RIJKSUNIVERSITEIT GRONINGEN

Short dental implants in the posterior region

The effect of platform-switching and a nanorough surface on peri-implant bone loss

Proefschrift

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Chapter 1

Introduction

Introduction

With the introduction of local anaesthesia (cocaine) by William Halsted in the 19th century, dentists started experimenting with implantation of lost teeth by natural teeth (Halsted 1885). As one of the shortcomings using natural teeth was resorption of the root, Greenfield started in 1913 with placing metal hollow-cylinders made of iridoplatinum and gold in jaw bone (Greenfield 1913). This 'hollow-basket' design was very similar to the design adopted many years later by the Straumann Group (Basel, Switzerland) (Telleman et al. 2006). The biocompatibility of titanium, the current used material for dental implants, was discovered by Bothe et al. (1940) in a comparative study on the tissue reactions of several metals in cats. Thereupon, in the mid-1950's, Brånemark, an orthopaedic surgeon from Sweden, discovered that titanium implants were almost impossible to be removed from the bone, and called this phenomenon osseointegration. In 1965 he placed the first titanium implants in alveolar bone of humans (Brånemark et al. 1969). These first titanium implants were short in length (<10 mm), comparing to the commonly used 10-14 mm length implants used by the turn of the century.

Nowadays, short (<10 mm in length) implants are increasingly used for the prosthodontic rehabilitation of the (partially) edentulous posterior mandible or maxilla. Short implants have been associated with lower survival rates when compared with longer implants (≥10 mm in length) (Lee et al. 2005, Romeo et al. 2010). There are several presumed reasons for a lower survival rate of short implants in the posterior maxilla and mandible. First, compared with longer implants with a comparable diameter the available area for bone to implant contact is less when short implants are used. Secondly, short implants are mostly placed in the posterior region where the quality of the alveolar bone is poorer than in the anterior region, especially in the maxilla (type III or IV, Lekholm & Zarb 1985). Thirdly, often a very outsized crown has to be made to reach occlusion, because of the extensive resorption in the posterior region, which causes a higher crown to implant ratio.

To avoid the use of short implants the alveolar bone can be augmented using a bone grafting technique. This modification in the patient's anatomy makes it possible to insert a longer implant, but an extra surgical intervention also leads to greater patient's morbidity, higher costs and a longer treatment period. Esposito et al. (2010) concluded from their systematic review on augmentation procedures of the maxillary sinus: "Short implants (5-8 mm) may be as effective and cause fewer complications than longer implants placed using a more complex technique." And from their systematic review on horizontal and vertical bone augmentation techniques they concluded: "Short implants appear to be a better alternative to vertical bone grafting of resorbed mandibles. Complications, especially for vertical augmentation, are common (Esposito et al. 2009)."

Up to now, there is no consensus in the literature on the definition of a short implant. Some authors consider 10 mm the minimal length for predictable success, so they consider any implant <10 mm in length as short (Morand & Irinakis 2007, Annibali et al. 2011). Others defined an implant length of 10 mm also as a short implant (Das Neves et al. 2006, Sun et al. 2011). Because an implant can be placed at different levels, a short implant has also been defined as an implant with a designed intra-bony length of 8 mm or less (Renouard & Nisand 2006, Neldam & Pinholt 2010).

Several authors have reviewed the literature of applying short implants in the prosthodontic rehabilitation of (partial) edentulous patients. Das Neves et al. (2006) concluded that short implants should be considered as an alternative treatment to advanced bone augmentation surgeries. Renouard & Nisand (2006) performed a structured review about the impact of implant length and diameter on survival rates and demonstrated a trend for an increase failure rate with short and wide-diameter implants. Two reviews compared short implants to standard length implants and concluded that the recent literature has demonstrated similar survival rates (Kotsovilis et al. 2009, Romeo et al. 2010). Above all, reviewers concluded that important confounders (viz. length, surface topography, smoking, implant location (mandible vs. maxilla) and bone augmentation procedure) needed to be addressed in future studies as they might be a key factor for the success in the use of short implants (Neldam & Pinholt 2010, Romeo et al. 2010, Annibali et al. 2011, Sun et al. 2011). No systematic review with meta-analyses to determine the role of these possible predictors was already performed on short implants in the partially edentulous patients.

Oral implants research still aims for refining the implant design and surface topography striving to prevent marginal bone loss, which is especially important around short implants. A relatively new development in the design of the implant-abutment connection is the concept of platform switching; placing a smaller-diameter abutment on a wider-diameter implant. The dimensional mismatch between implant and abutment creates a circumferential horizontal difference in dimension between the implant and the abutment restorative platform. Early results of platform-switched implants showed radiographically no changes in marginal bone levels, contrary to standard platform-matched implants (Wagenberg & Froum 2006). Several hypotheses were posed to explain the rationale behind the concept of platform switching for marginal bone preservation. The biomechanical rationale proposed that by platform switching the stress-concentration zone (from the forces of occlusal loading) is directed from the crestal bone-implant interface to the axis of the implant and so greatly reduces the stress level in the cervical

bone area (Maeda et al. 2007). Another hypothesis concerns the role of an altered location of the biologic width by medializing the implant-abutment connection and subsequent microgap (Berglundh & Lindhe 1996, Hermann et al. 2001, Todescan et al. 2002). And several studies described the role of inflammatory cell infiltrate at the implant-abutment microgap (Ericsson et al. 1995, 1996, Broggini et al. 2006). The systematic review of Atieh et al. (2010) about platform switching of standard length implants (≥10 mm) showed that marginal bone loss around platform-switched implants indeed was significantly less compared with platform-matched implants. There is no evidence yet, whether platform switching of implants shorter than 10 mm in length effects marginal bone loss. As short implants might be expected to develop a greater maximum compressive stress in their coronal region in comparison to longer implants (Hagi et al. 2004, Neldam & Pinholt 2011), platform switching could lead to less marginal bone loss.

Innovations with regard to the surface microtopography and chemistry have been reported to achieve higher survival rates of short implants (Hagi et al. 2004, Renouard & Nisand 2006, Kotsovillis et al. 2009, Romeo et al. 2010, Annibali et al. 2011). Nowadays, there is considerable interest in whether nanometer-sized irregularities on the implant surface affect the bone response as it already has been shown that implant surface roughness on a micrometer level does influence cell and tissue response (Shalabi et al. 2006, Lang & Jepsen 2009, Wennerberg & Albrektsson 2009a,b). In 2008, Meirelles et al. reported a study in which they developed an experiment in which microroughness was controlled. This study demonstrated that nanometer-sized hydroxyapatite particles (10 nm) on the implant surface indeed resulted in a stronger bone response. Furthermore, it was shown that nanoroughness and calcium phosphate (CaP) particles on implant surfaces increased activation of platelets (Park et al. 2001, Kikuchi et al. 2005, Arvidsson et al. 2007, Mendes et al. 2007). These platelets may play an initiating role in the process called contact osteogenesis; activated platelets stimulate osteogenetic cells to migrate to the surface of the implant. On the implant surface, these osteogenic cells differentiate into osteoblasts and start depositing new bone (Davies 2003, 2007). There is no evidence yet, whether a nanorough surface through a deposition of CaP, leads to higher implant survival rates or less marginal bone loss of implants shorter than 10 mm in length.

Given the lack of evidence in the research fields exemplified in the previous paragraphs, the general aim of this thesis is to analyse short implants placed in the resorbed posterior region of partially dentate patients and to compare marginal bone loss, survival rate, clinical performance and patient's satisfaction of short implants provided with either a platform-switched implant-abutment connection or a platform-matched implant-abutment connection.

The specific aims are:

- to assess, by a systematic review of the literature, the clinical outcome of short implants (<10 mm in length) in partially edentulous patients and to evaluate the sources of heterogeneity between studies by subgroup analyses (viz. implant length, implant surface topography, smoking, implant location (mandible vs. maxilla), bone augmentation procedure) (Chapter 2).

- to compare marginal bone-level change, survival rate, clinical performance and patient's satisfaction in a randomized clinical trial of short implants (8.5 mm in length) provided with either a platform-matched or a platform-switched implant-abutment connection, placed in the resorbed posterior region of partially edentulous patients (Chapter 3).

- to compare early peri-implant endosseous healing properties of the dual acid-etched surface to the dual acid-etched surface with a discrete crystalline deposition of nanometer-sized CaP in a active remodelling (i.e. grafted bone) and native (i.e. mature bone) maxillary area (Chapter 4).

- to compare marginal bone-level change, survival rate, clinical performance and patient's satisfaction in a randomized clinical trial (Chapter 5) and a split-mouth study (Chapter 6) of short implants (8.5 mm in length) with a nanorough surface (through a deposition of CaP) provided with either a platform-matched or a platform-switched implant-abutment connection, placed in the resorbed posterior region of partially edentulous patients.

The surgical and prosthodontic treatment protocol applied in the clinical studies is illustrated in a clinical report (Chapter 7).

References

Annibali, S., Cristalli, M. P., Dell'Aquila, D., Bignozzi, I., La Monaca, G. & Pilloni, A. (2012) Short Dental Implants: A systematic Review. *Journal of Dental Research* 91, 25-32.

Arvidsson, A., Franke-Stenport, V., Andersson, M., Kjellin, P., Sul, Y. T. & Wennerberg, A. (2007) Formation of calcium phosphates on titanium implants with four different bioactive surface preparations. An in vitro study. *Journals of Materials Science: Materials in Medicine* 18, 1945-1954.

Atieh, M. A., Ibrahim, H. M. & Atieh, A. H. (2010) Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis. *Journal of Periodontology* 81, 1350-1366.

Berglundh, T. & Lindhe, J. (1996) Dimension of the periimplant mucosa. Biological width revisited. *Journal of Clinical Periodontology* 23, 971-973.

Bothe, R. T., Beaton, L. E. & Davenport, H. A. (1940) Reaction of bone to multiple metallic implant. *Surgery, Gynecology & Obstetrics* 71, 598-602.

Brånemark, P. I., Breine, U., Adell, R., Hansson, B. O., Lindström, J. & Ohlsson, Å. (1969) Intraosseous anchorage of dental prosthes. I. Experimental studies. *Scandinavian Journal of Plastic & Reconstructive Surgery* 3, 81-100.

Broggini, N., McManus, L. M., Hermann, J. S., Medina, R., Schenk, R. K., Buser, D. & Cochran, D. L. (2006) Peri-implant inflammation defined by the implant-abutment interface. *Journal of Dental Research* 85,473-478.

Das Neves, F. D., Fones, D., Bernardes, S. R., do Prado, C. J. & Neto, A .J. (2006) Short implants- An analysis of longitudinal studies. *The International Journal of Oral and Maxillofacial Implants* 21, 86-93.

Davies, J. E. (2007) Bone bonding at natural and biomaterial surfaces. *Biomaterials* 28, 5058-5067.

Davies, J. E. (2003) Understanding peri-implant endosseous healing. *Journal of Dental Education* 67, 932-949.

Ericsson, I., Nilner, K., Klinge, B. & Glantz, P. O. (1996) Radiographical and histological characteristics of submerged and non-submerged titanium implants. An experimental study in the Labrador dog. *Clinical Oral Implants Research* 7, 20-26.

Ericsson, I., Persson, L. G., Berglundh, T., Marinello, C. P., Lindhe, J. & Klinge, B. (1995) Different types of inflammatory reactions in peri-implant soft tissues. *Journal of Clinical Periodontology* 22, 255-261.

Esposito, M., Grusovin, M. G., Rees, J., Karakoulos, D., Felice, P., Alissa, R., Worthington, H. V. & Coulthard, P. (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. *The Cochrane database of systematic reviews* 7, CD008397.

Esposito, M., Grusovin, M. G., Felice, P., Karatzopoulos, G., Worthington, H. V. & Coulthard, P. (2009) Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. *The Cochrane database of systematic reviews* 7, CD003607.

Goené, R. J., Testori, T. & Trisi, P. (2007) Influence of a nanometer-scale surface enhancement on de novo bone formation on titanium implants: a histomorphometric study in human maxillae. *The International Journal Periodontics & Restorative Dentistry* 27, 211-219.

Greenfield, E. J. (1913) Implantation of artificial crown and bridge abutments. *Dental Cosmos* 55, 364-369, 430-439.

Hagi, D., Deporter, D. A., Pilliar, R. M. & Arenovich, T. (2004) A targeted review of study outcomes with short (≤7 mm) endosseous dental implants in partially edentulous patients. *Journal of Periodontology* 75, 798-804.

Halsted, W. (1885) Practical comments on the use and abuse of cocaine: suggested by its invariably succesful employment in more than a thousand minor surgical operations. *New York Medical Journal* 43, 294-295.

Hermann, J. S., Buser, D., Schenk, R. K., Schoolfield, J. D. & Cochran, D. L. (2001) Biologic width around one-and two- piece titanium implants. *Clinical Oral Implants Research* 12, 559-571.

Hermann, J. S., Schoolfield, J. D., Nummikoski, P. V., Buser, D., Schenk, R. K. & Cochran, D.L. (2001) Crestal bone changes around titanium implants: A methodologic study comparing linear radiographic with histometric measurements. *International Journal of Oral Maxillofacial Implants* 16, 475-485.

Kikuchi, L., Park, J. Y., Victor, C. & Davies, J. E. (2005) Platelet interactions with calcium-phosphate-coated surfaces. *Biomaterials* 26, 5285-5295.

Kotsovilis, S., Fourmousis, I., Karoussis, I. K. & Bamia, C. (2009) A systematic review and meta-analysis on the effect of implant length on the survival of rough-surface dental implants. *Journal of Periodontology* 80, 1700-1718.

Lang, N. P. & Jepsen, S. (2009) Implant surfaces and design. *Clinical Oral Implants Research* 20, 228-231.

Lee, J. H., Frias, V., Lee, K. W. & Wright, R. F. (2005) Effect of implant size and shape on implant success rates: A literature review. *Journal of Prosthetic Dentistry* 94, 377-381.

Lekholm, U. & Zarb, G. A. (1985) Patient selection and preparation. In: Bränemark, P. I., Zarb, G. A. & Albrektsson, T. (eds). *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*, 1st edition, pp. 199-209. Chicago: Quintessence Publishing.

Maeda, Y., Miura, J., Taki, I. & Sogo, M. (2007) Biomechanical analysis on platform switching: Is there any biomechanical rationale? *Clinical Oral Implants Research* 18, 581-584.

Meirelles, L., Albrektsson, T., Kjellin, P., Arvidsson, A., Franke-Stenport, V., Andersson, M., Currie, F. & Wennerberg, A. (2008) Bone reaction to nano hydroxyapatite modified titanium implants placed in a gap-healing model. *Journal of Biomedical Materials Research. Part A.* 87, 624-631.

Mendes, V. C., Moineddin, R. & Davies J. E. (2007) The effect of discrete calcium phosphate nanocrystals on bone-bonding to titanium surfaces. *Biomaterials* 28, 4748-4755.

Morand, M. & Irinakis, T. (2007) The challenge of implant therapy in the posterior maxilla: providing a rationale for the use of short implants. *The Journal of Oral Implantology* 33, 257-266.

Neldam, C. A. & Pinholt, E. M. (2010) State of the art of short dental implants: a systematic review of the literature. *Clinical Implant Dentistry and Related Research* 26, (epub ahead of print).

Orsini, G., Piatelli, M., Scarano, A., Petrone, G., Kenealy, J., Piatelli, A. & Caputi, S. (2007) Randomized, controlled histologic and histomorphometric evaluation of implants with nanometer-scale calcium phosphate added to the dual acid-etched surface in the human posterior maxilla. *Journal of Periodontology* 78, 209-218.

Park, J. Y., Gemmell, C. H. & Davies, J. E. (2001)

Platelet interactions with titanium: modulation of platelet activity by surface topography. *Biomaterials* 22, 2671-2682.

Renouard, F. & Nisand, D. (2006) Impact of length and diameter on survival rates. *Clinical Oral Implants Research* 17, 35-51.

Romeo, E., Bivio, A., Mosca, D., Scanferla, M., Ghisolfi, M. & Storelli, S. (2010) The use of short dental implants in clinical practice: literature review. *Minerva Stomatologica* 59, 23-31.

Rudy, R. J., Levi, P. A., Bonacci F. J., Weisgold, A. S. & Engler-Hamm, D. (2008) Intraosseous anchorage of dental prosthese: an early 20th century contribution. *Compendium of Continiung Education in Dentistry* 29, 220-228.

Shalabi, M. M., Gortemaker, A., van 't Hof, M. A., Jansen, J. A. & Creugers, N. H. J. (2006) Implant surface and bone healing: a systematic review. Journal of Dental Research 85, 496-500.

Sun, H. L., Huang, C., Wu, Y. R. & Shi, B. (2011) Failure rates of short (≤ 10 mm) dental implants and factors influencing their failure: a systematic review. *International Journal of Oral Maxillofacial Implants* 26, 816-825.

Telleman, G., Meijer, H. J. A. & Raghoebar, G. M. (2006) Long-term evaluation of hollow screw and hollow cylinder dental implants; clinical and radiographic results after 10 years. *Journal of Periodontology* 77, 203-210.

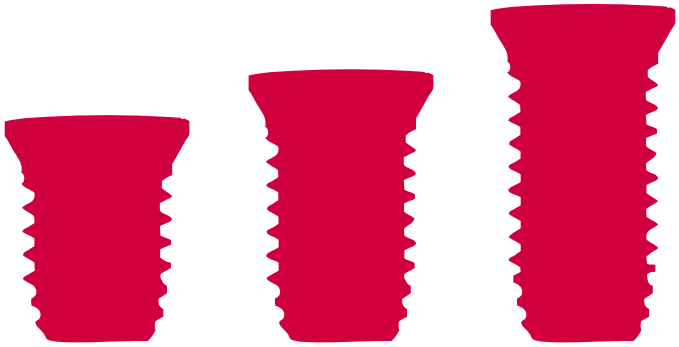
Todescan, F. F., Pustiglioni, F. E., Imbronito, A. V., Albrektsson, T. & Gioso, M. (2002) Influence of the microgap in the peri-implant hard and soft tissues: A histomorphometric study in dogs. *International Journal of Oral Maxillofacial Implants* 17, 467-472.

Trammell, K., Geurs, N. C., O'Neal, S. J., Liu, P. R., Haigh, S. J., McNeal, S., Kenealy, J. N. & Reddy, M. S. (2009) A prospective, randomized, controlled comparison of platform-switched and matched-abutment implants in short-span partial denture situations. *The International Journal of Periodontics & Restorative Dentistry* 29, 599-605.

Wagenberg, B. & Froum, S. J. (2010) Prospective study of 94 platform-switched implants observed from 1992 to 2006. *The International Journal of Periodontics & Restorative Dentistry* 30, 9-17.

Wennerberg, A. & Albrektsson, T. (2009a) Structural influence from calcium phosphate coatings and its possible effect on enhanced bone integration. *Acta Odontologica Scandinavica* 67, 333-340.

Wennerberg, A. & Albrektsson, T. (2009b) Effects of titanium surface topography on bone integration: a systematic review. *Clinical Oral Implants Research* 20, 172-184.



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Chapter 2

A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient

Abstract

Aim: This study evaluated, through a systematic review of the literature, the estimated implant survival rate of short (<10 mm) dental implants installed in partially edentulous patients.

Materials and methods: A systematic search was conducted in the electronic databases of MEDLINE (1980-October 2009) and EMBASE (1980-October 2009) to identify eligible studies. Two reviewers independently assessed the methodological quality of the articles using specific study design-related quality assessment forms.

Results: Twenty-nine methodologically acceptable studies were selected. A total of 2611 short implants (lengths 5-9.5 mm) was analysed. An increase in implant length was associated with an increase in implant survival (from 93.1% to 98.6%). Heterogeneity between studies was explored by subgroup analyses. The cumulative estimated failure rate of studies performed in the maxilla was 0.010 implants/year, compared with 0.003 found in the studies in the mandible. For studies that also included smokers the failure rate was 0.008 compared with 0.004 found in studies that excluded smokers. Surface topography and augmentation procedure were not sources of heterogeneity.

Conclusion: There is fair evidence that short (<10 mm) implants can be successfully placed in the partially edentulous patient, though with an increasing survival rate per implant length and the prognosis may be better in the mandible of non-smoking patients.

