.

A study group from the Harvard Dental School in Boston[21] evaluated different colors in order to mask the restorative materials. Stripes of different colors (white, light pink, pink, light orange, orange, violet, gold) were placed into the peri-implant sulcus of 15 implant single crowns and spectrophotometric assessment was performed. The findings indicate that light pink and light orange show the least color changes, hence the best results in terms of esthetics.

Form and design properties of the ideal trans-mucosal abutment

A review of 29 clinical and 22 laboratory studies with a mean follow-up of at least 3 years assessing the performance of abutments made of zirconium dioxide ceramics, reported that results were as good as those of the former gold standard, the titanium abutment.[22] Abutments made of alumina oxide however show significantly less resistance towards mechanical loading[23] and have been replaced by the zirconium abutment.

Based on the scientific data regarding biology and optical properties, Happe and Nolte proposed an individual full ceramic abutment design, based on a custom-made zirconium abutment with an individualized margin made of high fluorescent light orange dental porcelain.[24] This hybrid design provides zirconia in the depths under the soft tissue surface where good biocompatibility is needed, and the fluorescent porcelain in the sulcus where the tissue is thin and good optical properties are of concern. Besides these advantages, the dental porcelain, in contrast to the zirconia, allows etching and adhesive luting of full ceramic restorations.

As tissue retractions amounting to around 1 mm in the first year have to been taken into account, the crown margin in the esthetic zone has to be placed at least 1 mm subgingival. For cemented restorations this may bear the risk of difficult access for the removal of cement.

Dental materials placed in the oral cavity usually are polished to provide a smooth surface that is easy to clean and hampers plaque formation. But does an ultra-polished surface contribute to good soft tissue integration and what is known about the surface properties of abutment materials?

Surface roughness

Verran and Boyd (2001) have proposed three categories of surface roughness, termed as macro- (Ra ~ 10 μm), micro- (Ra ~ 1 μm) and nano-roughness (Ra ~ 0.2 μm).[25] Micro-roughness has been suggested to be appropriate for the intrabony/endosseous part of dental implants.[26] In contrast, commercially available Brånemark standard abutments (Nobelpharma) have a nano-roughness of approximately Ra = 0.2 μm .

It is generally believed that roughened surfaces influence microbial colonization by enhancing microbial retention within surface irregularities. The initial adhesion of bacteria preferably starts at locations where they are sheltered against shear forces so that they find the time to change from reversible to irreversible attachment. Roughening of the surface increases the area available for adhesion by a factor of 2 to 3, and in addition rough surfaces are difficult to clean, resulting in a rapid re-growth of the biofilm by multiplication of remaining species, rather than by recolonization.[27]

The influence of the surface roughness has been studied with titanium abutments in a clinical evaluation performed by Quirynen.[28] Results indicated that a roughening of the surface (Ra = 0.8 μm) resulted in a dramatic increase in the subgingival plaque amount of about 25 times more, as well as in its pathogenicity.

Amoroso[29] reported on the adherence of *Porphyromonas gingivalis* to titanium surfaces of different roughness *in vitro*. Four different roughness samples were produced employing different protocols like sand blasting or polishing. They were categorized as being "very smooth" (hand polished for a mirror finishing process: Ra = 0.035 μm), "smooth" (machined polish: Ra = 0.15 μm), "rough" (sandblasted with glass beads: Ra = 0.22 μm), and "very rough" (sandblasted with aluminum oxide beads: 0.45 μm). The adhesion for *Porphyromonas gingivalis* was measured *in vitro*. The results indicated a highly significant difference between the very smooth and other sample groups. There were no differences in bacterial adherence evident between these other groups.

In order to examine the effect of surface polishing on supragingival and subgingival bacterial colonization, Quirynen[30] conducted a clinical study with six edentulous patients who received at least four implants. Four abutments with different surface roughness, ranging from Ra = 0.05 μm (highly polished) to Ra = 0.2 μm (standard) were placed for 3 months in the oral cavity and compared with each other in the same subject, based on quantitative and qualitative microbiologic and clinical examinations. Subgingivally, only the two roughest abutments harbored spirochetes after 1 month. After 3 months, the subgingival composition of the flora showed little variation on the different abutments, although spirochetes were only noticed around the roughest abutment. Clinically, small differences in probing depth were observed. The roughest abutment showed some attachment gain (0.2 mm) during 3 months, whereas all other abutments had an attachment loss ranking from 0.8 to greater than 1 mm. The results indicate that a reduction in surface roughness less than 0.2 μm had no major effect on the microbiological composition supragingivally or subgingivally. These observations indicate the existence of a threshold roughness, below which no further impact on the bacterial adhesion and colonization should be expected. However, clinical evaluation seems to indicate that a certain surface roughness is necessary for increased resistance to attachment loss in that particular period.