Introduction

Short implants are increasingly used for the prosthetic solution of the extremely resorbed posterior zone of partially edentulous patients. However, there is no consensus in the literature on the definition of a short implant. Some authors consider 10 mm the minimal length for predictable success; thus they consider any implant <10 mm in length as short (Morand & Irinakis 2007). Others defined an implant length of 10 mm also as a short implant (Das Neves et al. 2006). Because an implant can be placed at different levels, a short implant has also been defined as an implant with a designed intrabony length of 8 mm or less (Renouard & Nisand 2006).

Several authors have provided an overview of the literature of short implants in a narrative or structured review. Hagi et al. (2004) showed that, when applying 6 and 7 mm implants, short implants with a press-fit shape and a sintered porous surface geometry revealed the best performance. Das Neves et al. (2006) analysed the treatment outcome of longitudinal studies using Brånemark and compatible implants of 7, 8.5 and 10 mm implants and concluded that short implants should be considered as a alternative treatment to advanced bone augmentation surgeries. Renouard and Nisand (2006) performed a structured review of the impact of implant length and diameter on survival rates in fully and partially edentulous patients and their review demonstrated a trend for an increase failure rate with short and wide-diameter implants. Two recent reviews have been published in which short implants were compared with conventional implants. Kotsovilis et al. (2009) concluded from their systematic review that the placement of short (≤8 mm or <10 mm) rough-surface implants is not a less efficacious treatment modality compared with the placement of conventional (≥10 mm) rough-surface implants. Romeo et al. (2010) concluded that the recent literature has demonstrated a similar survival rate for short and standard implants. But some important confounders need to be studied in future studies as they might be a key factor for the success in the use of short implants.

In the past, short implants have been associated with lower survival rates (Lee et al. 2005, Romeo et al. 2010). There are several presumed reasons for a lower survival rate of short implants in the posterior maxilla or mandible. Firstly, compared with longer implants with a comparable diameter, there is less bone to implant contact when short implants are used, simply because there is less implant surface. Secondly, short implants are mostly placed in the posterior zone, where the quality of the alveolar bone is relatively poor, especially in the maxilla (type III or IV, Lekholm & Zarb 1985). Thirdly, often, a very outsized crown has to be made to reach occlusion, because of the extensive resorption in the posterior region, which causes a higher (<1->2) crown to implant ratio. Crown to implant ratios between 0.5 and 1 were proposed to prevent peri-implant bone stress, crestal bone loss and eventually implant failure (Haas et al. 1995, Rangert et al. 1997, Glantz & Nilner 1998). But

the most recent systematic review on two studies on crown to implant ratios concluded that the ratio does not influence the peri-implants crestal bone loss (Blanes 2009).
To avoid the use of short implants, the extremely resorbed bone can be augmented using a bone-grafting technique. This modification in the patient's anatomy makes it possible to insert a longer implant, but an extra surgical intervention also leads to greater patient morbidity, higher costs and a longer treatment period. Esposito et al. (2010) concluded, from their systematic review on augmentation procedures of the maxillary sinus, that "Short implants (5-8 mm) may be as effective and cause fewer complications than longer implants placed using a more complex technique." And from their systematic review on horizontal and vertical bone augmentation techniques for dental implant treatment, Esposito et al. (2009) concluded "Short implants appear to be a better alternative to vertical bone grafting of resorbed mandibles. Complications, especially for vertical augmentation, are common."
New developments of the different implant systems, especially regarding the surface micro-topography and chemistry, have resulted in higher survival rates of short implants (Hagi et al. 2004, Renouard & Nisand 2006, Kotsovillis et al. 2009, Romeo et al. 2010). The implant surface used to be a smooth turned surface, but nowadays, different techniques, e.g., acid etching, grit blasting and titanium plasma spraying, have altered the micro-topography of the implant surface by making the surface rougher. Application of these techniques results in a tremendously enlarged implant surface. Recent developments have been at the level of nano-topography (Meirelles et al. 2008a, b).
To our knowledge, no systematic review with meta-analyses to determine the role of possible predictors has been performed on short (<10 mm) endosseous implants in the partially edentulous patients. Hence, the objective of this article was to systematically assess the clinical outcome of short implants (<10 mm) in partially edentulous patients and to evaluate the sources of heterogeneity between studies by subgroup analyses (viz., length, surface topography, smoking, implant location (mandible versus maxilla) and bone augmentation procedure).

Materials and methods

Data identification and selection

A MEDLINE and EMBASE search from January 1980 to October 2009 was conducted to identify studies on short endosseous implants in partially edentulous patients. In the present study, an implant of length <10 mm was defined as a short implant, regardless of the level of placement. A search strategy was set up in duplicate and independently by the first author and by an expert in searching literature databases. The electronic search was carried out by applying the following free text words and the applied thesaurus (MeSH): # 1 Search dental implant OR dental implants OR dental implantation OR endosseous dental implantation OR endosseous implant OR endosseous implants OR endosseous implantation, # 2 Search short* OR short-length OR short OR short length OR length, # 3 Search # 1 AND # 2 NOT (case-report OR case report OR case reports) NOT review NOT animal. To complete the search, we checked the reference lists in the literature obtained for additional relevant articles. No language restrictions were applied.
Two reviewers (G.T and L.D.H) evaluated the relevance of the studies by a first selection based on the title and abstract. Disagreement about whether a study should be included for full inspection was resolved by a consensus discussion. Full-text documents were obtained for all possibly relevant articles. One reviewer (G.T) read the full-text documents of all relevant articles and selected the articles for further methodological appraisal using the inclusion and exclusion criteria described below. To test the quality of the data extraction, a second reviewer (L.D.H), who was blinded to data extraction of the first reviewer, again extracted the data of a random subset of 25% of the included articles to see whether there was a consensus in extracting data. There was an excellent agreement between the two reviewers (κ>0.95) for the extraction of the data.

Inclusion criteria:
- Study design: randomized controlled trial (RCT) or prospective cohort study.
- Patients: partially edentulous.
- Follow-up: >1 year.
- Implant length: <10 mm.
- Minimum total number of short implants (<10 mm) placed in the assessed implant cohort of a particular study: five (when two implants of length 6 mm and 3 implants of length 7 mm were placed, the study was also included).

Exclusion criteria:
- Study design: retrospective study, case report, review, non-clinical studies, explanation of technique or manual.
- Implants: (alumina)-zirconium implants or mini-implants for orthodontic anchorage.
- Suprastructures: cantilever constructions.
- Subjects: animals.

Validity assessment

Two reviewers (G.T and L.D.H) assessed the methodological quality using the forms 'quality assessment of a cohort study' and 'quality assessment of a randomized clinical trial' developed by the Dutch Cochrane Centre, a centre of the Cochrane Collaboration (tables 1 & 2). These two validity tools consist of eight and nine items, which have to be scored with a plus, minus or a question mark. It was decided that studies scoring four or more plusses were

Table 1. Quality assessment of a cohort study

Item	+	-	?
1. Are the characteristics of the comparative study groups clearly described?			
2. Can selection bias be excluded sufficiently?			
3. Is the intervention clearly described? Are all patients treated according to the same intervention?			
4. Are the outcomes clearly described? Are the methods used to assess the outcome adequate?			
5. Is blinding used to assess the outcome? If not, does this have any effect on the evaluation of the results?			
6. Is the duration of the follow-up sufficient?			
7. Can selective loss-to-follow-up be excluded sufficiently?			
8. Are the most important confounders or prognostic factors identified?			

Four or more plusses = methodologically acceptable

Table 2. Quality assessment of a randomized controlled trial (RCT)

Item	+	-	?
1. Was the intervention assignment randomized?			
2. The person who included the patients should not be informed about the randomization order. Was that the case?			
3. Were the patients blinded for treatment?			
4. Were the practitioners blinded for treatment?			
5. Were the evaluators blinded for treatment?			
6. Were the groups comparable at the beginning of the trial? If not, were the analyses corrected for this?			
7. Are there relatively enough patients available for complete follow-up? If not, can selective loss-to-follow-up be excluded sufficiently?			
8. Are the included patients analysed in the group in which they were randomized?			
9. Are the groups, besides the intervention, treated likewise?			

Four or more plusses = methodologically acceptable

considered methodologically acceptable. The two observers independently generated a score for the articles included. No blinding for author, institute or journal was performed.

Missing data

When not all needed data were provided in the publication, the author was sent an e-mail for further details. Non-responders were sent a reminder and a postal letter.

Statistical analysis

The pre-consensus degree of agreement between the two reviewers (G.T and L.D.H) regarding eligible studies was expressed as a percentage of agreement of Cohen's unweighted κ.

For each study, the estimated failure rate per year and the estimated implant survival rate after 2 years (%) were assessed. In this systematic review, an implant failure was defined as each implant from a cohort that was removed because of loss of integration, implant mobility, symptoms as pain, neuropathies, paraesthesia or violation of the mandibular canal or psychological reason (Albrektsson et al. 1986). The estimated failure rate was calculated by dividing the number of events (implant failures) by the total implant exposure time. The total exposure time was calculated by taking the sum of (Pjetursson et al. 2008):

1. The exposure time of implants that could be followed for the entire observation time.
2. The exposure time up to a failure of implants which were lost during the observation time.
3. The exposure time up to the end of observation time for implants that did not complete the observation period as a result of reasons such as missed appointments, work commitments, refusal to participate in the follow-up, change of address, chronic illnesses or death.

When the exposure time was not given separately for the short implants or the follow-up was not a closed period but had dispersal over years, a percentage (given by the number of short implants) of the total implant exposure time of all the implants was taken as the best available approximation. Exclusion of these studies, as the follow-up was not a closed period or because also longer implants were studied, was not preferred. For the calculation of the estimated survival rate after 2 years, the total number of events was considered to follow a Poisson's distribution.

Summary estimates of the annual failure were calculated for different implant lengths in a stratified analysis. The different lengths of 5, 6, 7, 8, 8.5, 9 and 9.5 mm were studied. Sources of heterogeneity were explored using stratified analyses for the determinants surface topography, location (maxilla versus mandible), smoking and bone augmentation procedures. The results of smooth turned surfaces were compared to roughened surfaces (i.e. dual

acid-etched or titanium plasma sprayed) and the failures of short implants in the maxilla were compared to the mandible. Smokers were divided into two groups; 1) only non-smokers included in the study; 2) no restrictions about smoking habits; non-smokers, moderate and heavy smokers (≥15 cigarettes per day) were included in the study. Whether an augmentation procedure was performed simultaneously with placing the implant was scored as; 1) no augmentation procedure; 2) augmentation performed which might be either local sinus floor elevation surgery, a local covering of a fenestration of the implant surface or a local covering of a dehiscence of the implant surface.

In order to assess the heterogeneity of the studies included, Cochran's *Q* statistic and associated *p*-value and the I^2 -test were calculated. I^2 quantified no heterogeneity by 0%, mild heterogeneity by <30%, moderate heterogeneity by 30-60% and notable heterogeneity by >60%. Standard errors were calculated to obtain 95% confidence intervals (CIs) of the estimated failure rates.

Two-year survival proportions were calculated via the relationship between estimated failure rate and survival function S, S (T) =exp(-T x failure rate), by assuming constant failure rates (Kirkwood & Sterne 2003a,b). The 95% CIs for the survival proportions were calculated using the 95% confidence limits of the event rates.

Analyses were performed using the statistical software package "Meta-analysis" (Comprehensive Meta-analysis Version 2.2, Biostat, Englewood NJ (2005), http://www.meta-analysis.com).

Results

Data identification and selection

The MEDLINE and EMBASE search identified 960 and 393 publications, respectively. A total of 164 publications were eligible for full-text analysis. Checking references in the literature obtained did yield one additional publication (Becker et al. 1999). Of the 165 publications, 61 publications fulfilled the inclusion criteria. Methodological assessment of these 61 eligible publications revealed 39 methodologically acceptable publications. The inter-reviewer agreement on the methodological appraisal was measured with an unweighted κ: 0.83. Disagreement was generally caused by slight differences in interpretation and was easily resolved in a consensus discussion. Unfortunately, eight eligible articles had to be excluded from the meta-analysis because the contacted authors did not respond on either of the attempts for obtaining more details about the study. Furthermore, one author did not want to engage in a reanalyses of his data. In addition, the data of one study were published twice, the data of the most recent publication were included (Glauser et al. 2003, Glauser et al. 2005). Finally, a total of 29 publications were selected for data analysis. Figure 1 outlines the algorithm of the study selection procedure.

Figure 1. Algorithm of study selection procedure

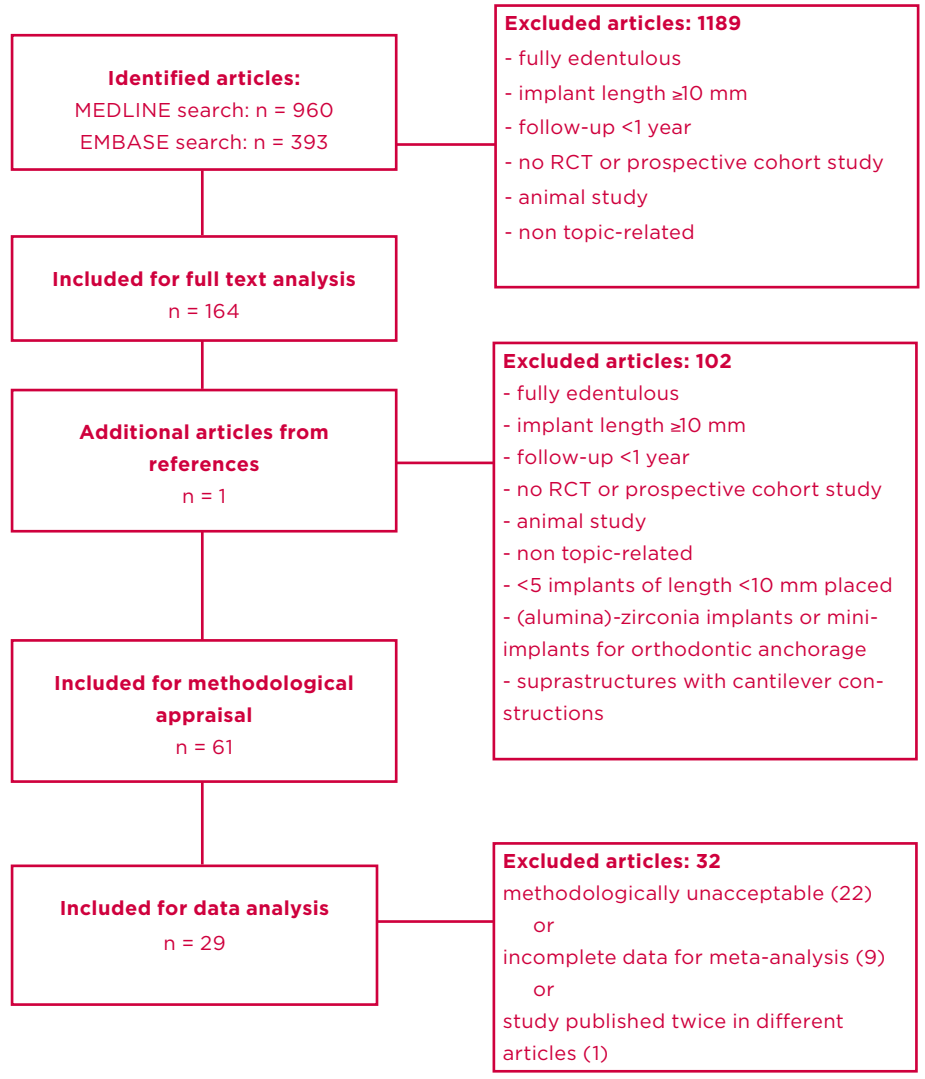


Table 3. Overview of the included studies and annual failure and survival rates grouped by implant length

Study	Year of publi-cation	Total no. of implants	Implant length (mm)	Surface topo-graphy	Location	Smoking status	Augmen-tation procedure	Mean follow-up time (years)	No. of failure	Total implant exposure time (months)	Estimated implant failure rate (per year)	Estimated implant survival rate after 2 years (%)
Corrente	2009	10	5	rough	maxilla	moderate included	yes	1.7	0	193	0.030	94.2
Deporter	2001b	2	5	rough	maxilla	excluded	yes	2	0	77	0.072	86.6
Summary estimate (95% CI) of 5 mm implant											**0.036** (0-0.114)	**93.1** (79.7-100)
Pjetursson	2009	7	6	rough	maxilla	included	unknown	3.2	3	234	0.134	76.5
Nedir	2004	5	6	rough	maxilla	included	yes	4.4	0	189	0.031	94.0
Nedir	2004	1	6	rough	mandible	included	yes	4.4	0	38	0.136	76.2
Tawil	2003	16	6	machined	mandible	unknown	unknown	2.5	0	1335	0.004	99.2
Mericske-Stern	2001	5	6	rough	both arches	moderate included	unknown	4.3	0	230	0.025	95.1
Brocard	2000	16	6	rough	both arches	included	yes	3.9	3	720	0.050	90.5
Becker	1999	2	6	machined	mandible	moderate included	unknown	1.6	0	68	0.081	85.0
Becker	1999	5	6	machined	maxilla	moderate included	unknown	1.6	1	171	0.070	86.9
Summary estimate (95% CI) of 6 mm implant											**0.013** (0-0.029)	**97.4** (94.4-100)
Corrente	2009	38	7	rough	maxilla	moderate included	yes	1.7	1	731	0.016	96.8
Glauser	2005	1	7	rough	both arches	included	yes	4	0	32	0.158	72.9
Beschnidt	2003	4	7	rough	both arches	included	yes	5.3	1	226	0.053	89.9
Tawil	2003	27	7	machined	mandible	unknown	unknown	2.5	5	2252	0.027	94.7
Davarpanah	2002	96	7	rough	both arches	moderate included	no	2.7	4	4243	0.011	97.8
Deporter	2001b	44	7	rough	maxilla	excluded	yes	2	0	1703	0.004	99.2
Deporter	2001a	32	7	rough	mandible	excluded	unknown	2.7	0	1088	0.005	99.0
Testori	2001	3	7	rough	maxilla	moderate included	no	3.6	1	147	0.082	84.9
Testori	2001	4	7	rough	mandible	moderate included	no	3.6	0	196	0.030	94.2
Polizzi	2000	2	7	rough	both arches	included	unknown	3	0	57	0.095	82.7
Becker	1999	1	7	machined	mandible	moderate included	unknown	1.6	0	34	0.150	74.1
Becker	1999	5	7	machined	maxilla	moderate included	unknown	1.6	3	171	0.211	65.6
Gunne	1999	37	7	machined	both arches	unknown	unknown	7.3	4	3601	0.013	97.4
Lekholm	1999	22	7	machined	maxilla	unknown	unknown	8.1	4	1999	0.024	95.3
Lekholm	1999	79	7	machined	mandible	unknown	unknown	8.1	2	7316	0.003	99.3
Bahat	1993	126	7	machined	maxilla	unknown	unknown	2.5	12	3818	0.038	92.7
Summary estimate (95% CI) of 7 mm implant											**0.012** (0.006-0.019)	**97.6** (96.3-98.8)
Pjetursson	2009	157	8	rough	maxilla	included	unknown	3.2	2	5238	0.004	99.0
Degidi	2006	10	8	rough	both arches	moderate included	unknown	2	0	120	0.111	80.1
Romeo	2006	111	8	rough	both arches	excluded	no	6.4	4	8525	0.006	98.8
Ferrigno	2005	103	8	rough	both arches	moderate included	yes	5	4	5784	0.008	98.4
Cecchinato	2004	33	8	rough	both arches	included	unknown	2	4	737	0.065	87.7
Nedir	2004	35	8	rough	maxilla	included	minor	4.4	0	1321	0.005	99.0
Nedir	2004	62	8	rough	mandible	included	minor	4.4	0	2340	0.003	99.4
Romeo	2004	72	8	rough	both arches	moderate included	no	3.9	6	5479	0.013	97.4
McGlumphy	2003	2	8	rough	maxilla	moderate included	unknown	5	0	104	0.055	89.6
McGlumphy	2003	18	8	rough	mandible	moderate included	unknown	5	2	985	0.024	95.2
Tawil	2003	7	8	machined	maxilla	unknown	unknown	2.5	1	584	0.021	95.9
Tawil	2003	20	8	machined	mandible	unknown	unknown	2.5	0	1668	0.004	99.2
Mericske-Stern	2001	44	8	rough	both arches	moderate included	unknown	4.3	3	2025	0.018	96.5
Brocard	2000	232	8	rough	both arches	included	yes	3.9	15	10440	0.017	96.6
Buser	1997	389	8	rough	both arches			2	12	14532	0.010	98.0
Summary estimate (95% CI) of 8 mm implant											**0.008** (0.005-0.011)	**98.4** (97.8-99.0)