The same study group[31] examined the long-term effects of two different abutment designs placed in six patients. Each patient received a standard machined titanium abutment (Ra = 0.21 μm, control) and a zirconium abutment with an ultra-polished smooth surface (Ra = 0.06 μm, test). After 3 months, spirochetes and motile microorganisms were only detected subgingivally around the titanium abutments. After 12 months, however, both abutment types harbored equal proportions of spirochetes and motile microorganisms, both supra- and subgingivally. Microbial culturing after 12 months failed to detect large inter-abutment differences. Clinically, the smoothest abutments showed a slightly higher increase in probing depth between months 3 and 12, and more bleeding on probing. The results confirm the findings of the previously mentioned short-term study, indicating that a further reduction of surface roughness, below a "threshold Ra = 0.2 μm" has no major impact on the supra- and subgingival microbial composition. Ultra-polished abutments made of zirconium tend to show higher probing depths.

Fig 2-1 Mid-facial soft tissue recession and shine through of the restorative materials at implant 11 (color difference to contralateral ΔE = 9.27 [1 mm apical from margin]).

Fig 2-2 Free subepithelial connective soft tissue graft of appropriate size harvested from the palatal.

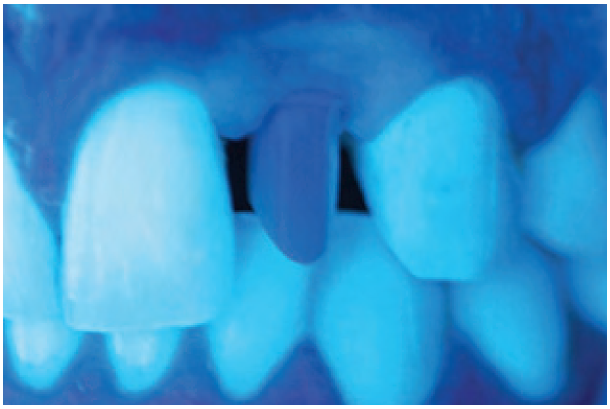
Fig 2-3 The graft was inserted into a pouch buccally of the implant via a small vertical access incision in order to increase the soft tissue thickness.

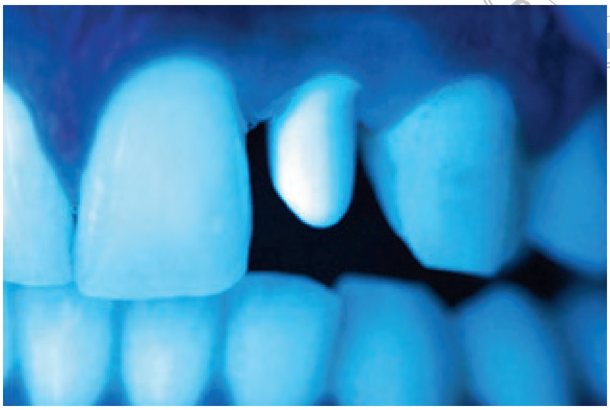
Fig 2-4 Three months after the intervention the increased soft tissue thickness reduces the shine through effect (color difference to contralateral ΔE = 3.92 [1 mm apical from margin]).

Surface free energy (wettability)

The surface free energy (SFE) of materials, also called wettability, is another factor that may affect plaque formation in the oral cavity. Glantz was the first who described this phenomenon *in vivo*. He detected a "positive" correlation between substratum SFE and the weight of accumulated plaque after 1, 3, and 7 days.[32]

The effect of substratum SFE on supra- and subgingival plaque maturation around implants was investigated by comparing 3-month-old plaque from abutments with either a high (titanium) or a low (Teflon coating) SFE.[28] Low-SFE substrata harbored a significantly less mature plaque supra- as well as subgingivally, characterized by a higher proportion of cocci and a lower proportion of motile organisms and spirochetes. The influence on plaque formation remains





Figs 2-5 and 2-6 Two zirconia abutments in the same patient under the influence of ultraviolet light with a wavelength of 300-400nm. Left: conventional zirconia showing no fluorescent properties. Right: dyed zirconia with fluorescent properties.