Table 3. Continued

Study	Year of publi-cation	Total no. of implants	Implant length (mm)	Surface topo-graphy	Location	Smoking status	Augmen-tation procedure	Mean follow-up time (years)	No. of failure	Total implant exposure time (months)	Estimated implant failure rate (per year)	Estimated implant survival rate after 2 years (%)
Glauser	2005	4	8.5	rough	both arches	included	yes	4	0	130	0.044	91.6
Sullivan	2005	21	8.5	rough	both arches	moderate included	no	3.6	1	1095	0.011	97.8
Farzad	2004	7	8.5	machined	both arches	unknown	unknown	3.9	0	328	0.018	96.5
Beschnidt	2003	12	8.5	rough	both arches	included	yes	5.3	1	678	0.018	96.5
Tawil	2003	2	8.5	machined	maxilla	unknown	unknown	2.5	0	167	0.035	93.2
Tawil	2003	44	8.5	machined	mandible	unknown	unknown	2.5	2	3670	0.002	99.6
Davarpanah	2002	189	8.5	rough	both arches	moderate included	no	2.7	11	8354	0.016	96.9
Davarpanah	2001	56	8.5	rough	both arches	unknown	no	3	2	1905	0.013	97.4
Testori	2001	8	8.5	rough	maxilla	moderate included	no	3.6	0	393	0.015	97.0
Testori	2001	14	8.5	rough	mandible	moderate included	no	3.6	0	687	0.009	98.2
Polizzi	2000	8	8.5	rough	both arches	included	unknown	3	1	226	0.053	89.9
Becker	1999	17	8.5	machined	mandible	moderate included	unknown	1.6	0	581	0.010	98.0
Becker	1999	7	8.5	machined	maxilla	moderate included	unknown	1.6	0	239	0.024	95.3
Grunder	1999	31	8.5	rough	both arches	included	no	2.4	0	884	0.007	98.6
Summary estimate (95% CI) of 8.5 mm implant											**0.006** (0.002-0.009)	**98.8** (98.2-99.6)
Degidi	2009	21	9	rough	both arches	moderate included	no	5	0	1260	0.008	98.4
Degidi	2006	39	9	rough	both arches	moderate included	unknown	2	0	468	0.012	97.6
Cecchinato	2004	65	9	rough	both arches	included	unknown	2	1	1452	0.008	98.4
Nedir	2004	7	9	rough	maxilla	included	minor	4.4	0	264	0.022	95.7
Nedir	2004	1	9	rough	mandible	included	minor	4.4	0	38	0.136	76.2
Deporter	2001b	89	9	rough	maxilla	excluded	yes	2	3	3445	0.010	98.0
Deporter	2001a	16	9	rough	mandible	excluded	unknown	2.7	0	544	0.011	97.8
Summary estimate (95% CI) of 9 mm implant											**0.010** (0.002-0.018)	**98.0** (96.4-99.6)
Degidi	2006	68	9.5	rough	both arches	moderate included	unknown	2	0	816	0.007	98.6
Summary estimate (95% CI) of 9.5 mm implant											**0.007** (0-0.028)	**98.6** (94.6-100)

Abbreviations: No.= Number, CI= Confidence interval

Table 4. Sources of heterogeneity and their possible role as expressed in estimated failure rate per year

Implant length (mm)	Studies (n)	Implants (n)	Heterogeneity (Cochran's Q-test)		Summary of estimated failure rate (95% CI)	Source of heterogeneity							
						estimated failure rate by surface (95% CI)		estimated failure rate by location (95% CI)		estimated failure rate by smoking (95% CI)		estimated failure rate by augmentation (95% CI)	
			p-value	I^2		rough	machined	mandible	maxilla	excluded	included	not performed	performed
5	2	12	>0.05	0.00	0.036 (0- 0.114)	Only implants with rough surfaces		Only implants placed in the maxilla		0.072 (0-0.272)	No studies available	In all studies augmentation procedures were performed	
6	6	57	>0.05	3.29	0.013 (0-0.029)	0.045 (0.007-0.082)	0.005 (0-0.017)	0.096 (0-0.289)	0.058 (0-0.125)	no studies available	0.053 (0.008-0.098)	no studies available	0.046 (0-0.92)
7	13	521	>0.05	36.50	0.012 (0.006-0.019)	0.008 (0.001-0.014)	0.018 (0.005-0.031)	0.004 (0-0.008)	0.021 (0.002-0.040)	0.004 (0-0.012)	0.063 (0-0.160)	0.012 (0.001-0.023)	0.005 (0-0.014)
8	12	1295	>0.05	12.99	0.008 (0.005-0.011)	0.008 (0.006-0.011)	0.005 (0-0.016)	0.004 (0-0.009)	0.005 (0-0.011)	0.006 (0.000-0.011)	0.008 (0.001-0.015)	0.008 (0.003-0.013)	0.009 (0.005-0.013)
8.5	10	420	>0.05	0.00	0.006 (0.002-0.009)	0.014 (0.007-0.020)	0.007 (0-0.015)	0.002 (0-0.006)	0.020 (0-0.053)	no studies available	0.011 (0-0.027)	0.013 (0.006-0.020)	0.044 (0-0.166)
9	6	238	>0.05	0.00	0.010 (0.002-0.018)	Only implants with rough surfaces		0.011 (0-0.042)	0.002 (0-0.007)	0.002 (0-0.007)	0.009 (0-0.025)	0.008 (0-0.029)	0.002 (0.003-0.007)
9.5	1	68	>0.05	0.00	0.007 (0-0.028)	Only 1 study included		Only 1 study included		Only 1 study included		Only 1 study included	
All lengths	29	2611	>0.05	0.00	0.007 (0.006-0.009)	0.008 (0-0.010)	0.010 (0.005-0.016)	0.003 (0.001-0.006)	0.010 (0.005-0.016)	0.004 (0-0.007)	0.008 (0.004-0.013)	0.010 (0.006-0.013)	0.007 (0.004-0.010)

I^2 quantifies inconsistency: no heterogeneity by 0%, mild heterogeneity by <30%, moderate heterogeneity by 30-60%, notable heterogeneity by >60%
Abbreviations: CI= Confidence interval, n= number

The 29 eligible publications included a total of 28 prospective cohort and 1 randomized controlled trial (RCT). The mean follow-up of the 29 publications was 3.7 years (range 1.6-8.1 year). The first study was published in 1993, the latest in 2009. The median year of publication was 2003. The 29 studies included a total of 2611 short implants (lengths 5, 6, 7, 8, 8.5, 9 and 9.5 mm). An overview of all studies included is given in table 3. This table is ranked by implant length (from 5 to 9.5 mm). A study can be mentioned twice or more times in table 3 as a variety of implant lengths can be used in a particular study, e.g. in the study of Corrente et al. (2009) 10 implants of length 5 mm and 38 of length 7 mm were placed. The summary of the estimated survival rate after 2 years for the different implant length was 93.1% (95% CI: 79.7%-100%) for 5 mm, 97.4% (95% CI: 94.4%-100%) for 6 mm implants, 97.6% (95% CI: 96.3%-98.8%) for 7 mm implants, 98.4% (95% CI: 97.8 %-99.0%) for 8 mm implants, 98.8% (95% CI: 98.2%-99.6%) for 8.5 mm implants, 98.0% (95% CI: 96.4%-99.%) for 9 mm implants and 98.6% (95% CI: 94.6%-100%) for 9.5 mm implants.

Sources of heterogeneity between included studies

Sources of heterogeneity were explored in a sensitivity analysis with post hoc subgroups analyses. The main question behind these analyses was not to see whether there were subgroups to be found, but merely to check whether results would vary between these subgroups. These so-called stratified analyses were run for implant surface topography (rough versus machined), location (mandible versus maxilla), smoking status (smokers were excluded versus smokers were included) and augmentation procedure (not performed simultaneously with placing the implants versus performed simultaneously with placing the implants). The overall results of all implant lengths showed a similar estimated failure rate for the different surface topographies 0.008 (95% CI: 0-0.010) for rough implants and 0.010 (95% CI: 0.005-0.016) for the machined implants, respectively, a difference of 29% between the two different surface topographies compared with the summary of the estimated failure rate of all lengths of 0.007 (95% CI: 0.006-0.009). The estimated failure rate of implants placed in the maxilla was significantly higher (0.010 (95% CI: 0.005-0.016)) than that for implants in the mandible (0.003 (95% CI: 0.001-0.006)), a significant difference of 100%. The estimated failure rate from studies in which smokers were strictly excluded were twice as low (0.004 (95% CI: 0.000-0.007)) compared with those in which heavy smokers (≥15 cigarettes/day) were also included (0.008 (95% CI: 0.004-0.013)), a difference of 57%. The difference in estimated failure rate in bone augmentation procedure simultaneously with placing the implants was not conspicuous. When there was no augmentation procedure was performed, the estimated failure rate was 0.010 (95% CI: 0.006-0.013) compared with when augmentation was performed 0.007 (95% CI: 0.004-0.010), a difference of 43%.
Heterogeneity was also calculated with the Cochran's Q-test per implant

length and of all lengths together (see table 4). All *p*-values were higher than the conventional cut point of 0.05, which indicated homogeneity of the different studies with one implant length and of all the studies together. The I^2-test quantifies heterogeneity and for the implant lengths 5, 8.5, 9, 9.5 and of all lengths together, there seemed to be no heterogeneity, for implants length 6 and 8 mm there was mild heterogeneity and for the group with implant length 7 mm, there seemed to be moderate heterogeneity.

Discussion

This systematic review of short implants (<10 mm) in partially edentulous patients shows a (negative) significant association between failure rate and implant length; the longer the implant the higher the implant survival rate within the range of 5 to 8.5 mm length. The results for the shortest implants (5 mm, n=12) has to be considered with some caution, however, as only two studies were available (Deporter et al. 2001, Corrente et al. 2009). This increasing survival rate with implant length was not reported in the systematic review of Kotsovilis et al. (2009), who found no statistical difference between short (≤8 or <10 mm) and conventional (≥10 mm) implants, but they did not perform a meta-regression analysis per implant length. Romeo et al. (2010) also found a similar survival rate for short and standard implants.

This review also shows that the estimated failure rates of studies in which short implants were placed in the mandible were lower than studies that placed short implants in the maxilla. These results are in line with the treatment outcome of 'normal' length or standard implants, i.e. implants with a length >10 mm (Friberg et al. 1991). Moreover, implant failures of studies that excluded smokers were lower than the results of studies that included (heavy) smokers (≥15 cigarettes/day) patients. The association between smoking and implant failure, as found in the current review, could not always be shown in other studies. In the systematic review by Pjetursson et al. (2008), a difference in implant survival rate was found, but could not reach statistical significance. Also in line with standard length implants, no difference in implant survival rate was observed between studies with and without (minor or major) augmentation procedures. The latter findings are consistent with the findings of Brocard et al. (2000), Buser et al. (2002), Hämmerle et al. (2002) and Pjetursson et al. (2008), who also reported that the survival percentages are comparable for implants placed in augmented bone or in non-augmented bone. In addition, in the current review, also, no difference between the survival rates of implants with a rough surface and with a smooth turned surface was noted. This is not consistent with the results of other studies specifically addressing this topic. Pjetursson et al. (2008) reported in a systematic review significant better results for implants with a rough surface simultaneously placed with a sinus floor elevation. The systematic review on implant surface

roughness and bone healing of Shalabi et al. (2006) presented a positive relationship between bone-to-implant contact and surface roughness. Wennerberg and Albrektsson (2009) concluded in their systematic review that surface topography (or surface roughness) does influence bone response at the micrometer level and might influence bone response on a nanometer level. They also conclude that the majority of published papers present an inadequate surface characterization. This might be the reason why in the current study no difference in implant survival was found for the different surfaces. Wennerberg and Albrektsson (2009) wrote "a surface termed 'rough' in one study was not uncommonly referred as 'smooth' in another; many investigators falsely assumed that surface preparation per se identified the roughness of the implant".

The studies included were also checked for the outcome measure peri-implant bone loss, but unfortunately only three of the 29 selected studies reported data on per-implant bone loss around short implants (Deporter et al. 2001a, b, Romeo et al. 2006). There were also not enough data in the publications included to assess the determinant implant diameter in a subgroup analysis.

Two studies, Polizzi et al. (2000) and Mericske-Stern et al. (2001), of the 29 included studies for this review were only about single tooth replacements. A total of 59 implants with different length were included with an event rate of 4. These were insufficient data to perform a meta-analysis. The rest of the studies used assessed in this review included single- and multiple- (splinted) tooth replacements. In the data presented in these studies, no distinction was made between the implant-supported prosthetic rehabilitation and the removed implants; short implants could even be splinted to longer implants. This is a weakness of this systematic review, but one can assume that if there is severe peri-implantitis or loss of integration at one of a couple of splinted implants, the best practice is to remove this implant; otherwise, the other implants might also be lost.

Our study is an implant-based analysis, while we would have preferred to perform a patient-based analysis, as events (implant loss) tend to cluster within the same patients. However, for this kind of analysis, the data were not exactly sufficiently described, which was partly due to the fact that most of the studies included in this review are not only about short implants. Amongst others, we found some heterogeneity between studies, mostly due to the fact that most of the included studies were aggregated data sets. Some studies allowed including certain groups (viz., smoking) whereas others excluded smokers. To precisely estimate the influence of such determinants (viz., smoking) one needs access to the original data sets in order to perform the analyses on an individual level. It was, however, impossible to obtain all original datasets. To explore and to estimate the influence of the sources of heterogeneity we carried out a subgroup analysis. Although point estimates of the calculated failure rates per implant length were different, the CIs around these point estimates were comparable, when correcting for the normal find-

ing that theses intervals were extended after subgroups analyses. The latter observations lead to the conclusion that the heterogeneity is not enough to reject the results of the estimated failure rate per implant length.
Our main outcome measure was the estimated implant survival rate after 2 years. We have chosen a 2-year survival rate, as we believe that after >1 year in function, the implant survival rate as a function of time after loading has become rather constant (Esposito et al. 1998). To check this constancy, we looked at studies with a follow-up up to 1 year and we estimated the survival rates after 2 years. From these calculations, very outranged numbers as 0.3 -12.0% survival rates were obtained. For this reason, only studies with a mean follow-up longer than 1 year were selected. The shortest mean follow-up, included in this review, was 1.6 year. Our findings were confirmed by the prospective study of Cochran et al. (2009), who found, in their radiographic evaluation of crestal bone, the least bone loss between 1-year post-loading and the last 5-year recall. The most bone loss was found 6 months after implant placement.

Conclusion

The findings from this systematic review add to the growing evidence that short (<10 mm) implants can be placed successfully in the partially edentulous patients, though the survival rates of implants still increased with the lengths of implants within the range of 5 to 8.5 mm (93.1 – 98.8%). There appears little change in survival from 8.5 to 9.5 mm lengths (98.8-98.6%). Installation of short dental implants in the mandible has a better prognosis over installation in the maxilla. Furthermore, the results of studies excluding smokers revealed higher implant survival rates than studies including heavy smokers (≥15 cigarettes per day). Surface topography and an augmentation procedure preceding the implant installation apparently did not affect the failure rate of short implants.

References

Albrektsson, T., Zarb, G., Worthington, P. & Eriksson, A. R. (1986) The long-term efficacy of currently used dental implants; A review and proposed criteria of success. *The International Journal of Oral and Maxillofacial Implants* 11, 11-25.

Bahat, O. (1993) Treatment planning and placement of implants in the posterior maxillae: report of 732 consecutive Nobelpharma implants. *The International Journal of Oral and Maxillofacial Implants* 8, 151-161.

Becker, W., Becker, B. E., Alsuwyed, A. & Al-Mubarak, S. (1999) Long-term evaluation of 282 implants in maxillary and mandibler molar positions: a prospective study. *Journal of Periodontology* 70, 896-901.

Beschnidt, S. M., Muche, R., Krausse, A. & Strub, J. R. (2003) Implant survival and success rates in partially edentulous patients-Part I. *Schweizer Monatsschrift für Zahnmedizin* 113, 396-403.

Blanes, R. J. (2009) To what extent does the crown-implant ratio affect the survival and complications of implant-supported reconstructions? A systematic review. *Clinical Oral Implants Research* 20, 67-72.

Brocard, D., Barthet, P., Baysse, E., Duffort, J. F., Eller, P., Justumus, P., Marin, P., Oscaby, F., Simonet, T., Benque, E. & Brunel, G. (2000) A multicenter report on 1,022 consecutively placed ITI implants: a 7-year longitudinal study. *The International Journal of Oral and Maxillofacial Implants* 15, 691-700.

Buser, D., Ingimarsson, S., Dula, K., Lussi A., Hirt, H. P. & Belser, U. C. (2002) Long-term stability of osseointegrated implants in augmented bone: a 5-year prospective study in partially edentulous patients. *The International Journal of Periodontics & Restorative Dentistry* 22, 109-117.

Buser, D., Mericske-Stern, R., Bernard, J. P., Behneke, A., Behneke, N., Hirt, H. P., Belser, U. C. & Lang, N. P. (1997) Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants. *Clinical Oral Implants Research* 8, 161-172.

Cecchinato, D., Olsson, C. & Lindhe, J. (2004) Submerged or non-submerged healing of endosseous implants to be used in the rehabilitation of partially dentate patients. *Journal of Clinical Periodontology* 31, 299-308.

Corrente, G., Abundo, R., Des Ambrois, A. B., Savio, L. & Perelli, M. (2009) Short porous implants in the posterior maxilla: a 3-year report of a prospective study. *The International Journal of Periodontics & Restorative Dentistry* 29, 23-29.

Cochran, D. L., Nummikoski, P. V., Schoolfield, J. D., Jones, A. A. & Oates, T. W. (2009) A prospective multicenter 5-year radiographic evaluation of crestal bone levels over time in 596 dental implants placed in 192 patients. *Journal of Periodontology* 80, 725-733.

Das Neves, F. D., Fones, D., Bernardes, S. R., do Prado, C. J. & Neto, A. J. (2006) Short implants - An analysis of longitudinal studies. *The International Journal of Oral and Maxillofacial Implants* 21, 86-93.

Davarpanah, M., Martinez, H., Etienne, D., Zabalegui, I., Mattout, P., Chiche, F. & Michel, J. F. (2002) A prospective multicenter evaluation of 1,583 3i implants: 1- to 5-year data. *The International Journal of Oral and Maxillofacial Implants* 17, 820-828.

Davarpanah, M., Martinez, H., Celletti, R., Alcoforado, G., Tecucianu, J. F. & Etienne, D. (2001) Osseotite implant: 3-year prospective multicenter evaluation. *Clinical Implant Dentistry and Related Research* 3, 111-118.

Degidi, M., Iezzi, G., Perrotti, V. & Piatelli, A. (2009) Comparative analysis of immediate functional loading and immediate non-functional loading to traditional healing periods; a 5-year follow-up of 550 dental implants. *Clinical Implant Dentistry and Related Research* 11, 257-266.

Degidi, M., Piattelli, A. & Carinci, F. (2006) Parallel screw cylinder implants: comparative analysis between immediate loading and two-stage healing of 1,005 dental implants with a 2-year follow up. *Clinical Implant Dentistry and Related Research* 8, 151-160.

Deporter, D., Pilliar, R. M., Todescan, R., Watson, P. & Pharoah, M. (2001a), Friberg, B., J Managing the posterior mandible of partially edentulous patients with short, porous-surfaced dental implants: early data from a clinical trial. *International Journal of Oral and Maxillofacial Implants* 16, 653-658.

Deporter, D. A., Todescan, R., Watson, P. A., Pharoah, M., Pilliar, R. M. & Tomlinson, G. (2001b) A prospective human clinical trial of Endopore dental implants in restoring the partially edentulous maxilla using fixed prostheses. *International Journal of Oral and Maxillofacial Implants* 16, 527-536.

Esposito, M., Grusovin, M. G., Rees, J., Karasoulos, D., Felice, P., Alissa, R., Worthington, H. V. & Coulthard, P. (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. *The Cochrane database of systematic reviews* 17, CD008397.

Esposito, M., Grusovin, M. G., Felice, P., Karatzopoulos, G., Worthington, H. V. & Coulthard, P. (2009) Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. *The Cochrane database of systematic reviews* 7, CD003607.

Esposito, M., Hirsch, J. M., Lekholm, U. & Thomsen, P. (1998) Biological factors contributing to failures of osseointegrated oral implants. (1) Succes criteria and epidemiology. *European Journal of Oral Sciences* 106, 527-551.

Farzad, P., Andersson, L., Gunnarsson, S. & Sharma, P. (2004) Implant stability, tissue conditions, and patient self-evaluation after treatment with osseointegrated implants in the posterior mandible. *Clinical Implant Dentistry and Related Research* 6, 24-32.

Ferrigno, N., Laureti, M. & Fanali, S. (2006) Dental implants placement in conjunction with osteotome sinus floor elevation: a 12-year life-table analysis from a prospective study on 588 ITI implants. *Clinical Oral Implants Research* 17, 194-205.

Friberg, B., Jemt, T. & Lekholm, U. (1991) Early failures in 4,641 consecutively placed Brånemark dental implants: a study from stage 1 surgery to the connection of completed prostheses. *The international Journal of Oral and Maxillofacial Implants* 6, 142-146.

Glantz, P. O. & Nilner, K. (1998) Biomechnical aspects of prosthetic implant-borne reconstructions. *Periodontology 2000* 17, 119-124.

Glauser, R., Ruhstaller, P., Windisch, S., Zembic, A., Lundgren, A., Gottlow, J. & Hämmerle, C. H. (2005) Immediate occlusal loading of Brånemark System TiUnite implants placed predominantly in soft bone: 4-year results of a prospective clinical study. *Clinical Implant Dentistry and Related Research* 7, S52-S59.

Glauser, R., Lundgren, A. K., Gottlow, J., Sennerby, L., Portmann, M., Ruhstaller, P. & Hämmerle, C. H. (2003) Immediate occlusal loading of Brånemark TiUnite implants placed predominantly in soft bone: 1-year results of a prospective clinical study. *Clinical Implant Dentistry and Related Research* 5, S47-S56.

Grunder, U., Gaberthuel, T., Boitel, N., Imoberdorf, M., Meyenberg, K., Andreoni, C. & Meier, T. (1999) Evaluating the clinical performance of the Osseotite implant: defining prosthetic predictability. *The Compendium of Continuing Education in Dentistry* 20, 628-33, 636, 638-640.

Gunne, J., Astrand, P., Lindh, T., Borg, K. & Olsson, M. (1999) Tooth-implant and implant supported fixed partial dentures: a 10-year report. *The International Journal of Prosthodontics* 12, 216-221.

Haas, R., Mensdorff-Pouilly, N., Mailath, G. & Watzek, G. (1995) Brånemark single tooth implants: A preliminary report of 76 implants. *The Journal of Prosthetic Dentistry* 73, 274-279.

Hagi, D., Deporter, D. A., Pilliar, R. M. & Arenovich, T. (2004) A targeted review of study outcomes with short (≤7 mm) endosseous dental implants in partially edentulous patients. *Journal of Periodontology* 75, 798-804.

Hämmerle, C. H., Jung, R. E. & Feloutzis, A. (2002) A systematic review of the survival of implants in bone sites augmented with barrier membranes (guided bone regeneration) in partially edentulous patients. *Journal of Clinical Periodontology* 29, S226-S231.

Kotsovilis, S., Fourmousis, I., Karoussis, I. K. & Bamia, C. (2009) A systematic review and meta-analysis on the effect of implant length on the survival of rough-surface dental implants. *Journal of Periodontology* 80, 1700-1718.

Kirkwood, B. R. & Sterne, J. A. C (2003a) Chapter 24: Poisson regression. In: *Essential Medical Statistics*, 2nd edition, pp. 249-262, Oxford: Blackwell Science Ltd.

Kirkwood, B. R. & Sterne, J. A. C (2003b) Chapter 26: Survival analysis: displaying and comparing survival patterns. In: *Essential Medical Statistics*, 2nd edition, pp. 272-286, Oxford: Blackwell Science Ltd.

Lee, J. H., Frias, V., Lee, K. W. & Wright, R. F. (2005) Effect of implant size and shape on implant success rates: A literature review. *Journal of Prosthetic Dentistry* 94, 377-381.

Lekholm, U., Gunne, J., Henry, P., Higuchi, K., Linden, U., Bergstrom, C. & van Steenberghe, D. (1999) Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. *The International Journal of Oral and Maxillofacial Implants* 14, 639-645.

Lekholm, U. & Zarb, G. A. (1985) Patient selection and preparation. In: Brånemark, P. I., Zarb, G. A. & Albrektsson, T. (eds). *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*, 1st edition, pp. 199-209. Chicago: Quintessence Publishing.

McGlumphy, E. A., Peterson, L. J., Larsen, P. E. & Jeffcoat, M. K. (2003) Prospective study of 429 hydroxyapatite-coated cylindric omniloc implants placed in 121 patients. *The International Journal of Oral and Maxillofacial Implants* 18, 82-92.

Meirelles, L., Arvidsson, A., Andersson, M., Kjellin, P., Albrektsson, T. & Wennerberg, A. (2008a) Nano-hydroxyapatite structures influence early bone formation. *The Biomedical Materials Research* 87, 299-307.

Meirelles, L., Currie, F., Jacobsson, M., Albrektsson, T. & Wennerberg, A. (2008b) The effect of chemical and nanotopographical modifications on the early stages of osseointegration. *The International Journal of Oral & Maxillofacial Implants* 23, 641-647.

Mericske-Stern, R., Grutter, L., Rosch, R. & Mericske, E. (2001) Clinical evaluation and prosthetic complications of single tooth replacements by non-submerged implants. *Clinical Oral Implants Research* 12, 309-318.

Morand, M. & Irinakis, T. (2007) The challenge

of implant therapy in the posterior maxilla: providing a rationale for the use of short implants. *The Journal of Oral Implantology* 33, 257-266.

Nedir, R., Bischof, M., Briaux, J. M., Beyer, S., Szmukler-Moncler, S. & Bernard, J. P. (2004) A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Results from a private practice. *Clinical Oral Implants Research* 15, 150-157.

Pjetursson, B. E., Rast, C., Brägger, U., Schmidlin, K., Zwahlen, M. & Lang, N. P. (2009) Maxillary sinus floor elevation using the (transalveolar) osteotome technique with or without grafting material. Part I: Implant survival and patients' perception. *Clinical Oral Implants Research* 20, 667-676.

Pjetursson, B. E., Tan, W. C., Zwahlen, M., Lang, N. P. (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. *Journal of Clinical Periodontology* 35, 216-240.

Polizzi, G., Rangert, B., Lekholm, U., Gualini, F. & Lindstrom, H. (2000) Brånemark System Wide Platform implants for single molar replacement: clinical evaluation of prospective and retrospective materials. *Clinical Implant Dentistry and Related Research* 2, 61-69.

Rangert, B. R., Sullivan, R. M. & Jemt, T. M. (1997) Load factor control for implants in the posterior partially edentulous segment. *The International Journal of Oral and Maxillofacial Implants* 12, 360-370.

Renouard, F. & Nisand, D. (2006) Impact of length and diameter on survival rates. *Clinical Oral Implants Research* 17, 35-51.

Romeo, E., Bivio, A., Mosca, D., Scanferla, M., Ghisolfi, M. & Storelli, S. (2010) The use of short dental implants in clinical practice: literature review. *Minerva Stomatologica* 59, 23-31.

Romeo, E., Ghisolfi, M., Rozza, R., Chiapasco, M. & Lops, D. (2006) Short (8-mm) dental implants in the rehabilitation of partial and complete edentulism: a 3- to 14-year longitudinal study. *The International Journal of Prosthodontics* 19, 586-592.

Romeo, E., Lops, D., Margutti, E., Ghisolfi, M., Chiapasco, M. & Vogel, G. (2004) Long-term survival and success of oral implants in the treatment of full and partial arches: a 7-year prospective study with the ITI dental implant system. *The International Journal of Oral and Maxillofacial Implants* 19, 247-259.

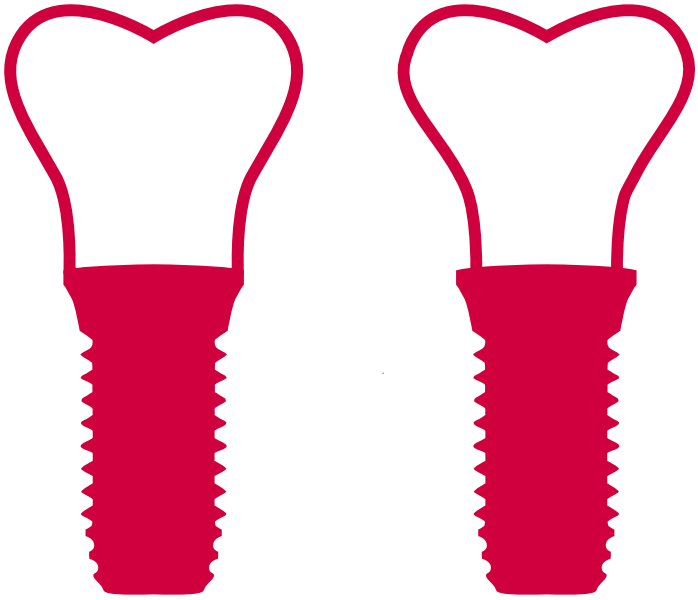
Shalabi, M. M., Gortemaker, A., van 't Hof, M. A. Jansen, J. A. & Creugers, N. H. J. (2006) Implant surface and bone healing; a systematic review. *Journal of Dental Research* 85, 496-500.

Sullivan, D., Vincenzi, G. & Feldman, S. (2005) Early loading of Osseotite implants 2 months after placement in the maxilla and mandible: a 5-year report. *The International Journal of Oral and Maxillofacial Implants* 20, 905-912.

Tawil, G. & Younan, R. (2003) Clinical evaluation of short, machined-surface implants followed for 12 to 92 months. *The International Journal of Oral and Maxillofacial Implants* 18, 894-901.

Testori, T., Wiseman, L., Woolfe, S. & Porter, S. S. (2001) A prospective multicenter clinical study of the Osseotite implant: four-year interim report. *The International Journal of Oral and Maxillofacial Implants* 16, 193-200.

Wennerberg, A. & Albrektsson, T. (2009) Effects of titanium surface topography on bone integration; a systematic review. *Clinical Oral Implants Research* 20, 172-184.



This chapter is an edited version of the manuscript: Telleman, G., Raghoebar, G. M., Vissink, A. & Meijer, H .J. A. (2012) Impact of platform switching on interproximal bone levels around short implants in the posterior region; 1-year results from a randomized clinical trial. Journal of Clinical Periodontology doi: 10.1111/j.1600-051x.2012.01887.x. (Epub ahead of print).

Chapter 3

Impact of platform switching on marginal bone levels around short implants in the posterior region; 1-year results from a randomized clinical trial

Abstract

Aim: To assess the outcome of short implants (8.5 mm in length) supplied with a conventional platform-matched implant-abutment connection or a platform-switched design.

Materials and methods: Eighty patients with one or more missing teeth in the posterior zone were randomly assigned to be treated with implants with either a conventional (control) or a platform-switched (mismatch 0.35-0.40 mm) implant-abutment connection (test). Follow-up visits were conducted 1 month and 1 year after placing the implant crown. Outcome measures were marginal bone loss, using standardized peri-apical radiographs, implant survival, clinical parameters and patient's satisfaction.

Results: One year after loading, marginal bone loss around test implants (0.50±0.51 mm) was significantly less than around control implants (0.74±0.48 mm) (p=0.006). Moreover, bone loss was less around 1 versus 2 adjacent implants (p=0.001), in both the test (0.29±0.36 vs. 0.70±0.54 mm) and control (0.50±0.45 vs. 0.88±0.45 mm) group. With regard to implant survival, clinical parameters and patient's satisfaction no differences were observed between the test and control group.

Conclusion: This study suggested that marginal bone loss may be reduced by platform switching. One year after loading, marginal bone levels were better maintained at implants restored according to the platform switching concept.

Introduction

From the moment the healing abutment is placed and the implant is exposed to the oral environment biologic width formation starts. A mucosal attachment of a certain minimum vertical dimension (3-4 mm) is formed and as a consequence marginal bone loss may take place (Berglundh & Lindhe 1996, Hermann et al. 2001a,b). Whether or not marginal bone loss will occur depends, amongst others, on the presence of a microgap between implant and abutment and on the location of this microgap in relation to level of the crestal bone. One-piece implants (no microgap) and implants placed above the alveolar crest have been show to prevent marginal bone loss (Hermann et al. 2001a, Todescan et al. 2002, Broggini et al. 2006, Cochran et al. 2009). The implant-abutment connection is thought to be an important factor regarding peri-implant bone loss as also the highest number of inflammatory cells has been observed at the implant-abutment interface (Broggini et al. 2006).

An alternative implant-abutment configuration involves a non-matching diameter for the implant and abutment. In, so called, platform-switched implants the diameter of the abutment is less than the diameter of the implant, resulting in a horizontal offset at the top of the implant that separates the crestal bone and the connective tissue from the interface. Early results of these platform-switched implants showed no changes in peri-implant bone levels, contrary to standard platform-matched implants (Wagenberg & Froum 2010). Several hypotheses were posed to explain the rationale behind the concept of platform switching for crestal bone preservation. The biomechanical rationale proposed that by platform switching the stress-concentration zone (from the forces of occlusal loading) is directed from the crestal bone-implant interface to the axis of the implant and so reduces the stress level in the cervical bone area (Maeda et al. 2007). Cochran et al. (2009) showed that placing the implant-abutment connection below the crestal bone level may cause bone resorption to re-establish the biologic width. Following this theory, platform switching medializes the microgap and the dimension of the biologic width. A horizontal mismatch of 0.3 mm was found to decrease the vertical dimension of the junctional epithelium (Becker et al. 2009, Farronato et al. 2012). Another hypothesis concerned the role of inflammatory cell infiltrate at the implant-abutment connection. The presence of peri-implant microbiota was suggested to influence marginal bone loss by maintaining the inflammatory cell infiltrate within the implant-abutment connection (Ericsson et al. 1995, 1996, Broggini et al. 2006). However, no association was found between marginal bone loss and peri-implant microbiota at platform-matched and platform-switched implants (Canullo et al. 2010a).

Pre-clinical data of Cochran et al. (2009) showed minimal histologic bone loss of platform-switched implants. The pre-clinical data were in contrast to the data described by Becker et al. (2007, 2009) who concluded that platform switching may not be of crucial importance for maintenance of the

crestal bone level. The systematic review of Atieh et al. (2010) concluded that marginal bone loss around platform-switched implants was significantly less compared with platform-matched implants. Although the assessed bone loss of both implant-abutment connections was very different (0.021-0.99 mm for platform-switched and 0.101-1.67 mm for platform-matched implants). This large variation in results was thought to be due to the use of different implant diameters, mismatches and implant systems (Hürzeler et al. 2007, Cappiello et al. 2008, Canullo et al. 2009, 2010b, Crespi et al. 2009, Kielbassa et al. 2009, Prosper et al. 2009, Tramell et al. 2009, Vigolo & Givani 2009, Enkling et al. 2011). Moreover, three of the 10 included studies reported no differences in bone-level changes between the platform concepts tested (Crespi et al. 2009, Kielbassa et al. 2009, Enkling et al. 2011).

Short implants (<10 mm in length) are increasingly used as there is fair evidence that short implants can be placed successfully in the partially edentulous patient, but with a tendency towards an increasing survival rate per implant length (Telleman et al. 2011a). So, especially in short implants it is important to preserve peri-implant bone. However, short implants might be expected to develop a greater maximum compressive stress in their coronal region in comparison with longer implants, which could lead to bone microfracture and marginal bone loss (Hagi et al. 2004).

To our knowledge there is very limited evidence regarding the effect of platform switching on implants shorter than 10 mm in length in partially edentulous patients (Trammell et al. 2009). Therefore, the aim of this study was to compare the outcome of short implants (8.5 mm in length), provided with either a platform-matched implant-abutment connection or a platform-switched implant-abutment connection, placed in the posterior region of partially edentulous patients.

Materials and methods

Patients

Partially edentulous patients referred to the department of Oral and Maxillofacial Surgery (UMCG, The Netherlands) for implant therapy, were considered for inclusion if they fulfilled the following criteria:

- at least 18 years of age;
- capable of understanding and giving informed consent;
- one or more missing teeth being a (pre)molar in the maxilla or mandible;
- at the place of the future implant a maximum of 10 mm bone in vertical dimension and a minimum of 8 mm in horizontal dimension available.

Exclusion criteria were:

- medical and/or general contraindications for the surgical procedures (ASA score ≥ III (Smeets et al. 1998));
- presence of active clinical periodontal disease in the dentition as expressed by probing pocket depths ≥5 mm and bleeding on probing;
- presence of peri-apical lesions or any other abnormalities or infections at the implant site as determined on a radiograph;
- smoking;
- a history of radiotherapy to the head and neck region.

Study design

This was a randomized clinical trial with two parallel groups. The study was approved by the Medical Ethical Committee of the University Medical Center Groningen. Before enrolment, written and verbal information was given to the patients and written informed consent was obtained.

Two different implant-abutment connections were studied on implants with a length of 8.5 mm. The platform-switched implants (Osseotite Certain Prevail, Biomet 3i, Palm Beach Gardens, FL, USA) used in the test group had a horizontal mismatch of 0.35 mm and 0.40 mm, respectively, for the implants with a diameter of 4 and 5 mm. In a vertical dimension, the implant-abutment connection lied 0.09 mm and 0.11 mm, for implants with a diameter of 4 and 5 mm, respectively, above the implant shoulder (figure 1a). The control implants (Osseotite XP Certain, Biomet 3i) had the same dimensions as the platform-switched implants except for the implant-abutment connection, which was platform-matched (figure 1b). Both implant types had an extended platform and a full dual-acid etched surface.

A specifically designed locked computer software program was used to randomly assign patients to one of the two study groups. Randomization by minimization (Altman 1991) was used to balance the possible prognostic variables (gender, age (≤50, >50 years), location of the implant site (maxilla, mandible), tooth or teeth to replace (premolar, molar, premolar & molar), number of implants to be placed (1, 2 or more)) between the two treatment groups. An investigator with no clinical involvement in the trial informed the surgeon, who inserted the implants, about the allocation result on the day of surgery, just before implant surgery was started. The prosthodontist was informed about the allocation result before the impression of the healing abutment was made. The surgeon and prosthodontist could not be blinded for the allocation result as they could see by the inner color of the implant whether it was a test or control implant.

Interventions

All implants were placed in healed sites, i.e. at least 3 months after tooth removal allowing the extraction site to have healed. Implants were placed and restored according to the protocol described in detail by Telleman et al. (2011b). Briefly, the incision was made on top of the alveolar crest and a surgical template was used. The implant shoulder was placed at bone level,

Figure 1a. Dental radiograph of a test implant (Osseotite Certain Prevail, Biomet 3i)

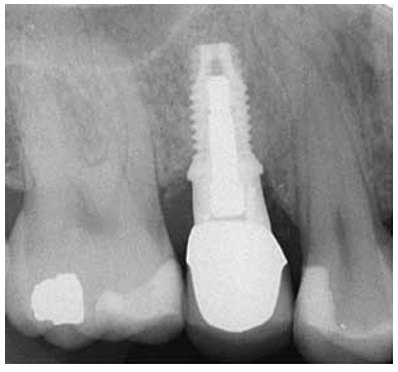
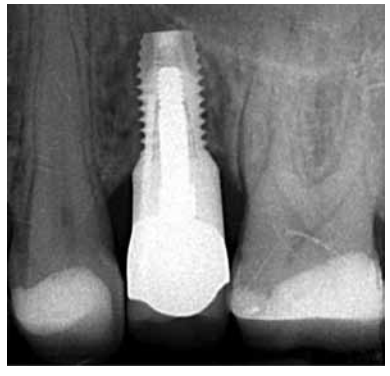


Figure 1b. Dental radiograph of a control implant (Osseotite XP Certain, Biomet 3i)



both mesial and distal even with the alveolar crest, if necessary the bone was flattened. The distance between the implant and the neighbouring teeth was at least 1.5 mm, the distance between two implants was at least 3 mm. On this implant, a coded healing abutment (Encode®, Biomet 3i) with a height of 4 mm was placed to develop an emergence profile. Next, if any, implant dehiscences or fenestrations at the buccal side of the implant were covered with autogenous bone chips collected during implant bed preparation and anorganic bovine bone (Bio-oss®, Geistlich Pharma AG, Wolhusen, Switzerland) overlaid with a collagen membrane (Bio-Gide®, Geistlich Pharma AG). Finally, the wound was closed with sutures (Vicryl 3-0, Johnson & Johnson, Brunswick, NJ, USA). Two weeks following implant surgery the sutures were removed. Three months after implant placement, seating of the healing abutment was evaluated and impressions were made. The healing abutment was scanned from the cast and an individualized abutment was milled. The abutment was placed with 20 Ncm and the metal ceramic crown was cemented (GC Fuji 1, GC Europe NV, Leuven, Belgium).
All surgical procedures were performed by a single experienced oral and maxillofacial surgeon. Six experienced prosthodontics performed the prosthetic procedure.