Figs 2-7 and 2-8 Different samples of restorative materials. On the right side an extracted anterior tooth. The picture below shows the optical appearance under the influence of ultraviolet light with a wavelength between 300–400 nm.

after early plaque formation and influenced the composition of the biofilm.[27]

The “relative” importance of both parameters (SFE and roughness) on supragingival plaque formation has been examined *in vivo* by Quirynen et al. They studied undisturbed plaque formation on polymer strips with low and medium SFE, glued to a tooth surface. Each strip had a smooth (Ra = 0.1 µm) and a rough part (Ra > 2 µm). After 3 days of undisturbed plaque formation, significant inter-substrata differences were observed on the smooth regions, while the rough regions of the strips were nearly all completely covered with plaque. Surface roughening resulted in a four-fold increase in plaque formation for both polymers. Surface roughness seems to predominate over SFE where bacterial adhesion is concerned.[27] Therefore surface free energy clinically plays a minor role in abutment design.

Clinical interpretation

The contradictory results regarding titanium versus gold abutments still leave it unclear whether titanium is biologically superior to gold as an abutment material. As the evidence from clinical trials show no difference between the two materials in terms of peri-implant bone stability, it can be concluded that abutments made of gold should not be considered as a risk for crestal bone loss and soft tissue recession.

If titanium and ceramic abutments are compared, the data from animal studies, human histologic material, and clinical trials indicate similar reactions between the two materials regarding peri-implant soft tissue and crestal bone stability. However human histologic material shows an even better reaction of human mucosa to zirconium as compared to titanium. The reason for this could be the fact that there is less accumulation of bacteria on zirconium than on titanium. Thus, this results in a lower inflammation rate of the tissue.

For implant borne restorations in the esthetic zone the use of full ceramic components is crucial, especially in thin biotypes. Full ceramic components made of zirconia are mechanically superior to abutments made of alumina. Regarding the surface design of abutment parts that are in touch with peri-implant tissues, the literature reports that a further reduction of surface roughness, below a “threshold Ra = 0.2 µm” (machined polished) has no major impact on the supra- and subgingival microbial composition. Thus an ultra-smooth (hand-polished, mirror-finish) surface may lead to recession and ultra-polished abutments made of zirconium tend to show higher probing depths. Surface free energy clinically plays a minor role in abutment design.

References

1. Lewis S, Beumer J, Homburg W, Moy P. The “UCLA” abutment. Int J Oral Maxillofac Implants 1988;3:183–189.
2. Priest G. Virtual-designed and computer-milled implant abutments. J Oral Maxillofac Surg 2005;63:22–32.
3. Myshin HL, Wiens JP. Factors affecting soft tissue around dental implants: a review of the literature. J Prosthet Dent 2005;94:440–444.
4. Linkevicius T, Apse P. Influence of abutment material on stability of peri-implant tissues: a systematic review. Int J Maxillofac Implants 2008;23:449–456.
5. Rimondini L, Cerroni L, Carrassi A, Torricelli P. Bacterial colonization of zirconia ceramic surfaces: an *in vitro* and *in vivo* study. Int J Oral Maxillofac Implants 2002;17:793–798.
6. Abrahamson I, Berglundh T, Glantz PO, Lindhe J. The mucosal attachment at different abutments. An experimental study in dogs. J Clin Periodontol 1998;25:721–727.
7. Welander M, Abrahamson I, Berglundh T. The mucosal barrier at implant abutments of different materials. Clin Oral Impl Res 2008;19:635–41.
8. Kohal RJ, Weng D, Bächle M, Strub JR. Loaded custom-made zirconia and titanium implants show similar osseointegration: an animal experiment. J Periodontol 2004;75:1262–1268.
9. Abrahamson I, Cardaropoli G. Peri-implant hard and soft tissue integration to dental implants made of titanium and gold. Clin Oral Implants Res 2007:169–174.
10. Degidi M, Artese L, Scarano A, Perrotti V, Gehrke P, Piattelli A. Inflammatory infiltrate, microvessel density, nitric oxide synthase expression, vascular endothelial growth factor expression, and proliferative activity in peri-implant soft tissues around titanium and zirconium oxide healing caps. J Periodontol 2006:73–80.