Outcome measures
The primary outcome measure was the mean marginal bone-level change (mesial and distal sides combined) from the time of implant placement (T_{0m}) to 1 year after placing the crown on the implant; which is 16 months after placing the implant (T_{16m}) as measured on standardized radiographs. Secondary outcome measures were implant survival, changes in marginal soft tissue

level of the implant and the neighbouring teeth and patient's satisfaction. All measurements were performed by one and the same examiner. To assess the reliability of the radiographic examination, this examiner was assisted by a second examiner. The operationalization of the variables is described below.

Radiographic assessments
Before implant placement (T_{pre}), directly after implant placement (T_{0m}), 1 month after the placement of the implant crown, which is 5 months after placing the implant (T_{5m}) and 1 year after placing the implant crown, which is 16 months after placing the implant (T_{16m}) digital peri-apical radiographs (Planmeca Intra X-ray unit, Planmeca, Helsiniki, Finland) were taken using a paralleling technique. For each patient an individualized X-ray holder was made to standardize radiographs. The calibration, using specially designed computer software (Biomedical Engineering, UMCG, The Netherlands) was carried out in the vertical plane for each radiograph, by using the known distance of several threads (Sewerin 1990). To assess the reliability of the radiographic examination 30 radiographs of 20 patients (10 from each study group) were assessed by two examiners.

Clinical assessments
Preoperatively (T_{pre}), 1 month (T_{5m}) and 1 year (T_{16m}) after the placement of the implant crowns, the soft tissue around the implants and their neighbouring teeth were clinically examined using the following clinical parameters:
- Plaque Index (Mombelli et al. 1987);
- Sulcus Bleeding Index (Mombelli et al. 1987);
- Gingival Index (Loë & Silness 1963);
- Presence of dental calculus;
- Sulcus probing pocket depth: using a manual periodontal probe (Williams Color-Coded Probe; Hu-Friedy, Chicago, IL, USA).

Before the incision was made, the mucosa thickness was assessed by applying a periodontal probe through the mucosa at the spot where the implant would be placed.

Microbiological assessments
To analyse the composition of the subgingival plaque, preoperatively an anaerobic culture test was conducted. In each quadrant of the dentition the deepest pocket was selected for microbiological sampling. After gentle air-drying, two consecutive sterile paper points were inserted to the depth of the pockets and left in place for 10 seconds. Paper points from all four selected periodontal sites were pooled in 2.0 ml of reduced transport fluid (RTF) (Syed & Loesche 1972). The presence and proportions of Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis, Prevotella intermedia, Bacteroides forsythus, Peptostreptococcus micros, Fusobacterium nucleatum and Campylobacter rectus were assessed. The analyses were performed by the

laboratory of the department Oral Microbiology (UMCG, the Netherlands) as described in the study of Heydenrijk et al. (2002).

Patient's satisfaction

Patient's satisfaction was assessed using a self-administered questionnaire to be completed at T_{pre} and T_{5m}. The questionnaire compromised of questions or statements that could be answered on a five-point rating scale ranging from "very dissatisfied" and "not in agreement" (score 1) to "very satisfied" and "in agreement" (score 5). Topics were aesthetics, function and treatment procedure. Furthermore, patients were asked to mark their overall satisfaction about their mouth in which they missed teeth, which were replaced by implants, at T_{pre} and T_{5m} on 10-point rating scale from 0 to 10, in which 10 is the highest score.

Statistical analysis

Sample size was calculated using G*power version 3.1 (Faul et al. 2009). As there were no data in the literature of the mean marginal bone loss of short platform-matched implants, it was assumed that a mean marginal bone loss of 1.0 ± 0.5 mm would occur, from implant placement to 16 months thereafter, as the maximum marginal bone loss is seen up to 1.5 mm to the first implant thread. We considered 0.5 mm of radiographic marginal bone loss as a relevant difference between study groups, with an expected standard deviation of 0.75 mm. With a one-sided significance level of 5% and a power of 95%, a minimum of 36 patients per group was required, if one implant per patient was placed. A total of 72 patients for both groups would be needed, the total number of patients was set to at least 80 to deal with withdrawal.

To assess the interobserver agreement for the continuous variables of the marginal bone-level changes (scored on peri-apical radiographs) two-way random models were used to calculate the intraclass correlation coefficient.

To see whether the data were normally distributed the frequency distribution was plotted in a histogram. To test whether the result from the frequency analyses differed significantly from a normal distribution Kolmogorov-Smirnov and Shapiro-Wilk tests were done. For between groups comparisons of normally distributed variables, *t*-tests were used. Variables that were not normally distributed were statistically explored using Mann-Whitney tests.

Fisher's exact test was used to assess whether there was a difference in implant survival rate. Pearson's correlation coefficients were used to assess whether the observed marginal bone-level change was dependent on the possible confounders implant location, implant diameter, result of the microbiological culture, mucosal thickness before placement and type of bone (Lekholm & Zarb, 1985). Wilcoxon signed-rank tests were used for changes in patient's satisfaction before and after the implant treatment.

In all analyses, expect for patient's satisfaction the statistical unit was an implant and for all analyses a significance level of $p<0.05$ was chosen. Data were analysed using the Statistical Package for Social Sciences (version 16.0, SPSS Inc., Chicago, IL, USA).

Results

Patients

Between November 2005 and December 2009 a total of 80 (39 control group, 41 test group) patients were included in this trial. Baseline patients and treatment characteristics are listed in table 1. There were no drop-outs and all patients attended the follow-up visits; thus data from 80 patients were available for the intention-to-treat analysis.

Marginal bone-level changes

The intraclass correlation coefficient for average measures was 0.87 for the radiographic interobserver agreement (Cronbach's Alpha=0.87), which can be interpreted as almost perfect agreement (Viera & Garrett 2005).

Figures 2a and 2b show the frequency distributions of the mean marginal bone loss of the platform-matched and -switched implants. Bone loss was significantly less around platform-switched implants, both 1 month and 1 year after loading (table 2). When comparing marginal bone loss in cases provided with one and two or more implants, a similar tendency was observed (table 2).

Clinical outcome

Four of 59 implants in the control group were lost (survival rate 93.2%); three before loading and one 11 months after loading. In the test group three of 56 implants were lost before loading (survival rate 94.6%). The mean probing pocket depth around the implants did not significantly increase between T_{5m} and T_{16m} (table 2). Also no between-group differences in clinical parameters plaque accumulation, bleeding tendency, gingiva index (table 3) were observed. The adjacent teeth of the platform-switched implants showed significant more presence of dental calculus before implant placement, 1 month and 1 year after placing the crown (table 3).

Confounders

Marginal bone loss is significant ($p=0.001$) higher as two or more adjacent implants were placed, when compared with single implants. So, the number of implants placed is an important confounder in marginal bone loss. The presumed confounders implant location, implant diameter, microbiological status, mucosal thickness and type of bone apparently played no significant role.

Patient's satisfaction

Feelings of shame and of visibility of being partial edentulous clearly decreased as well as that patient's self-confidence increased (table 4). Patients

Table 1. Baseline characteristics of the patients

Variable	Platform-matched implant-abutment connection (control group; n=39)	Platform-switched implant-abutment connection (test group; n=41)
Mean age ± SD and range (years):		
	51.6 ± 10.60 (27-67)	48.0 ± 13.8 (18-70)
Female/male ratio:		
	27/12	26/15
Implant position:		
Maxillary (P1/P2/M1/M2)	29 (3/12/13/1)	24 (2/8/13/1)
Mandibular (P1/P2/M1/M2)	30 (1/8/17/4)	30 (1/11/17/1)
Implant diameter:		
4.1 mm	35	40
5.0 mm	24	16
Number of implants to be placed in a patient:		
1	21	27
2 or more	18	14
Microbiology (before implant placement):		
Within normal range	16	17
Porphyromonas gingivalis >0.0%	1	0
Peptostreptococcus micros >3.0%	10	12
Fusobacterium nucleatum >3.0%	6	4
Combination of bacteria out of normal range	4	5
Culture was non-conclusive	2	3
Cause of tooth loss:		
Persistent apical periodontitis	13	17
Combined periodontic-endodontic lesion	1	0
Periodontal disease	4	3
Fracture	8	7
Dental caries	10	8
Congenitally missing tooth	2	3
Unknown	0	1
Mucosal thickness at the implant site before placement(%):		
1 mm	0.0	9.3
2 mm	64.7	46.5
3 mm	33.3	34.9
4 mm	2.0	9.3
Bone type (Lekholm & Zarb, 1985):		
1	0.0	0.0
2	38.7	36.8
3	48.4	47.4
4	12.9	10.5
Implant dehiscence or fenestration:		
	1	1

were especially satisfied about their increased ability to chew, and about the colour and the form of the crown. Most patients were satisfied with the colour and form of the mucosa; others were indifferent about this particular subject. No differences were observed between the groups.

Discussion

This trial showed that 16 months after implant placement, marginal bone loss was significantly less around short implants provided with a platform-switch, while with regard to implant survival, clinical parameters and patient's satisfaction both designs showed similar favourable results. A difference of 0.24 mm in radiographic bone preservation might not be clinically relevant, but a reduction in bone resorption of 33% (42% around single implants, 21% around two adjacent implants) is interesting, especially around single implants striving for perfection. The marginal bone loss around platform-switched implants resembled the mean resorption as reported in the systematic review and meta-analysis of Atieh et al. (2010) on longer implants. Atieh et al. (2010) also did not detect a statistically significant difference in implant survival between the two platform designs. Furthermore, implant survival rates were

Figure 2. Frequency distribution of mean marginal bone loss of implants of the 59 control (A) and 56 test (B) implants. Both distribution differ significantly from a normal distribution and shows a negative kurtosis. (control implants: $D(55)=0.115$, $p=0.083$, $W(55)=0.940$, $p=0.011$; test implants: $D(53)=0.132$, $p=0.021$, $W(53)=0.907$, $p=0.001$).

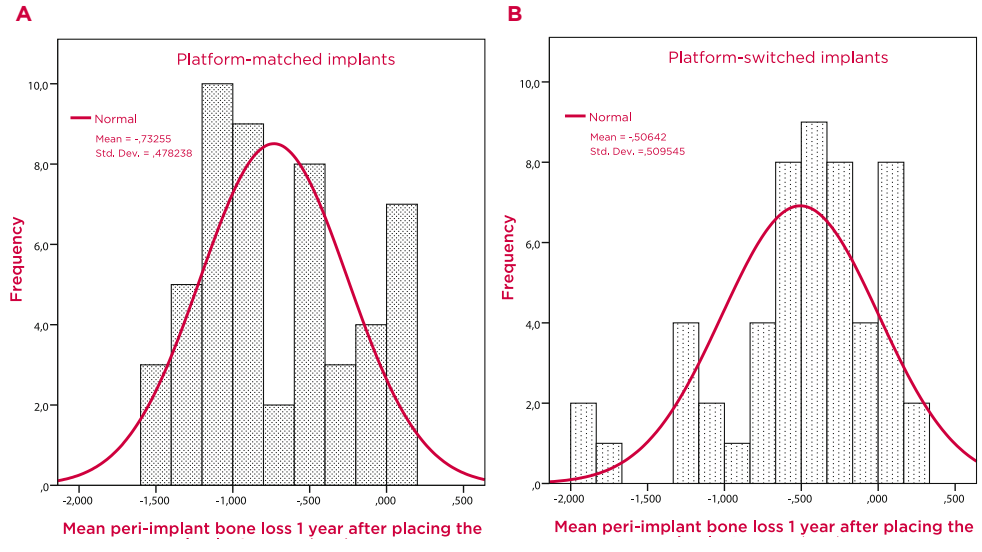


Table 2. Changes in marginal bone level and pocket probing depths at implant and tooth sides from baseline to 16 months. Negative results in marginal bone-level changes indicate marginal bone loss and positive results in pocket probing depth changes indicate enlarged peri-implant pockets.

All implants	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=56)	Platform-switched (n=53)	Platform-matched (n=55)	Platform-switched (n=53)	Platform-matched (n=55)	Platform-switched (n=53)
Marginal bone-level changes (mm)	**-0.71*** (±0.48)	**-0.47*** (±0.46)	**-0.03** (±0.48)	**-0.03** (±0.25)	**-0.74*** (±0.48)	**-0.50*** (±0.51)
1 implant	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=20)	Platform-switched (n=25)	Platform-matched (n=19)	Platform-switched (n=25)	Platform-matched (n=19)	Platform-switched (n=25)
Marginal bone-level changes (mm)	**-0.42** (±0.48)	**-0.27** (±0.32)	**-0.06** (±0.28)	**-0.02** (±0.25)	**-0.50**[§] (±0.45)	**-0.29**[§] (±0.36)
Pocket probing depth changes (mm)						
Implant	Not available	Not available	**-0.16** (±1.10)	**-0.02** (±0.57)	**-0.16** (±1.10)	**-0.02** (±0.57)
Tooth mesially of the implant	**-0.11** (±0.49)	**-0.02** (±0.46)	**0.07** (±0.49)	**-0.03** (±0.54)	**-0.04** (±0.43)	**-0.08** (±0.54)
Tooth distally of the implant	**0.04** (±0.49)	**0.08** (±0.84)	**0.06** (±0.60)	**0.03** (±0.53)	**0.10** (±0.67)	**0.13** (±0.84)
2 or more implants	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=36)	Platform-switched (n=28)	Platform-matched (n=36)	Platform-switched (n=28)	Platform-matched (n=36)	Platform-switched (n=28)
Marginal bone-level changes (mm)	**-0.89** (±0.39)	**-0.66** (±0.49)	**-0.01** (±0.30)	**0.04** (±0.25)	**-0.88**[♯] (±0.45)	**-0.70**[♯] (±0.54)
Pocket probing depth changes (mm)						
Implant	Not available	Not available	**0.18** (±0.50)	**-0.01** (±0.72)	**0.18** (±0.50)	**-0.01** (±0.72)
Tooth mesially of the implant	**-0.03** (±0.43)	**0.10** (±0.45)	**0.00** (±0.43)	**0.00** (±0.60)	**-0.03** (±0.39)	**0.10** (±0.63)
Tooth distally of the implant	**0.38** (±0.18)	**0.20** (±0.60)	**0.44** (±0.66)	**-0.10** (±0.52)	**0.63** (±0.48)	**0.10** (±0.40)

For between groups comparisons: *p=0.006, [§]p=0.072, [♯]p=0.059
Abbreviation: n=number of implants

Table 3. Clinical parameters of implants and adjacent teeth

Clinical parameters	% at T_{pre}		% at T_{5m}		% at T_{16m}	
	Platform-matched (n=59)	Platform-switched (n=56)	Platform-matched (n=56)	Platform-switched (n=53)	Platform-matched (n=55)	Platform-switched (n=53)
Implant Plaque Index [1]						
score 0, no detection of plaque	-	-	90.9	81.8	81.8	70.4
score 1, plaque on probe	-	-	9.1	18.2	16.4	25.9
score 2, plaque seen by naked eye	-	-	0	0	1.8	3.7
score 3, abundance of soft matter	-	-	0	0	0	0
Implant Bleeding Index[1]						
score 0, no bleeding	-	-	56.4	52.7	61.8	50.0
score 1, isolated bleeding spots	-	-	41.8	45.5	36.4	44.4
score 2, confluent line of blood	-	-	1.8	1.8	1.8	5.6
score 3, heavy or profuse bleeding	-	-	0	0	0	0
Implant Gingival Index[2]						
score 0, normal mucosa	-	-	96.3	89.1	96.4	90.7
score 1, mild inflammation	-	-	3.7	10.9	3.6	9.3
score 2, moderate inflammation	-	-	0	0	0	0
score 3, severe inflammation	-	-	0	0	0	0
Implant dental calculus						
score 0, no dental calculus	-	-	100	100	100	98.1
score 1, dental calculus present	-	-	0	0	0	1.9
Adjacent teeth Plaque index[1]						
score 0, no detection of plaque	57.6	53.0	77.2	66.7	80	70.3
score 1, plaque on probe	37.3	36.4	22.8	30.3	20	26.6
score 2, plaque seen by naked eye	5.1	10.6	0	3.0	0	3.1
score 3, abundance of soft matter	0	0	0	0	0	0
Adjacent teeth Bleeding index[1]						
score 0, no bleeding	83.1	71.6	83.9	77.3	90.9	84.4
score 1, isolated bleeding spots	16.9	25.4	16.1	21.2	9.1	15.6
score 2, confluent line of blood	0	3.0	0	1.5	0	0
score 3, heavy or profuse bleeding	0	0	0	0	0	0
Adjacent teeth Gingival Index[2]						
score 0, normal mucosa	96.6	87.9	98.2	89.4	98.2	96.9
score 1, mild inflammation	3.4	12.1	1.8	10.6	1.8	3.1
score 2, moderate inflammation	0	0	0	0	0	0
score 3, severe inflammation	0	0	0	0	0	0
Adjacent teeth dental calculus	*	*	*	*	*	*
score 0, no dental calculus	91.5	75.8	94.6	80.3	89.1	71.9
score 1, dental calculus present	8.5	24.2	5.4	19.7	10.9	28.1

[1] (Mombelli et al. 1987) [2] (Loë & Silness, 1963) *Significant difference between control and test group (*p*=0.02)
Abbreviation: n=number of implants

Table 4. Patient's satisfaction

	T_{pre} % in agreement		T_{5m} % in agreement	
	Platform-matched (n=39)	Platform-switched (n=41)	Platform-matched (n=35)	Platform-switched (n=38)
Feelings				
presence of shame	21.1	25.0	2.6*	0*
self-confidence decreased	18.4	7.5	0*	0*
self-confidence increased	5.3	5.0	42.1*	32.5*
visible being partial edentulous	42.1	40.0	0*	0*
Function				
evade eating with the edentulous zone/implant	57.9	55	0*	0*
the ability to chew is decreased	65.7	55	2.6*	0*
the ability to chew is increased	5.2	2.5	94.7*	92.5*
implant does influence the speech	-	-	2.6	2.5
implant does influence the taste	-	-	7.9	7.5
Aesthetics				
satisfied with the colour of the crown	-	-	82.7	94.3
satisfied with the form of the crown	-	-	86.9	92.5
satisfied with the colour of the mucosa around the crown	-	-	75.8	71.4
satisfied with the form of the mucosa around the crown	-	-	79.3	71.4
Overall satisfaction (0-10)	5.3 ± 2.0	5.6 ± 1.4	9.3 ± 0.9*	9.1 ± 0.9*

* significantly improved compared with pretreatment values (p=0.00-0.001)
Abbreviation: n=number of patients

lower than the survival rates reported for 8.5 mm implants (98.8%; 95% CI: 98.2-99.6%) in the systematic review of Telleman et al. (2011a). A reason for the lower survival rates in the study could be the number of implants placed in the maxilla, as one of the conclusions of the review to short implants was that the failure rate of studies performed in the maxilla was 0.010 implants/year compared with 0.003 in the mandible. Another reason might be due to the fact that in the systematic review, also results of studies were included in which short implants could be splinted to longer implants. And a reason could be that the implants used had an extended platform for which the use of countersink was needed for implant placement, this might have led to less initial implant stability (Renouard & Nisand 2006).

Marginal bone loss was significantly higher around two or more adjacent implants than around single implants in both the control and the test group.

Not much is written about the difference in bone resorption around single or multiple adjacent platform switching implants. Atieh et al. (2010) stated that these implants may preserve interimplant bone height, but they could not confirm the validity of that concept. Our results revealed that there is a strong tendency that around 2 or more adjacent platform-switched implants peri-implant bone is better preserved than around conventional implant-abutment connected implants, albeit that bone resorption still is apparently less when neighbouring natural teeth keep up the dental bone peak. Our study was not powered for a subgroup analysis, thus no conclusive conclusion could be drawn.

With a significant difference in bone resorption as observed in our study, a difference in clinical parameters might be expected. However, we did not detect a difference in clinical parameters. This observation is in accordance with the results of the histological study of Canullo et al. (2011a). The latter authors concluded that switching and traditional platform implants had similar histological and soft tissue features, despite different bone-level changes. Furthermore, Dellavia et al. (2011) concluded that platform switching apparently did not affect the inflammatory cellular and molecular pattern around the implant-abutment connection which is held responsible for bone loss in this area.

The implants applied in our trial had an implant-abutment diameter difference in horizontal dimension of 0.35 or 0.40 mm. Atieh et al. (2010) reported that subgroup analyses showed that an implant-abutment difference ≥0.4 mm was associated with a more favourable response. A bigger mismatch is often caused, as in the current study, by the use of a wider diameter. It has been speculated that the findings of reduced bone loss accompanying a larger implant-abutment difference may be due to an increased implant diameter rather than to the platform (Enkling et al. 2011). However, the study of Canullo et al. (2011b) on the impact of implant diameter of platform-switched implants clearly concluded no relation to bone resorption. When we compared the single 4 mm diameter implants with single 5 mm implants, indeed a tendency of higher bone loss was present, but by far did not reach significancy. Atieh et al. (2010) did not consider the vertical dimension of the platform-switch. In the implants we used the implant-abutment connection is 0.09 and 0.11 mm (depending on the diameter) above the outermost margin of the collar of the implant, so when placed at bone level, as in the current study, the implant-abutment connection is slightly higher. From the study of Cochran et al. (2009) we know that the least bone resorption was shown with the platform-switch situated 1 mm above the alveolar crest. So, the design of our platform-switched implants in vertical dimension might have contributed to the favourable results. Conversely, Veis et al. (2010) reported the least bone resorption when implants were placed subcrestally. Obviously from these contrasting results, more comparative studies to the different designs (in horizontal and vertical dimension) and level of placement of platform-switched implants are needed.

The marginal bone-level changes in this study were only measured in vertical dimension on the peri-apical radiographs, although bone resorption in horizontal extension also might have occurred. Analysis of the radiographs was done in consensus with most studies reported in the literature as the horizontal dimension is very difficult to measure. Up to now, only one study about platform switching measured the marginal bone-level changes in both the vertical and horizontal dimension on digital orthopantomographs (Enkling et al. 2011).
We would have expected to find mucosal thickness before implant placement to be a predictor for marginal bone loss, as a thin biotype has been shown to be more susceptible to marginal tissue recession and alveolar bone loss (Muller et al. 2000, Linkevicius et al. 2010, Lee et al. 2011). It could be that the number of implants placed in this study was too low to assess the role of the possible confounder mucosal thickness.

In conclusion, 1 year after loading marginal bone levels were better maintained around short implants restored according to the platform switching concept. This study suggested that marginal bone loss may be reduced by platform switching. However, to find the perfect platform switching design, comparative studies to the different designs and level of placement are needed.

References

Altman, D. G. (1991) Clinical trials. *Practical Statistics for Medical Research,* 1st edition, pp. 443-445. London: Chapmann & Hall.

Atieh, M. A., Ibrahim, H. M. & Atieh, A. H. (2010) Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis. *Journal of Periodontology* 81, 1350-1366.

Becker, J., Ferrari, D., Herten, M., Kirsch, A., Schaer, A. & Schwarz, F. (2007) Influence of platform switching on crestal bone changes at non-submerged titanium implants: a histomorphometrical study in dogs. *Journal of Clinical Periodontology* 34, 1089-1096.

Becker, J., Ferrari, D., Mihatovic, I., Sahm, N., Schaer, A. & Schwarz, F. (2009) Stability of crestal bone level at platform-switched non-submerged titanium implants: a histomorphometrical study in dogs. *Journal of Clinical Periodontology* 36, 532-539.

Berglundh, T. & Lindhe, J. (1996) Dimension of the periimplant mucosa. Biological width revisited. *Journal of Clinical Periodontology* 23, 971-973.

Broggini, N., McManus, L. M., Hermann, J. S., Medina, R., Schenk, R. K., Buser, D. & Cochran, D. L. (2006) Peri-implant inflammation defined by the implant-abutment interface. *Journal of Dental Research* 85, 473-478.

Canullo, L., Goglia, G., Iurlare, G. & Ianello, G. (2009) Short-term bone level observations associated with platform switching in immediately placed and restored single maxillary implants: a preliminary report. *The International Journal of Prosthodontics* 22, 277-282.

Canullo, L., Quaranta, A. & Teles, R. P. (2010a) The microbiota associated with implants restored with platform switching: a preliminary report. *Journal of Periodontology* 81, 403-411.

Canullo, L., Fedele, G. R., Ianello, G. & Jepsen, S. (2010b) Platform switching and marginal bone-level alterations: the results of a randomized-controlled trial. *Clinical Oral Implants Research* 21, 115-121.

Canullo, L., Pellegrini, G., Allievi, C., Trombelli, L, Annibali, S. & Dellavia, C. (2011a) Soft tissues around long-term platform switching implant restorations: a histological human evaluation. Preliminary results. *Journal of Clinical Periodontology* 38, 86-94.

Canullo, L., Iannello, G., Penarocha, M. & Garcia, B. (2011b) Impact of implant diameter on bone-level changes around platform switched implants: preliminary results of 18 months follow-up a prospective randomized match-paired controlled trial. *Clinical Oral Implants Research* 24, epub ahead of print.

Cappiello, M., Luongo, R., Di Iorio, D., Bugea, C., Cocchetto, R. & Celletti, R. (2008) Evaluation of peri-implant bone loss around platform-switched implants. *The International Journal of Periodontics & Restorative Dentistry* 28, 347-355.

Cochran, D. L., Bosshardt, D. D., Grize, L., Higginbottom, F. L., Jones, A. A., Jung, R. E., Wieland, M. & Dard, M. (2009) Bone response to loaded implants with non-matching implant-abutment diameters in the canine mandible. *Journal of Periodontology* 80, 609-617.

Crespi, R., Capparè, P. & Gherlone, E. (2009) Radiographic evaluation of marginal bone level around platform-switched and non-platform-switched implants used in an immediate loading protocol. *The International Journal of Oral & Maxillofacial Implants* 24, 920-926.

Dellavia, C., Canullo, L., Allievi, C., Lang, N. P. & Pellegrini, G. (2011) Soft tissue surrounding switched platform implants: an immunohis-

tochemical evaluation. *Clinical Oral Implants Research* 29, epub ahead of print.

Enkling, N. Jöhren, P., Klimberg, V., Bayer, S., Mericske-Stern, R. & Jepsen, S. (2011) Effect of platform switching on peri-implant levels: a randomized clinical trial. *Clinical Oral Implants Research* 22, 1185-1192.

Ericsson, I., Persson, L. G., Berglundh, T., Marinello, C. P., Lindhe, J. & Klinge, B. (1995) Different types of inflammatory reactions in peri-implant soft tissues. *Journal of Clinical Periodontology* 22, 255-261.

Ericsson, I., Nilner, K., Klinge, B. & Glantz, P. O. (1996) Radiographical and histological characteristics of submerged and non-submerged titanium implants. An experimental study in the Labrador dog. *Clinical Oral Implants Research* 7, 20-26.

Faul, F., Erdfekder, E., Buchner, A. & Lang, A. G. (2009) Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behavior Research Methods* 41, 1149-1160.

Farronato, D., Santoro, G., Canullo, L., Botticelli, D., Maorana, C. & Lang, N. P. (2012) Establishment of the epithelial attachment and connective tissue adaptation to implants installed under the concept of "platform-switching": a histologic study in mini-pigs. *Clinical Oral Implants Research* 23, 90-94.

Hagi, D., Deporter, D. A., Pilliar, R. M. & Arenovich, T. (2004) A targeted review of study outcomes with short (≤ 7 mm) endosseous dental implants placed in partially edentulous patients. *Journal of Periodontology* 75, 798-804.

Heydenrijk, K., Raghoebar, G. M., Meijer, H. J. A., van der Reijden, W., van Winkelhoff, A-J. & Stegenga, B. (2002) Two-part implants inserted in a one-stage or a two-stage procedure. A prospective comparative study. *Journal of Clinical Periodontology* 29, 901-909.

Hermann, J. S., Buser, D., Schenk, R. K., Schoolfield, J. D. & Cochran, D. L. (2001a) Biologic width around one-and two- piece titanium implants. *Clinical Oral Implants Research* 12, 559-571.

Hermann, J. S., Schoolfield, J. D., Nummikoski, P. V., Buser, D., Schenk, R. K. & Cochran, D. L. (2001b) Crestal bone changes around titanium implants: A methodologic study comparing linear radiographic with histometric measurements. *International Journal of Oral Maxillofacial Implants* 16, 475-485.

Hürzeler, M., Fickl, S., Zuhr, O. & Wachtel, H. C. (2007) Peri-implant bone level around implants with platform-switched abutments: preliminary data from a prospective study. *Journal of Oral and Maxillofacial Surgery* 65, 33-39.

Kielbassa, A. M., Martinez-de Fuentes, R., Goldstein, M., Arnhart, C., Barlattani, A., Jackowski, J., Knauf, M., Lorenzoni, M., Maiorana, C., Mericske-Stern, R., Rompen, E. & Sanz, M. (2009) Randomized controlled trial comparing a variable-thread novel tapered and a standard tapered implant: one-year results. *The Journal of Prosthetic Dentistry* 101, 293-305.

Lee, A., Fu, J. H. & Wang, H. L. (2011) Soft tissue biotype affects implant success. *Implant Dentistry* 20, e38-e47.

Löe, H. & Silness, J. (1963) Periodontal disease in pregnancy. I. Prevalence and severity. *Acta Odontologica Scandinavica* 21, 533-551.

Lekholm, U. & Zarb, G. A. (1985) Patient selection and preparation. In: Bränemark, P. I., Zarb G. A. & Albrektsson, T. (eds). *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*, 1st edition, pp. 199-209. Chicago: Quintessence Publishing.

Linkevicius, T., Apse, P., Grybauskas, S. & Puisys, A. (2010) Influence of thin mucosal tissues on crestal bone stability around implants with platform switching: a 1-year pilot study. *Journal of Oral and Maxillofacial Surgery* 68, 2272-2277.

Maeda, Y., Miura, J., Taki, I. & Sogo, M. (2007) Biomechanical analysis on platform switching: Is there any biomechanical rationale? *Clinical Oral Implants Research* 18, 581-584.

Mombelli, A., van Oosten, M. A. C., Schürch, E. & Lang, N. P. (1987) The microbiota associated with successful or failing osseointegrated titanium implants. *Oral Microbiology and Immunology* 2, 145-151.

Müller, H. P., Heinecke, A., Schaller, N. & Eger, T. (2000) Masticatory mucosa in subjects with different periodontal phenotypes. *Journal of Clinical Periodontology* 27, 621-626.

Prosper, L., Redaelli, S., Pasi, M., Zarone, F., Radaelli, G. & Gherlone, E. (2009) A randomized prospective multicenter trial evaluating the platform-switching technique for the prevention of postrestorative crestal bone loss. *The International Journal of Oral & Maxillofacial Implants* 24, 299-308.

Renouard, F. & Nisand, D. (2006) Impact of implant length and diameter on survival rates. *Clinical Oral Implants Research* 17, 35-51.

Sewerin, I. P. (1990) Errors in radiographic assessment of marginal bone height around osseointegrated implants. *Scandinavian Journal of Dental Research* 98, 428-433.

Smeets, E. C., de Jong, K. J. & Abraham-Inpijn, L. (1998) Detecting the medically compromised patient in dentistry by means of the medical risk-related history. A survey of 29,424 dental patients in the Netherlands. *Preventive Medicine* 27, 530-535.

Syed, S. A. & Loesche, W. J. (1972) Survival of human dental plaque flora in various transport media. *Applied Microbiology* 24, 638-644.

Telleman, G., Raghoebar, G. M., Vissink, A., den Hartog, L., Huddleston Slater, J. J. R. & Meijer, H. J. A. (2011a) A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. *Journal of Clinical Periodontology* 38, 667-676.

Telleman, G., Raghoebar, G. M., Vissink, A. & Meijer, H. J. A. (2011b) The use of a coded healing abutment as an impression coping to design and mill an individualized anatomic abutment: A clinical report. *The Journal of Prosthetic Dentistry* 105, 282-285.

Todescan, F. F., Pustiglioni, F. E., Imbronito, A. V., Albrektsson, T. & Gioso, M. (2002) Influence of the microgap in the peri-implant hard and soft tissues: A histomorphometric study in dogs. *International Journal of Oral Maxillofacial Implants* 17, 467-472.

Trammell, K., Geurs, N. C., O'Neal, S. J., Liu, P. R., Haigh, S. J., McNeal, S., Kenealy, J. N. & Reddy, M. S. (2009) A prospective, randomized, controlled comparison of platform-switched and matched-abutment implants in short-span partial denture situations. *The International Journal of Periodontics & Restorative Dentistry* 29, 599-605.

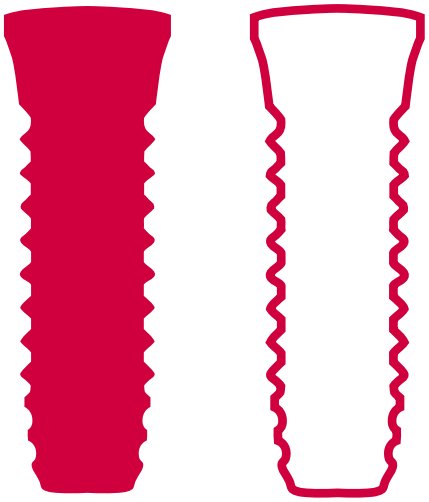
Veis, A., Parissis, N., Tsirlis, A., Papadeli, C., Marinis, G. & Zogakis, A. (2010) Evaluation of peri-implant marginal bone loss using modified abutment connections at various crestal level placements. *The International Journal of Periodontics & Restorative Dentistry* 30, 609-617.

Viera, A. J. & Garrett, J. M. (2005) Understanding interobserver agreement: The kappa statistic. *Family Medicine* 37, 360-363.

Vigolo, P. & Givani, A. (2009) Platform-switched restorations on wide-diameter implants: a 5-year clinical prospective study. *The International Journal of Oral & Maxillofacial Implants* 24, 103-109.

Wagenberg, B. & Froum, S. J. (2010) Prospective study of 94 platform-switched implants observed from 1992 to 2006. *The International Journal of Periodontics & Restorative Dentistry* 30, 9-17.

Chapter 3 Platform switching



This study was performed in cooperation with the Department of Biomaterials/Handicap Research, Institute for Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.

This chapter is an edited version of the manuscript: Telleman, G., Albrektsson, T., Hoffman, M., Johansson, C. B., Vissink, A., Raghoebar, G. M. & Meijer, H. J. A. (2010) Peri-implant endosseous healing properties of dual acid-etched mini-implants with a nanometer-sized deposition of CaP: A histological and histomorphometric human study. Clinical Implant Dentistry & Related Research 12, 153-160.

Chapter 4

Peri-implant endosseous healing properties of dual acid-etched mini-implants with a nanometer-sized deposition of CaP: a histological and histomorphometric human study

Abstract

Aim: The aim of this histological and histomorphometric study was to compare the early peri-implant endosseous healing properties of a dual acid-etched (DAE) surface (Osseotite, Biomet 3i, Palm Beach Gardens, FL, USA) to a DAE surface modified with nanometer-sized calcium phosphate (CaP) particles (NanoTite, Biomet 3i) in grafted and mature maxillary bone.

Materials and methods: Fifteen patients received two mini-implants, 1 with DAE surface (control) and 1 with a DAE + CaP surface (test) to fixate an iliac crest bone graft to the maxilla. A part of each mini-implant was in contact with the grafted bone and a part extended into the native maxillary bone. After a healing period of 3 months, the specimens were harvested and analysed.

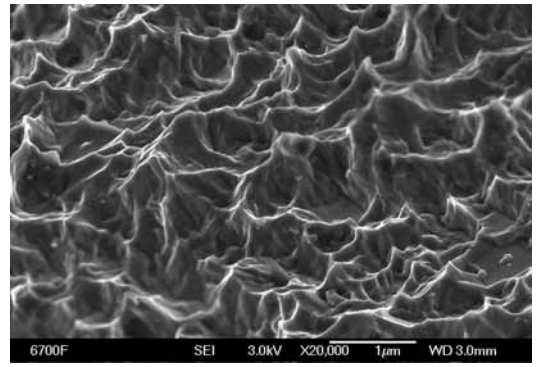
Results: Overall, a trend was seen for stronger bone response around the test mini-implants in the native bone of the maxilla. However, only the old bone particles measured by percentages of bone-to-implant contact and bone area were statistically significant (p=0.025 and p=0.042, respectively).

Conclusion: The NanoTite surface increases the peri-implant endosseous healing properties in the native bone of the maxilla comparing to the Osseotite surface, while this difference was not visible in the bone graft area. This might be a result of lower remodelling process of the graft.

Introduction

Surface modifications of endosseous implants are of growing interest for their prospects of improving osseointegration. A complex surface microtopography or surface roughness (Park et al. 2001. Shalabi et al. 2006) and, to a lesser extent, calcium phosphate (CaP) deposits on an implant surface are thought to accelerate early peri-implant bone healing by increasing activation of platelets (Kikuchi et al. 2005, Arvidsson et al. 2007, Mendes et al. 2007). These platelets would play an initiating role in the process called contact osteogenesis; they activate the osteogenetic cells to migrate to the surface of the implant. On the implant surface, these cells differentiate into osteoblasts and start to deposit new bone (Davies 2003, 2007). Especially in more challenging implant cases, such as immediate placement or loading of implants and insertion of implants in 'poor' quality bone, this acceleration of early peri-implant bone healing might be very useful.

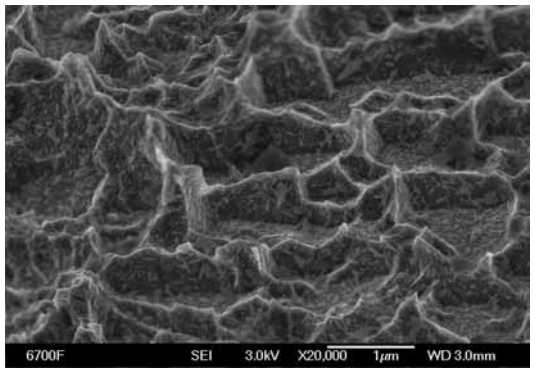
Figure 1. Scanning electron microscope (SEM) image of the dual acid-etched surface at x20,000 magnification (Osseotite, Biomet 3i)



Recently a modification of the dual acid-etched (DAE) surface (Osseotite, Biomet 3i, Palm Beach Gardens, FL, USA) was introduced. This novel surface is created by discrete crystalline deposition of nanometer-sized CaP particles on the DAE surface (NanoTite, Biomet 3i) (figure 1, 2, 3, 4). The calcium phosphate (CaP) deposit on the DAE implants does not form a confluent layer; the CaP-particles (20-100 nm in size) are deposited in the peaks and valleys of the DAE surface microtopography and occupy approximately 50% of the surface. In this way, a more complex surface microtopography is developed.
This study was initiated to assess the early endosseous healing properties of both (DAE and DAE + CaP) surfaces in a model applying mini-implants to fixate monocorticocancellous anterior iliac crest grafts used for augmentation of a severely resorbed maxilla. This model was chosen to see whether the

DAE surface + CaP has better healing properties than the DAE surface and to determine whether these properties are of particular benefit in areas with either high or low remodelling. Moreover, the remodelling process in the iliac crest graft and the osseointegration in the maxilla bone could be observed. Long-term results are known for the resorption of iliac crest onlay grafts (Verhoeven et al. 2006) but, to our knowledge, are never compared with the endosseous healing properties of the native bone.

Figure 2. Scanning electron microscope (SEM) image of the dual acid-etched surface with a crystalline deposition of nanometer-sized calcium phosphate particles at x20,000 magnification (NanoTite, Biomet 3i)



The aim of this histological and histomorphometric study was to compare the early peri-implant endosseous healing properties of the DAE surface to the DAE surface with a discrete crystalline deposition of nanometer-sized CaP in an active remodelling (i.e., grafted bone) and native (i.e., mature bone) maxillary area.

Materials and methods

Patients

Fifteen consecutive patients (6 women, 9 men) with a mean age of 62.3 ± 7.1 years (range 48-69) fulfilling the inclusion criteria agreed to participate in this study. The patients were referred to the Department of Oral and Maxillofacial Surgery of the University Medical Center Groningen driven by an insufficient retention of their upper denture related to a severely resorbed maxilla. The patients had been edentulous in the maxilla for 3 to 21 years.