11. Vigolo P, Givani A, Majzoub Z, Cordiolo G. A 4-year prospective study to assess peri-implant hard and soft tissues adjacent to titanium versus gold-alloy abutments in cemented single implants crowns. J Prosthodont 2006;15: 250–256.
12. Andersson B, Taylor A, Lang BR et al. Alumina ceramic implant abutments used for single-tooth replacement: a prospective 1- to 3-year multicenter study. Int J Prosthodont 2001;14:432–438.
13. Andersson B, Schärer P, Simion M, Bergström C. Ceramic Implant abutments used for short-span fixed partial dentures: a prospective 2-year multicenter study. Int J Prosthodont 1999;12:318–324.
14. Andersson B, Glauser R, Maglione M, Taylor A. Ceramic implant abutments for short-span FPDs: A prospective 5-year multi-center study. Int J Prosthodont 2003;16:640–646.
15. Vermylen K, Collaert B Linden U, Bjorn AL, De Bruyn H. Patient satisfaction and quality of single-tooth restorations. Clin Oral Implants Res 2003;14:119–124.
16. Belser U, Schmid B, Higginbottom F, Buser D. Outcome analysis of implant restorations located in the anterior maxilla: a review of the recent literature. Int J Oral Maxillofac Implants 2004;19:30–42.
17. Fürhauser R, Floresu D, Benesh T, Haas R, Mailath G, Watzek G. Evaluation of soft tissue around single-tooth implant crowns: the pink esthetic score. Clin Oral Implants Res 2005;16:639–644.
18. Meijer H, Stellingsma K, Meijndert L, Raghoebar GM. A new index for rating aesthetics of implant-supported single crowns and adjacent soft tissues – the Implant Crown Aesthetic Index. Clin Oral Implants Res 2004;16:645–649.
19. Park SE, Da Silva JD, Weber HP, Ishikawa-Nagai S. Optical phenomenon of peri-implant soft tissue. Part I. Clin Oral Implants Res 2007;18:569–574.
20. Jung R, Sailer I, Hämmerle CF, Attin T, Schmidlin P. *In vitro* color changes of soft tissues caused by restorative materials. In J Periodontics Restorative Dent 2007;27:251–257.
21. Ishikawa-Nagai S, Da Silva JD, Weber HP, Park SE. Optical phenomenon of peri-implant soft tissue. Part II. Preferred implant neck color to improve soft tissue esthetics. Clin Oral Implants Res 2007;18:575–580.
22. Sailer I, Philipp a, Zembic A, Pjetursson BW, Hämmerle CH, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res 2009;20(Suppl 4):4–31.
23. Butz F, Heydecke G, Okutan M, Strub JR. Survival rate, fracture strength and failure mode of ceramic implant abutments after chewing simulation. J Oral Rehabil 2005;32:838–843.
24. Happe A, Nolte A. Management des periimplantär-restaurativen Interfaces durch ein biologisches und biomeimetisches individuelles vollkeramisches Abutment. Poster presentation. 22. DGI-Jahrestagung, Frankfurt. 27–29 Nov 2008.
25. Verran J, Boyd RD. The relationship between substratum surface roughness and microbiological and organic soiling: a review. Biofouling 2001;17:59–71.
26. Bollen CML, Lamprecht P, Quirynen M. Comparison of surface roughness of oral hard materials of the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater 1997;13:258–269.
27. Teughels W, Van Assche N, Sliepen I, Quirynen M. Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res 2006;17 (Suppl 2):68–81.
28. Quirynen M, van der Mei HC, Bollen CM et al. An *in vivo* study of the influence of surface roughness of implants on the microbiology of supra- and subgingival plaque. J Dent Res 1993;72:1304–1309.
29. Amoroso PF, Adams RJ, Waters MG, Williams DW. Titanium surface modification and its effect on the adherence of *Porphyromonas gingivalis*: an *in vitro* study. Clin Oral Implants Res 2006;17:633–637.
30. Quirynen M, Bollen CM, Papaioannou W, van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis short-term observations. Int J Oral Maxillofac Implants 1996;11:169–178.
31. Bollen CM, Papaioanno W, Van Eldere J, Schepers E, Quirynen M, van Steenberghe D. The influence of abutment surface roughness on plaque accumulation and peri-implant mucositis. Clin Oral Implants Res 1996;7:201–211.
32. Glantz PO. On wettability and adhesiveness. Odontol Revy 1969;20:1–132.

Essay 3: Biologic and mechanical principals of the implant-abutment connection

What do we really know about the effect of platform switching?

Most dental implant systems consist of two components: the implant itself and the transmucosal abutment. The nature of this interface makes it sensitive to mechanical overloading and bacterial contamination. Different clinical problems may arise in this susceptible region, like micro-movements, loosening of abutment screws, fractures, leakage with contamination of the peri-implant tissues with subsequent inflammation, and crestal bone loss.

Mechanical loading

The implant-abutment connection of different implant systems shows different resistance to mechanical forces depending on the nature of the design of the connection. Interestingly enough the actual size of the microgap itself does not influence the amount of peri-implant bone resorption, as long as micro-movement does not become an additional factor.[1,2]

Internal connections, like a tube-in-tube or conical design, seem to be superior to external connection regarding resistance to mechanical loading.[3,4] Besides the connection, the material of the abutment itself and the abutment screw plays a major role in the stability of the restoration.[5] Survival rates after chewing simulation *in vitro* indicate that there are significant differences in fatigue to dynamic and static loading between abutment materials. *In vitro* chewing simulations indicate that zirconium abutments show similar performance to metal abutments,[6] but the use of abutments made of alumina oxide resulted in significantly more fractures.[7]

Abutment disconnection

According to Hermann et al[2] intentional or unintentional disconnection of the abutment will lead to a disruption of the soft tissue adhesion and to increased post-restorative bone remodeling. Abrahamson et al[8] showed in 1997 that the repeated abutment disconnection and reconnection as performed during the restorative treatment induced an apical repositioning of the soft tissues and marginal bone resorption. In contrast, a single shift of a healing abutment and replacement by a final abutment proved to induce no marginal bone remodeling.[9]

Bacterial contamination

When the prosthetic abutment is placed on the subgingival implant, contact with the peri-implant soft tissue and bacterial dissemination into the implant body is nearly unavoidable. The internal compartments of the implant and the suprastructure components are highly contaminated with microbes[10,11] and penetration of oral microorganisms through gaps between these components may bear the risk of soft tissue inflammation or be responsible for the failure of peri-implantitis treatment.[12]

These effects may be promoted by micro-movements at the implant–abutment connection.

In vitro experiments with different abutment connections showed bacterial leakage under dynamic mechanical loading[13] and attempts to seal the connection failed *in vitro*.[14] Conical connections are known to be more leak-proof to corpuscular bodies like bacteria, but *in vitro* testing under dynamic loading indicated that these connections are unable to prevent endotoxin leakage over time.[15] An *in vivo* randomized trial on the effect of an internal decontamination of dental implants showed that a 1% chlorhexidine gel seemed to be an effective method to reduce bacterial colonization of the implant cavity over a 6-month period.[16]

Platform switching

In order to increase the distance between the microgap and the crestal bone, some authors proposed to use abutments of smaller diameter than the implant, yielding to position the implant-abutment interface more inwardly and to expose more implant surface to the integrating tissues,[17] and thus prevent crestal bone resorption and enhance anterior esthetics in cases of adjacent implants.[18] This approach is called platform-switching, platform-shifting, horizontal mismatch, or horizontal displacement in the literature. Systems like Astra or Ankylos primarily had this feature because of their conical connection.

Besides the possible biological effect of displacing the gap away from the bone, the use of a smaller diameter abutment seems to display a different pattern of stress distribution over the implant. In a 3D finite element study Maeda et al[19] analyzed this pattern and found out, that platform switching has the biomechanical advantage of shifting the stress concentration area away from the cervical bone-implant interface towards the center. Thus it also has the disadvantage of increasing stress in the abutment or abutment screw. These findings compare with the results of a finite element analysis Rodriguez-Ciurana et al[20] published in 2009. Platform switching resulted in a smoother and more uniform stress distribution over the implant surface.

Animal studies

Becker et al[21] studied the effects of platform switching, employing an implant system with an internal connection in animals. In nine Beagle dogs, second premolars and molars were extracted bilaterally and replaced by implants with a diameter of 5 mm. Abutments were randomly connected with 4 mm or 5 mm healing abutments to employ either the platform-switching or non-platform-switching approach. At 7, 14, and 28 days, measurements were made that showed, after 28 days of healing test and control, histologic results in terms of the extension of the long junctional epithelium and the level of the bone crest.