Patients were selected by using the following inclusion criteria:

- Severely resorbed maxilla (class V and VI, Cawood & Howell 1991) with

Figure 3. An optical three-dimensional topographical image of the DAE surface with a surface roughness measured by Wennerberg and colleagues (University of Gothenburg, Sweden) of a mean height deviation (S_a) of 0.68 μm and a developed interfacial area ratio (S_{dr}) of 27% (Wennerberg & Albrektsson 1992, Wennerberg 1996).

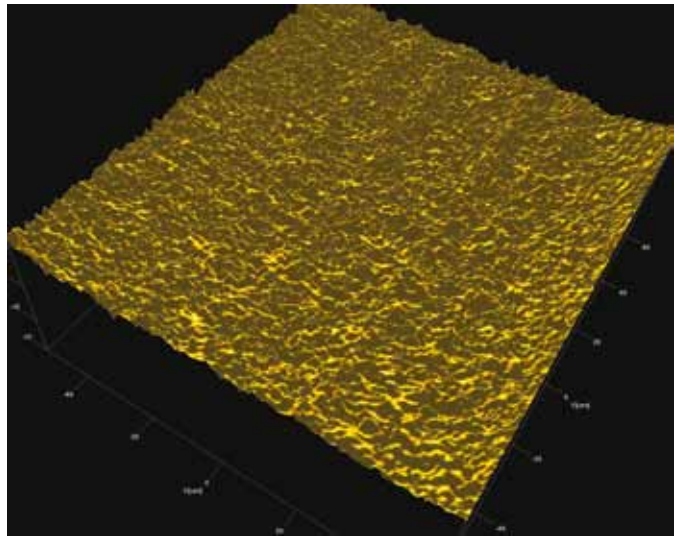
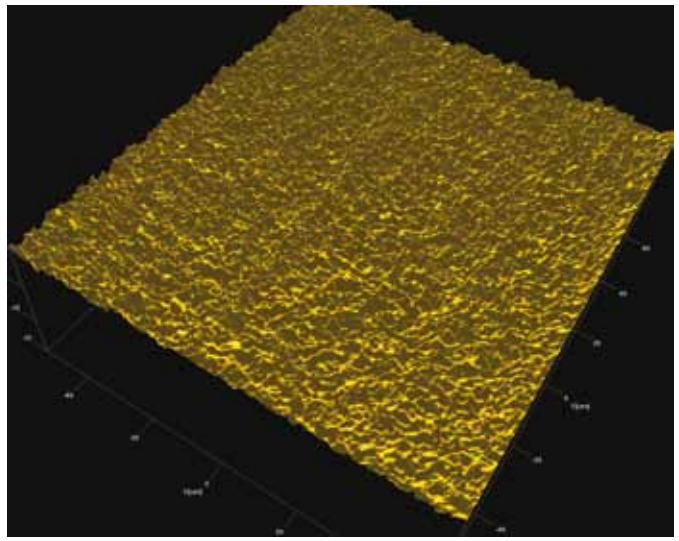


Figure 4. An optical three-dimensional topographical image of the DAE +CaP surface with a surface roughness measured by Wennerberg and colleagues (University of Gothenburg, Sweden) of a mean height deviation (S_a) of 0.5 μm and a developed interfacial area ratio (S_{dr}) of 40% (Wennerberg & Albrektsson 1992, Wennerberg 1996).



reduced stability and reduced retention of the upper denture
- Edentulous period of at least 1 year
- No history of radiotherapy in the head and neck region
- No history of bone-related diseases, autoimmune-related disorders and diabetes mellitus
- Patients either did not smoke or stopped smoking at least 6 weeks before surgery
- No history of reconstructive preprosthetic surgery or previous implant surgery

In all patients, overdentures were planned to be supported by 4 to 6 implants placed in the maxilla. Informed written consent to participate in this study was obtained from all patients.
Orthopantomograms, lateral cephalograms, and postero-anterior oblique radiographs were made to assess the height of the maxillary alveolar bone, the dimensions of the maxillary sinus, and the antero-posterior relationship of the maxilla to the mandible. The radiographs were also screened for sinus pathology. The mean vertical height of the alveolar bone on the orthopantomogram between the most caudal part of the maxillary sinus and the oral cavity under the maxillary sinus was 3 ± 2 mm (range 1-5 mm). The bone width in the anterior area was 2 ± 1 mm (range 2-5 mm).

Surgical protocol
The maxilla of each patient was reconstructed with autologous anterior medial iliac crest bone grafts under general anaesthesia. In all cases, bilaterally, a two-stage procedure (first stage, bone grafting; second stage, placement of implants) was performed because the height of the maxillary bone and/or the width of the alveolar crest were less than 5 mm. A bone height of 5 mm or more is a prerequisite for implant placement with sufficient primary stability (Raghoebar et al. 2001). In addition to elevation of the floor of the maxillary sinus, the width of the alveolar crest was reconstructed. An osteotomy was prepared in the lateral wall of the maxillary sinus by using the surgical procedure described by Raghoebar et al. (2001). After harvesting the bone grafts from the iliac crest, the floor of the maxillary sinus was augmented with bone blocks, and the remaining space was occupied by cancellous bone particles. The graft was ground in a bone mill (Stryker Leibinger GmbH, Freiburg, Germany). The monocorticocancellous bone blocks were then placed buccally of the cortex of the alveolar defect in order to increase the width of the superior alveolar process. The cancellous side of the bone graft was in contact with the maxillary bone, and, again cancellous bone particles were used to fill the small gaps between the bone graft and the alveolar crest.
Randomly, on one side, the grafts were fixed to the alveolar bone with one titanium screw (Martin Medizin Technik, Germany) (diameter 1.5 mm/ length 10 mm) and one custom-made mini-implant with a DAE surface (Osseotite)

(diameter 2.18 mm/ length 10 mm). On the other side, the grafts were fixed to the alveolar bone with one titanium screw (similar to the screw used on the other side) and one test custom-made mini-implant with nanometer-sized CaP particles on the DAE surface (NanoTite) (diameter 2.18 mm/ length 10 mm). The screws were inserted without tapping in a region where no endosseous implants were planned to be inserted. At least 3 mm of the mini-implants extended into native maxillary bone to obtain adequate stability of the bone graft and a sufficient length of the mini-implant surface in contact with native bone for histological and histomorphometric evaluation. The bone width was measured with a calliper. The bone grafts were covered by a membrane (Bio-Gide®, Geistlich Söhne AG, Wolhusen, Switzerland) (Tonetti & Hämmerle 2008).
Before the bone grafts were harvested, the patients received broad-spectrum antibiotics, starting 1 hour preoperatively (intravenously) and continued orally for 2 days after surgery. Postoperatively, the patients received an aqueous 0.2% chlorhexidine mouth rinse (1 minute, 3 times daily) for 2 weeks. One month postoperatively, the edentulous patients were allowed, if possible, to wear their denture in the operated area, after relining the denture with a soft liner.
After a healing period of 3 months, the control mini-implants with DAE surface and the test mini-implant with DAE surface modified with the nanometer-sized CaP particles were removed, and the implant placement procedure was performed (Raghoebar et al. 2001). This second-stage surgery was performed under general anaesthesia in the day clinic. Shortly after the mucoperiosteal flap was reflected, the width of the reconstructed alveolar crest was measured, and the titanium screws were removed. The test and the control mini-implants were removed using a trephine (internal diameter 4.25 mm). Surgical and prosthetic procedures were then followed to construct an implant-supported overdenture.

Clinical evaluation
Clinically, all patients were evaluated according to a standardized protocol 1, 3, 6 and 12 weeks after surgery. The clinical protocol included assessment of complications during surgery and postoperative healing (inflammation, redness of the mucosa, wound dehiscence, sequestration, and loss of bone particles).

Histological examination
The harvested specimens were immersed in 10% formalin and sent to the laboratories of the Biomaterials department, Sahlgrenska Academy, Gothenburg. The laboratory staff was blinded for test and control specimens. The aberrant surface texture of the nanometer-sized CaP particles is not visible when using magnification as used for light microscopy. The sample preparation followed the internal guidelines of the laboratories and, in brief, this involved change to fresh 4% neutral buffered formaldehyde upon arrival in

the laboratories and further immersed in the solution for 1 week. After being rinsed in tap water, the specimens were dehydrated in ethanol, from 70% to absolute ethanol. Following this, the samples were immersed in diluted resins and finally infiltrated in pure resin (Technovit 7200 VLC, Heraeus Kulzer GmbH & Co., Wehrheim, Germany). All these steps were carried out under stirring and vacuum conditions. Embedment in pure resin with polymerisation in ultraviolet light was the final step. The bloc samples were divided in the long axis of the implant in a band saw. A supporting plexiglass was glued onto the surface, and a thick central section (200 μm) was prepared from each biopsy. These sections were further ground to approximately 10 to 20 μm. The preparation of undecalcified cut and ground sections involved the usage of the EXAKT equipment (EXAKT Apparatebau GmbH & Co., Norderstedt, Germany) and followed the recommendations by Donath & Breuner (1982), Donath (1988), Johansson & Morberg (1995a,b). The sections were stained with Toluidine blue mixed in pyronin G prior to cover slipping and investigations in the light microscope. The histological staining differentiates between pale-purple-stained bone and darker-purple-stained new-formed bone. Soft tissue as well as cellular nuclei is blue stained.

All samples were investigated in a Leitz Aristoplan light microscope (Ernst Leitz GmbH, Wetzlar, Germany) coupled to a computer-based Microvid unit enabling quantitations of the bone-to-implant contact (BIC) and bone area (BA) inside the threads (Johansson 1991).

Histomorphometric examination

Histomorphometric examination was performed to quantitate peri-implant endosseous bone healing related to the type of implant surface and the quality of bone. Interindividual comparisons of data performed by two independent observers, on blinded sections, revealed similar qualitative judgements. One person performed all histomorphometrical measurements.

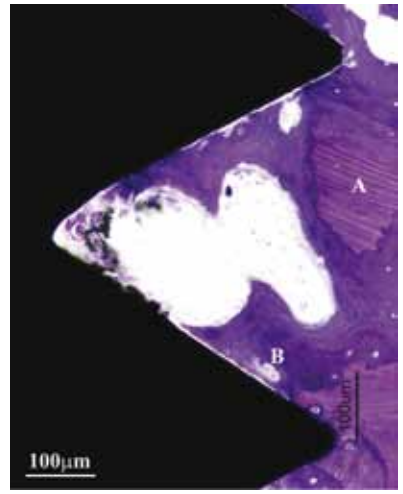
The percentages of BIC and BA of eight different implant threads were determined, namely, the four uppermost threads (these threads were all in contact with grafted bone) and the four lowest threads (these threads were all in contact with native maxillary bone).

To determine the process of osseointegration of the mini-implants in the maxilla and the remodelling process around the mini-implants in the grafted area, a distinction in percentages of BIC and BA was made between the old bone and the newly formed bone particles. For each thread, the total percentage of BIC and BA was measured, and for the old bone and the newly formed bone separately. For some bone particles, it was very difficult to identify whether the particle was an old piece of bone that was on its way to dissolve (from a graft or a result of initial drilling) or new bone; these minor areas were classified as unidentified areas, or 'bone dust' (figure 5). Such particles are to be expected in the bone remodelling process of the iliac crest graft. The unidentified areas were not counted for in the assessment of BIC and BA.

Statistical analysis

The histomorphometric data were collected and subjected to statistical analysis using a statistical program (SPSS 14.0 SPSS Inc., Chicago, IL, USA). The mean value of the eight (4 + 4) threads per mini-implant was filed; also, when there was no bone seen in a thread, these so called 'zero-values' were included. The data were analysed with descriptive statistics to see whether there was a standard distribution. To compare the means between the control and test implants and between the graft and native bone paired samples *t*-test were performed. A significance level of $p<0.05$ was chosen.

Figure 5. A thread of a mini-implant with a DAE + CaP surface (Toluidine blue) (A=old bone, B=newly formed bone, C=bone dust)



Results

Clinical results

No complications were observed during the surgery or during the postoperative healing period. At the time of reentry surgery, all mini-implants (test and control) were immobile and surrounded by bone.

Histology

All mini-implants were available for histological examination. Most of the surface of the mini-implants was covered with bone. However, because of physiologic resorption at the screw head, some mini-implants were lacking in coverage by bone, and, because of the harvesting process with the trephine bur, the bottom section of some specimens showed small artefacts. Nevertheless, at all mini-implants, areas of at least four threads covered by the monocorti-

cocancellous bone of the bone graft derived from the anterior iliac crest, and areas of at least four threads covered by native maxillary bone were distinguished (figure 6, 7).

Histomorphometry

An overview of the quantitative histomorphometric results is presented in tables 1 and 2. In table 1, the percentages of BIC and BA of the control (DAE surface) and test (DAE + CaP surface) per patient are given. In table 2, an overview is provided of the level of significance of the BIC and BA percentages of the upper (graft bone) and lower parts (native bone) and the old and newly formed bone of the control and test mini-implants.

Overall, a trend can be seen for a stronger bone response around the lower threads of the test mini-implants in the native bone of the maxilla (*p* value of BA=0.100), but only the old bone particles measured by percentages of BIC and BA were statistically significant (p=0.025 and p=0.042, respectively). Furthermore, when the overall results of the upper part of the mini-implant (into the iliac crest bone graft) were compared with those of the lower part (into the maxillary bone), both for the control and test mini-implants, BIC and BA were significantly higher for the native maxillary bone (p=0.009 and p=0.006) for the controls and (p=0.000 and p=0.003) for the test mini-implants, respectively.

Figure 6. Histological representation of a harvested specimen with a DAE surface (Toluidine blue)

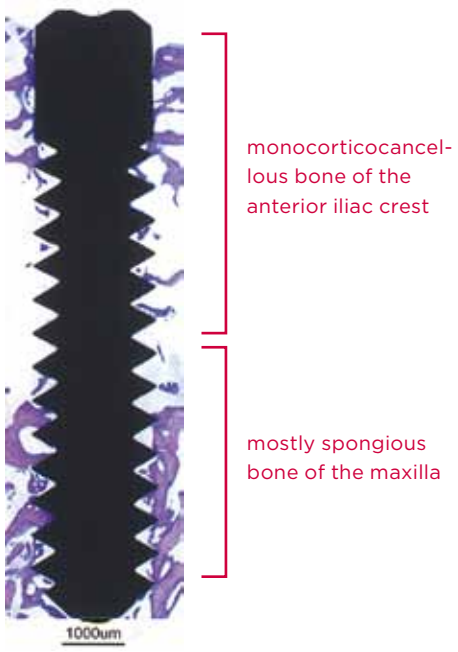
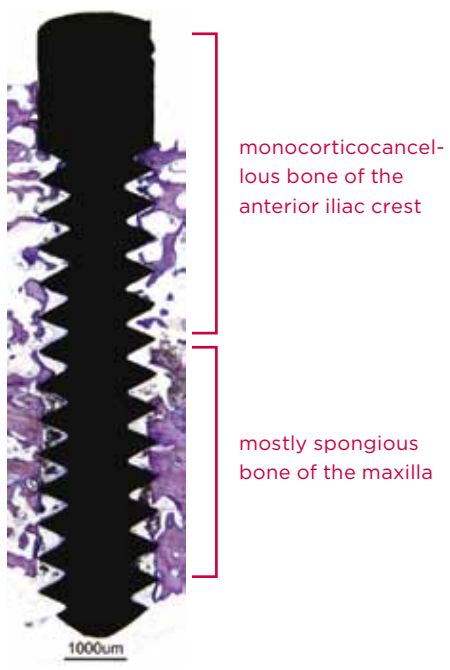


Figure 7. Histological representation of a harvested specimen with a DAE + CaP surface (Toluidine blue)



Discussion

This study showed better results at the level of the native bone for the test mini-implants (DAE + CaP surface) than for the control (DAE surface) after 3 months in service of fixating an iliac crest bone graft to the maxilla bone, but only the results of the old bone particles were statistically significant. This would mean that, if there are already old bone particles in contact with the surface of the mini-implants, a more active osteogenesis process is going on and that the osseointegration process is accelerated by the more complex microtopography and/ or CaP deposits.

When the BIC and BA percentages of the bone graft of both the control and the test mini-implants were compared with the native bone of the maxilla, significantly more bone was observed in the maxillary bone. As is obvious from

Table 1. BIC (%) and BA (%) of the control (DAE) and test (DAE + CaP) mini-implant per patient

patient	control (DAE) BIC%	test (DAE + CaP) BIC%	control (DAE) BA%	test (DAE + CaP) BA%
1	2.52	9.06	9.09	12.86
2	7.29	12.45	13.56	22.90
3	4.86	11.53	3.19	7.69
4	16.40	7.34	23.13	11.27
5	14.47	15.54	19.04	25.22
6	0	5.50	0	11.14
7	3.16	10.29	7.16	10.56
8	8.15	8.70	9.78	12.00
9	5.42	8.53	12.65	12.00
10	4.66	6.63	6.69	10.94
11	1.36	4.11	2.20	9.44
12	17.11	14.68	12.23	20.80
13	12.78	6.39	9.55	15.80
14	11.51	8.76	14.10	11.09
15	11.78	6.53	8.51	5.00
Mean± SD	**8.68 (±5.29)**	**9.07 (±3.30)**	**10.78 (±5.66)**	**13.25 (±5.62)**

Abbreviations: BA=bone area, BIC= bone-to-implant contact, CaP= calcium phosphate, DAE= dual acid-etched

Table 2. Levels of significance of the control (DAE) and test (DAE + CaP) mini-implants

	Control (DAE) (Mean ± SD)	Test (DAE + CaP) (Mean ± SD)	Significance
BIC (%) upper threads (graft)	**8.13 ± 8.35**	**8. 27 ± 8.85**	**0.968**
New BIC (%) upper threads	3.27 ± 7.27	5.57 ± 7.70	0.390
Old BIC (%) upper threads	4.86 ± 6.08	2.70 ± 2.48	0.294
BIC (%) lower threads (maxilla)	**27.02 ± 19.73**	**29.01 ± 15.19**	**0.746**
New BIC (%) lower threads	16.54 ± 18.21	9.62 ± 9.79	0.187
Old BIC (%) lower threads	10.48 ± 7.62	19.39 ± 13.27	0.025*
BA (%) upper threads (graft)	**14.73 ± 14.66**	**13.85 ± 7.34**	**0.848**
New BA (%) upper threads	4.24 ± 4.80	5.66 ± 5.77	0.299
Old BA (%) upper threads	10. 45 ± 15.12	8.18 ± 5.98	0.639
BA (%) lower threads (maxilla)	**29.97 ± 16.32**	**39.17 ± 21.22**	**0.100**
New BA (%) lower threads	15.50 ± 13.14	13.14 ± 14.64	0.593
Old BA(%) lower threads	14.46 ± 12.44	26.03 ± 19.68	0.042*

* $p<0.05$
Abbreviations: BA=bone area, BIC= bone-to-implant contact, CaP= calcium phosphate, DAE= dual acid-etched

the results of our study, the remodelling process in the iliac crest graft was still ongoing 3 months after grafting. This result raises the question whether it is premature to insert an implant 3 months after augmentation. More histological and histomorphometric research is needed to clarify when this remodelling process of the augmented areas is in such a stage that implantation is predictable.

Similar histological and histomorphometric investigations comparing the DAE surface to the DAE + CaP surface in the posterior maxillae showed results like ours. Furthermore, to our knowledge, no other study has compared the endosseous healing properties of augmented bone to those of native bone so far. Goené et al. (2007) placed 18 unloaded site evaluation implants (SEI's) in the posterior maxillae of nine patients and compared the two surfaces we studied. After 4 to 12 weeks the DAE + CaP surface showed a statistically significant higher percentage of BIC when a zero contact value in the control group was included ($p<0.01$), but bone volume (BV) percentages were comparable. The discrepancy between BIC and BV percentages could be explained from their observation that on the DAE + CaP surface an almost continuous layer of thin bone was seen. Orsini et al. (2007) also placed 32 unloaded SEI's in the posterior maxilla of 15 patients. They observed no difference in BIC and BV percentages when zero contact values were included ($p=0.20$). However, by excluding the zero contact values a trend towards statistical significance was seen in favour of the test SEI. In our study all the zero

values were included because all the harvested specimens were surrounded by bone, and no artefacts or fibrous encapsulation was seen.