Weng et al[22] published a split-mouth study with six mongrel dogs that received two types of implants. On one side a TiUnite Brånemark implant with an external hex were placed, while the other side received Ankylos implants with a morse taper connection. In each group, one implant was placed equicrestally and one implant subcrestally. After 3 months of healing the animals were sacrificed and histometrically assessed. The results showed a narrower funnel within the morse taper group and bone-to-implant contact on the crestal face of the shoulder only in the subcrestal morse taper group. Unfortunately no restorations were placed, so the results allow limited conclusions for the clinical use of the assessed systems where micro-movements play an important role.[1]

Clinical trials

Canullo et al[23] conducted a randomized controlled double-blind clinical trial to evaluate the soft tissue response to immediately placed implants using the platform switching concept. In 22 patients, 22 implants of 5.5 mm platform diameter were placed immediately into fresh extraction sockets in maxillae without compromised bone tissue. Eventual post-extraction bone defects were filled using bovine bone matrix mixed with collagen. Immediately after insertion, implants were randomly divided: 11 implants were connected with a 3.8 mm diameter abutment (test group) and 11 with a 5.5 mm diameter abutment (control group). A provisional crown was adapted and adjusted for non-functional immediate positioning. Two months later, definitive prosthetic rehabilitation was performed. Periodontal parameters like buccal peri-implant mucosal changes, and mesial and distal papilla height were measured at the time of implant placement, of definitive prosthesis insertion and every 6 months thereafter. The mean follow-up was 25 months. No statistically significant difference between the two groups in periodontal parameters was found.

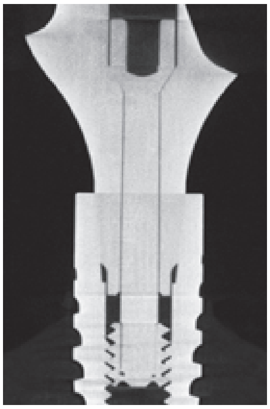
In a second randomized-controlled trial, Canullo et al[24] evaluated the marginal bone level alterations at implants restored according to the platform-switching concept. Eighty implants were divided according to the platform diameter in four groups: 3.8 mm (control), 4.3 mm (test group 1), 4.8 mm (test group 2) and 5.5 mm (test group 3), and randomly placed in the posterior maxilla of 31 patients. After 3 months, implants were connected to a 3.8 mm diameter abutment and final restorations were performed. The radiographic bone height was assessed by two independent examiners. After 21 months a total of 69 implants were available for analysis. Radiographic evaluation showed a mean bone loss of 0.99 mm for test group 1, 0.82 mm for test group 2, and 0.56 mm for test group 3. These values were statistically and significantly lower compared with the control group, which showed 1.49 mm mean bone loss. Thus there was an inverse correlation between the extent of horizontal mismatching and the amount of bone loss.

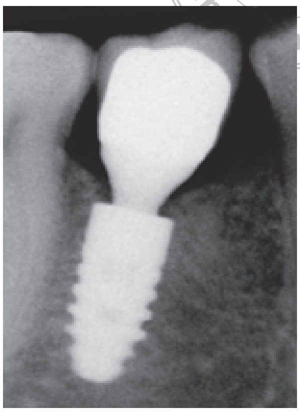
The authors concluded that the study suggests that marginal bone levels were better maintained at implants restored according to the platform-switching concept. However the fact that implants of different diameter were compared, an intrapatient control was not present in every patient, and a minimal distance between the implants of 2.5 mm was chosen have to be mentioned as limitations of the study.

Fickl et al conducted a clinical trial with 36 patients that received 89 implants with an external hex, 75 implants were placed 1.5 mm subcrestally and restored according to a platform-switching concept, and 14 were placed equicrestally and restored in a non-switching concept. Standardized radiographs were taken at the time of restoration (baseline) and 1 year later. The group with the subcrestal placement showed statistically significantly less bone loss when compared to the non-switched group. The author concluded that platform-switching seems to limit post-restorative crestal bone remodeling. The fact that intrapatient control was missing in most of the patients and two different crestal positions of the implant shoulder were compared, need to be discussed as limitations of the study.

A randomized prospective multicenter trial[25] involved 60 partially edentulous patients at 12 dental centers. The subjects were randomly selected to receive two different implant designs: either platform-enlarged implants or control cylindrical implants. A total of 360 implants were placed. These two designs were tested with and without platform-switching. Subcrestal placement was not evaluated. The results indicated that cylindrical implants experienced more bone loss than implants with an enlarged platform, even when platform-switched conical implants were compared with non-platform-switched, platform-enlarged implants. The authors concluded that the use of implants with an enlarged platform can result in better preservation of crestal bone, as compared with conventional cylindrical implants with a diameter-reduced abutment.

This conclusion stands in contrast to the findings of a review conducted from Abrahamson and Berglundh in 2009.[26] The authors addressed the question of whether different implant designs have an effect on marginal bone level alterations. They compared the results of clinical studies for different implant systems, including conical connections with platform switched and butt joint connections, regarding the marginal bone level and found no implant system to be superior in marginal bone preservation.





Figs 3-1 and 3-2 Conical connection with system immanent platform switching (picture courtesy of Dentsply Friadent). Perapical radiograph shows favorable crestal bone situation 6 months after crown placement on a implant system with conical connection with platform switching.

All of the clinical studies use two-dimensional radiographs for examination of the post-restorative remodeling. The limitations of this method have to be discussed and taken into account when drawing conclusions.

Clinical interpretation

The internal compartments of two-piece implants are contaminated with microbes and toxins, which communicate with the peri-implant tissues through a microgap between implant and abutment. The in-

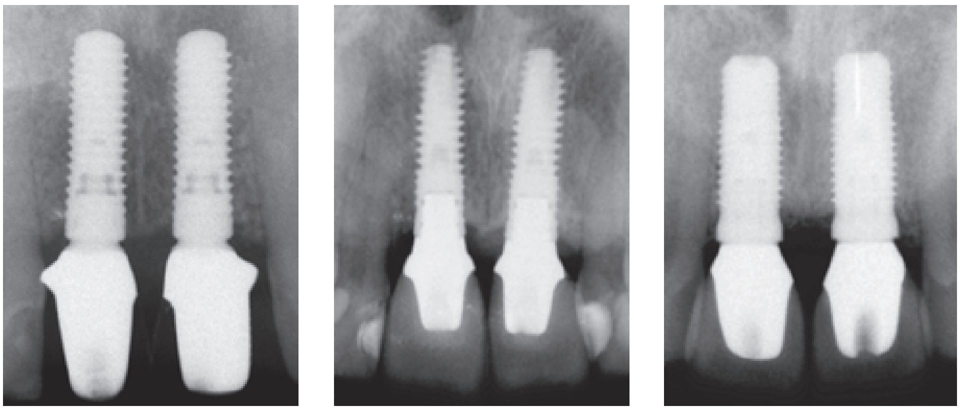


Fig 3-3 Different radiographic findings in radiographs regarding post restorative bone remodeling.

tensity of this communication seems to be related to the nature of the connection and the amount and frequency of mechanical loading. This may influence peri-implant bone and soft tissue. Platform switching yields to displace the microgap away from the bone in order to preserve peri-implant bone. This might be a solution for the clinical problem of compromised papilla height at adjacent implants in the esthetic zone, due to an insufficient underlying crestal bone level. Unfortunately this principal has not yet been scientifically proven. Yet, the current literature does not report a negative impact of this concept.

The platform-switching concept seems to be a relatively new concept in implant dentistry, but some implant systems with a conical connection have offered the feature of a horizontal shifting of the microgap for many years. The often-described positive effect on peri-implant crestal bone due to minimal resorption and bone growth on top of the implant shoulder may be the result of many factors. Some of these factors seem to be identified: the nature of the connection, the amount of horizontal mismatch, micro-movements, leakage and bacterial contamination, stress distribution over the implant surface, and the design of the implant. Although experimental studies have shown that conical connections and the platform-switching concept are beneficial, and studies in dogs have revealed positive biological effects, it seems to be questionable that they really have a substantial clinical benefit in the long run.

Acknowledgements

The author would like to thank the dental technicians Andreas Nolte and Dietmar Meyer (both Münster, Germany) for their support and technical expertise.

References

1. King GN, Hermann JS, Schoolfield JD, Buser D, Cochran DL. Influence of the size of the microgap on crestal levels in non-submerged dental implants: a radiographic study in the canine mandible. J Periodontol 2002;73:1111–1117.
2. Hermann JS, Schoolfield JD, Schenk RK, Buser D, Cochran DL. Influence of the size of the microgap on crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged implants in the canine mandible. J Periodontol 2001;72:1372–1383.

3. Zipprich H, Weigl P, Lange B, Lauer HC. Erfassung, Ursachen und Folgen von Mikrobewegungen am Implantat-Abutment-Interface. Implantologie 2007;15:31–46.
4. Steinebrunner L, Wolfart S, Ludwig K, Kern M. Implant-abutment interface design affects fatigue and fracture strength of implants. Clin Oral Implants Res 2008;19:1276–1284.
5. Tripodakis AP, Strub JR, Kappert HF, Witkowski S. Strenght and mode of failure of single implant all-ceramic abutment restorations under static load. Int J Prosthodont 1995;8:265–272.
6. Gehrke P, Dhom G, Brunner J, Wolf D, Degidi M, Piatelli A. Zirconium implant abutments: fracture strength and influence of cyclic loading on retaining-screw. Quintessence Int 2006;37:19–26.
7. Butz F, Heydecke G, Okutan M, Strub JR. Survival rate, fracture strength and failure mode of ceramic implant abutments after chewing simulation. J Oral Rehabil 2005;32:838–843.
8. Abrahamson I, Berglundh T, Lindhe J. The mucosal barrier after abutment dis/reconnection. An experimental study in dogs. J Clin Periodontol 1997;24:568–572.
9. Abrahamson I, Berglundh T, Sekino S, Lindhe J. Tissue reactions to abutment shift: an experimental study in dogs. Clin Implant Dent Relat Res 2003;5:82–88.
10. Mombelli A, van Oosten MA, Schurch E Jr, Lang NP. The microbiota associated with successful or failing osseointegrated titanium implants. Oral Microbiol Immunol 1987;2:142–151.
11. Quirynen M, van Steenberghe D. Bacterial colonization of the internal pat of two-stage implants. An *in vivo* study. Clin Oral Implants Res 1994;5:239–244.
12. Broggini N, McManus LM, Hermann JS, et al. Persistent acute inflammation at the implant-abutment interface. J Dent Res 2003;82:232–237.
13. Steinebrunner L, Wolfart S, Bößmann K, Kern M. *In vitro* evaluation of bacterial leakage along the implant abutment interfaces of different implant systems. Int J Oral Maxillofac Implants 2005;20:875–881.
14. Duarte AR, Rossetti PH, Rossetti LM, Torres SA, Bonchela WC. *In vitro* sealing ability of two materials at five different implant-abutment surfaces. J Periodontol 77;2006:1828–1832.
15. Harder S, Dimaczek B, Acil Y, Terheyden H, Freitag-Wolf S, Kern M. Molecular leakage at implant-abutment connection – *in vitro* investigation of tightness of internal conical implant-abutment connections against endotoxin penetration. Clin Oral Investig 2010;14:427–432.
16. Paolantonio M, Perinetti G, D`Ercole S, Graziani F, Catamo G, Sammartino G, Piccolomini R. Internal decontamination of dental implants: an *in vivo* randomized microbiologic 6-month trial on the effects of a chlorhexidine gel. J Periodontol 2008;79:1419–1425.
17. Lazzara RJ, Porter SS. Platform switching: a new concept in implant dentistry for controlling postrestorative crestal bone levels. Int J Periodontics Restorative Dent 2006;26:9–17.
18. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005;25:113–119.
19. Maeda Y, Miura J, Taki I, Sogo M. Biomechanical analysis on platform switching: is there any biomechanical rational? Clin Oral Implants Res 2006;10:581–584.
20. Rodriguez-Ciurana X, Vela-Nebot X, Segala-Torres M, Rodado-Alonso C, Méndez-Blanco V, Mata-Bugueroles M. Biomechanical repercussions of bone resorption related to biologic width: a finite element analysis of three implant-abutment configurations. Int J Periodontics Restorative Dent 2009;29:479–487.
21. Becker J, Ferrair D, Herten M, Kirsch A, Schaer A, Schwarz F. Influence of platform switching on crestal bone changes at non-submerged titanium implants: a histomorphometrical study in dogs. J Clin Periondontol 2007;34:1089–1096.
22. Weng D, Hitomi Nagata MJ, Bell M, Nascimento de Melo LG, Bosco AF. Influence of the microgap location and configuration on peri-implant bone morphology in nonsubmerged implants: an experimental study in dogs. Int J Oral Maxillofac Implants 2010;25:540–547.
23. Canullo L, Iurlaro G, Iannello G. Double-blind randomized controlled trial on post-extraction immediately restored implants using the switching platform concept: soft tissue response. Preliminary report. Clin Oral Implants Res 2009;20:414–420.
24. Canullo L, Fedele GR, Iannello G, Jepsen S. Platform switching and marginal bone-level alterations: the results of a randomized-controlled trial. Clin Oral Implants Res 2010;21:115–121.
25. Prosper L, Redaelli S, Pasi M, Zarone F, Radaelli G, Gherlone EF. A randomized prospective multicenter trial evaluating the platform-switching technique for the prevention of post-restorative crestal bone loss. Int J Oral Maxillofac Implants 2009;24:299–308.
26. Abrahamson I, Berglundh T. Effects of different implant surfaces and designs on marginal bone-level alterations: a systematic review. Clin Oral Impl Res 2009;20 (Suppl 4):207–215.