The model used in the present study was chosen for the 'poor' bone quality of the iliac crest bone graft. The question was whether this new surface could also accelerate the remodelling process in a bone graft. Presumably because of the poor vascularisation of the grafted area at the time of placement of the control and test mini-implants, the platelet activation did not take place as expected on this surface with complex microtopography and CaP deposits. The results of the native bone of the maxilla were significantly better for the test mini–implants; the new DAE surface with CaP particles might prove to be a more reliable implant in cases of immediate placement or immediate loading of implants.

From this study, it can be concluded that the DAE surface with CaP particles improved the peri-implant endosseous healing properties in the native bone of the maxilla when compared with the DAE surface, but did not improve the healing properties in the bone graft area. We assume that this might be a result of the lower remodelling process of the bone graft area, which is still in progress 3 months after grafting.

References

Arvidsson, A., Franke-Stenport, V., Andersson, M., Kjellin, P., Sul, Y. T. & Wennerberg, A. (2007) Formation of calcium phosphates on titanium implants with four different bioactive surface preparations. An in vitro study. *Journal of Materials Science. Materials in Medicine* 18, 1945-1954.

Cawood, J. I. & Howell, R. A. (1991) Reconstructive preprosthetic surgery. I. Anatomical considerations. *International Journal of Oral and Maxillofacial Surgery* 20, 75-82.

Davies, J. E. (2003) Understanding peri-implant endosseous healing. *Journal of Dental Education* 67, 932-949.

Davies, J. E. (2007) Bone bonding at natural and biomaterial surfaces. *Biomaterials* 28, 5058-5067.

Donath, K. & Breuner, G. A. (1982) A method for the study of undecalcified bones and teeth with attached soft tissues. The Säge-Schliff (sawing and grinding) technique. *Journal of Oral Pathology* 11, 318-326.

Donath, K. (1988) Die Trenn-Dünnschliff-Technik zur herstellung histologischer präparate von nicht schneidbaren geweben und materialen. *Der Präparator* 34, 197-206.

Goené, R. J., Testori, T. & Trisi, P. (2007) Influence of a nanometer-scale surface enhancement on de novo bone formation on titanium implants: a histomorphometric study in human maxillae. *The International Journal of Periodontics & Restorative Dentistry* 27, 211-219.

Johansson, C. B. (1991) *On tissue reactions to metal, PhD thesis*, Sweden: Department of Biomaterials, University of Gothenburg.

Johansson, C. B. & Morberg, P. (1995a) Cutting directions of bone with biomaterials in situ does influence the outcome of histomorphometrical quantifications. *Biomaterials* 16, 1037-1039.

Johansson, C. B. & Morberg, P. (1995b) Importance of ground section thickness for reliable histomorphometrical results. *Biomaterials* 16, 91-95.

Kikuchi, L., Park, J. Y., Victor, C. & Davies, J. E. (2005) Platelet interactions with calcium-phosphate-coated surfaces. *Biomaterials* 26, 5285-5295.

Mendes, V. C., Moineddin, R., Davies J. E. (2007) The effect of discrete calcium phosphate nanocrystals on bone-bonding to titanium surfaces. *Biomaterials* 28, 4748-4755.

Orsini, G., Piatelli, M., Scarano, A., Petrone, G., Kenealy, J., Piatelli, A. & Caputi, S. (2007) Randomized, controlled histologic and histomorphometric evaluation of implants with nanometer-scale calcium phosphate added to the dual acid-etched surface in the human posterior maxilla. *Journal of Periodontology* 78, 209-218.

Park, J. Y., Gemmell, C. H. & Davies, J. E. (2001) Platelet interactions with titanium: modulation of platelet activity by surface topography. *Biomaterials* 22, 2671-2682.

Raghoebar, G. M., Timmenga, N. M., Reintsema, H., Stegenga, B. & Vissink, A. (2001) Maxillary bone grafting for insertion of endosseous implants: results after 12-124 months. *Clinical Oral Implants Research* 12, 279-286.

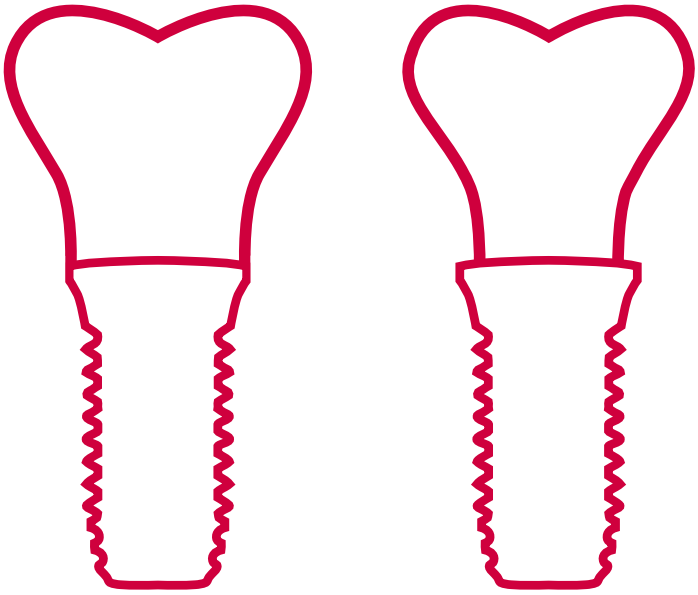
Shalabi, M. M., Gortemaker, A., van 't Hof, M. A., Jansen, J. A. & Creugers, N. H. J. (2006) Implant surface and bone healing: a systematic review. *Journal of Dental Research* 85, 496-500.

Tonetti, M. S. & Hämmerle, C. H. F. (2008) Advances in bone augmentation to enable dental placement: consensus report of the sixth European workshop on periodontology. *Journal of Clinical Periodontology* 35, 168-172.

Verhoeven, J. W., Cune, M. S. & Ruijter, J. (2006) Permucosal implants combined with iliac crest onlay grafts used in extreme atrophy of the mandible: long-term results of a prospective study. *Clinical Oral Implants Research* 17, 58-66.

Wennerberg, A., Albrektsson, T., Ulrich, H. & Krol, J. J. (1992) An optical three-dimensional technique for topographical descriptions of surgical implants. *Journal of Biomedical Engineering* 14, 412-418.

Wennerberg A. (1996) *On surface roughness and implant incorporation, PhD thesis*. Sweden: Department of Biomaterials, University of Gothenburg.



This chapter is an edited version of the manuscript: Telleman, G., Meijer, H. J. A., Vissink, A. & Raghoebar, G. M. Short implants with a nanometer-sized CaP surface provided with either a platform-switched or platform-matched abutment connection in the posterior region: a randomized clinical trial. Clinical Oral Implants Research (accepted 18-7-2012).

Chapter 5

Short implants with a nanometer-sized CaP surface provided with either a platform-switched or platform-matched abutment connection in the posterior region: 1-year results from a randomized clinical trial

Abstract

Aim: To assess the performance of short nanorough implants (8.5 mm in length) provided with either a platform-matched or a platform-switched implant-abutment connection, placed in the resorbed posterior region of partially dentate patients.

Materials and methods: A total of 149 implants with a dual acid-etched surface and a discrete crystalline deposition of nanometer-sized CaP particles, with either a platform-matched (control) or a platform-switched implant-abutment connection (test) were placed (randomly assigned) in 92 patients. Follow-up visits were conducted 1 month and 1 year after placing the implant crown. Outcome measures were marginal bone loss, using standardized periapical radiographs, implant survival, clinical parameters and patient's satisfaction.

Results: One year after loading, marginal bone loss around test implants (0.50±0.53 mm) was significantly less than around control implants (0.74±0.61 mm; $p<0.005$). Six of 76 implants in the control group (survival 92.1%) and three of 73 implants in the test group (survival 95.9%) were lost ($p=0.33$). With regard to clinical parameters and patient's satisfaction no significant differences were observed between test and control group.

Conclusion: For teeth replacements in the resorbed posterior region of partially dentate patients, short implants with a platform-switched implant-abutment connection showed significantly less marginal bone loss after 1 year in function, while implant survival, clinical parameters and patient's satisfaction were independent of the implant-abutment connection design.

Introduction

Short implants (<10 mm in length) are increasingly used for the prosthetic rehabilitation of the extremely resorbed posterior zone of partially edentulous patients. The findings from the systematic review of Telleman et al. (2011a) add to the growing evidence that short implants can be successfully placed in the partially edentulous patients, though with an increasing survival rate per implant length. In the past, short implants have been associated with lower survival rates (Lee et al. 2005, Romeo et al. 2010). Compared with longer implants with a comparable diameter, there is less bone to implant contact when short implants are used, simply because there is less implant surface. Furthermore, short implants are mostly placed in the posterior zone where the quality of the alveolar bone in this region is relatively poor, especially in the maxilla (type III or IV, Lekholm & Zarb 1985). To avoid the use of short implants, the extremely resorbed bone can be augmented using a bone grafting technique. This modification in the patient's anatomy allows for placement of longer implants, but is accompanied by an extra surgical intervention, greater patient's morbidity, higher costs and a longer treatment period. Esposito et al. (2010) concluded from their systematic review on augmentation procedures of the maxillary sinus: "Short implants (5-8 mm) may be as effective and cause fewer complications than longer implants placed using a more complex technique." And from their systematic review on horizontal and vertical bone augmentation techniques for dental implant treatment, they concluded (Esposito et al. 2009): "Short implants appear to be a better alternative to vertical bone grafting of resorbed mandibles. Complications, especially for vertical augmentation, are common." New developments of the various implant systems, especially innovations with regard to the surface microtopography and chemistry, have resulted in higher survival rates of short implants (Hagi et al. 2004, Renouard & Nisand 2006, Kotsovillis et al. 2009, Romeo et al. 2010). Nowadays, there is considerable interest in whether nanometer-sized irregularities on the implant surface affect the bone response as it already has been shown that implant surface roughness on a micrometer level does influence cell and tissue response (Shalabi et al. 2006, Lang & Jepsen 2009, Wennerberg & Albrektsson 2009a,b). In 2008, Meirelles et al. reported a study in which they developed an experiment in which microroughness was controlled and demonstrated that nanometer-sized hydroxyapatite particles (10 nm) on the implant surface indeed resulted in a stronger bone response. Furthermore, it was shown that nanoroughness and calcium phosphate (CaP) particles on implant surfaces also were accompanied by earlier peri-implant bone formation, presumably related to increased activation of platelets (Park et al. 2001, Kikuchi et al. 2005, Arvidsson et al. 2007, Mendes et al. 2007). It has been postulated that these platelets may play an initiating role in the process called contact osteogenesis; activated platelets stimulate osteogenetic cells to migrate to the surface

of the implant. On the implant surface, these osteogenic cells differentiate into osteoblasts and start depositing new bone (Davies 2003, 2007). Therefore, it has been postulated that especially in more challenging implants cases, as short implants placed in poor quality bone, this acceleration of early peri-implant bone healing might result in higher survival rates. Indeed, histological and histomorphometric human studies on implants with nanometer-sized deposition of CaP on their surface showed acceleration of early peri-implant bone healing (Goené et al. 2007, Orsini et al. 2007, Telleman et al. 2010).

Another new development in the implant design on the macrolevel is the concept of platform switching, i.e., placing a smaller-diameter abutment on a wider-diameter implant. The mismatch between implant and abutment creates a circumferential horizontal difference in dimension between the implant and the abutment restorative platform. Early results of platform-switched implants showed radiographically no loss of crestal bone levels, contrary to standard platform-matched implants (Wagenberg & Froum 2010). Several hypotheses have been posed to explain the rationale behind the concept of platform switching for marginal bone preservation. The biomechanical hypothesis is that by platform switching the stress-concentration zone (from the forces of occlusal loading) is directed from the crestal bone-implant interface to the axis of the implant and so greatly reduces the stress level in the cervical bone area (Maeda et al. 2007). Other studies showed that placing the implant-abutment connection below the crestal bone level may cause vertical bone resorption to re-establish the biologic width (Hermann et al. 2001, Cochran et al. 2009). Following this theory, platform switching medializes the microgap between implant and abutment and the location the biologic width. Another hypothesis concerned the role of inflammatory cell infiltrate at the implant-abutment connection. The presence of peri-implant microbiota was suggested to influence marginal bone loss by maintaining the inflammatory cell infiltrate within the implant-abutment connection (Ericsson et al. 1995, 1996, Broggini et al. 2006).
As was reported in the review on short implants (Telleman et al. 2011a), the survival rates are not yet optimal of the shortest implants, implants placed in the maxilla or implants placed in patients with a smoking habit. The nanorough surface and the concept of platform switching might lead to higher survival rates and less marginal bone loss. To our knowledge, no study has been reported about the effect of nanoroughness through the deposition of nanometer-sized CaP particles on the survival rates of short implants and the effect of platform switching on marginal bone-level changes around short implants placed in the posterior region of partially dentate patients. Therefore, the aim of this study was to compare the outcome of short nanorough implants (8.5 mm in length), provided with either a platform-matched implant-abutment connection or a platform-switched implant-abutment connection, placed in the resorbed posterior region of partially edentulous patients.

Materials and methods

Patients
Partially edentulous patients referred to the Department of Oral and Maxillofacial Surgery of the University Medical Center Groningen for implant therapy in the posterior region, were considered for inclusion if they fulfilled the following criteria:
- at least 18 years of age;
- capable of understanding and giving informed consent;
- one or more missing teeth being a premolar and/or molar in the maxilla or mandible;
- at the place of the future implant a maximum of 10 mm bone in vertical dimension and minimum of 5 mm in horizontal dimension available.

Exclusion criteria were as follows:
- medical and/or general contraindications for the surgical procedures (ASA score ≥ III (Smeets et al. 1998));
- presence of active clinical periodontal disease in the dentition as expressed by probing pocket depths ≥5 mm and bleeding on probing;
- presence of peri-apical lesions or any other abnormalities or infections at the implant site as determined on a radiograph;
- smoking;
- a history of radiotherapy to the head and neck region.

Study Design
This randomized clinical trial was approved by the Medical Ethical Committee of the University Medical Center Groningen. Before enrolment, written and verbal information was given to the patients and written informed consent was obtained.
Two different implant-abutment connections were studied. The platform-switched implants (NanoTite Certain Prevail, Biomet 3i, Palm Beach Gardens, FL, USA) used in the test group had a horizontal implant-abutment diameter difference of 0.35 mm and 0.40 mm (for implants with a diameter of 4 and 5 mm, respectively). In a vertical dimension, the implant-abutment connection lies 0.09 mm and 0.11 mm (for implants with a diameter of 4 and 5 mm, respectively) above the level of implant placement (figure 1a). The test implants were compared with the control implants (NanoTite XP Certain, Biomet 3i). The latter type of implants matches the platform-switched implants the most except for the implant-abutment connection (figure 1b). The implant types used, which both were made of the same titanium alloy, had a dual acid-etched (using hydrochloric and sulphuric acids) surface with a discrete crystalline deposition of nanometer-sized CaP particles. The CaP deposit on the dual acid-etched (DAE) implants did not form a confluent layer; the CaP particles (20-100 nm in size) are deposited in the peaks and valleys

of the DAE surface, and occupy approximately 50% of the surface. The average roughness of this surface is 0.5 μm, which is considered as minimally rough (Wennerberg & Albrektsson 2010). The developed surface area ratio, a measurement that provides information regarding surface enlargement if a given surface is flattened out, is 40% (Wennerberg & Albrektsson 2010). Both implant types (test and control) had an extended platform and all implants were 8.5 mm in length.

A specifically designed locked computer software program was used to randomly assign patients to one of the two study groups. Randomization by minimization (Altman 1991) was used to balance the possible prognostic variables between the two treatment groups. Minimization was used for the variables gender, age (≤50, >50 years), location of the implant site (maxilla, mandible), tooth or teeth to replace (premolar, molar, premolar & molar), and number of implants to be placed (1, 2 or more). The surgeon who inserted the implants was informed about the allocation result on the day of surgery, before implant surgery was started. The prosthodontist was informed about the allocation result before the impression of the healing abutment was made. Patients were not informed about the allocation result.

Interventions

All patients were treated at the Department of Oral and Maxillofacial Surgery of the University Medical Center Groningen. The implants were placed in healed sites, i.e., at least 3-4 months after tooth removal allowing the extraction site to have healed. Implants were placed and restored according to the protocol described in detail by Telleman et al. (2011b). Briefly, an incision was made on top of the alveolar crest and a surgical template was used. The

Figure 1a. Dental radiograph of a test implant (NanoTite Certain Prevail, Biomet 3i)

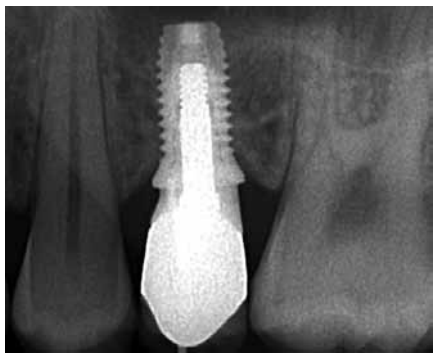
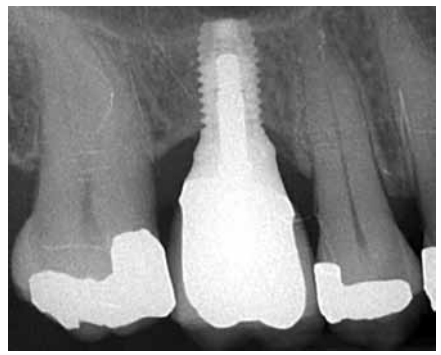


Figure 1b. Dental radiograph of a control implant (NanoTite XP Certain, Biomet 3i)



implant shoulder was placed at bone level, both mesial and distal even with the alveolar crest, if necessary the bone was flattened. The distance between the implant and the neighbouring teeth was at least 1.5 mm, the distance between two implants was at least 3 mm. On this implant, a coded healing abutment (Encode®, Biomet 3i) with a height of 4 mm was placed to develop an emergence profile. Next, if any, implant dehiscences or fenestrations at the buccal side of the implant were covered with autogenous bone chips collected during implant bed preparation and anorganic bovine bone (Bio-oss®, Geistlich Pharma AG, Wolhusen, Switzerland) overlaid with a collagen membrane (Bio-Gide®, Geistlich Pharma AG). Finally, the wound was closed with sutures (Vicryl 3-0, Johnson & Johnson, Brunswick, NJ, USA). Two weeks following implant surgery the sutures were removed. Three months after implant placement, seating of the healing abutment was evaluated and impressions were made. The healing abutment was scanned from the cast and an individualized abutment was milled. The abutment was placed with 20 Ncm and the metal ceramic crown was cemented (GC Fuji 1, GC Europe NV, Leuven, Belgium).

A single experienced oral and maxillofacial surgeon performed all surgical procedures. Six experienced prosthodontics performed the prosthetic procedure. The individual cad-cam made abutments were made by the implant manufactory (Encode®, Biomet 3i).

Outcome measures

The primary outcome measure was the mean marginal bone-level change (mesial and distal sides combined) from the time of implant placement (baseline) to 1 year after placing the crown on the implant; which is 16 months after placing the implant (T_{16m}) as measured on standardized digital radiographs. Secondary outcome measures were implant survival, changes in marginal soft tissue level of the implant and the neighbouring teeth and patient's satisfaction. One and the same examiner performed all measurements. To assess the reliability of the radiographic examination, this examiner was assisted by a second examiner. The operationalization of the variables is described below.

Radiographic assessments

Before implant placement (T_{pre}), directly after implant placement (baseline or T_{0m}), 1 month after the placement of the implant crown, which is 5 months after placing the implant (T_{5m}) and one year after placing the implant crown, which is 16 months after placing the implant (T_{16m}), digital peri-apical radiographs (Planmeca Intra X-ray unit, Planmeca, Helsinki, Finland) were taken using a paralleling technique. For each patient an individualized X-ray holder was made to standardize the peri-apical radiographs. The radiograph taken before implant placement was only used for diagnostic reasons to detect any infection of abnormality. The radiographs were analysed using specially designed computer software to perform linear measurements on the digital

radiographs (in cooperation with the Department of Biomedical Engineering, University Medical Center Groningen, The Netherlands). The calibration was carried out in the vertical plane for each radiograph, by using the known distance of several threads. This calibration ensured a correct measurement (Sewerin 1990). To assess the reliability of the radiographic examination 30 radiographs of 20 patients (10 from each study group) were assessed by two examiners. The interobserver agreement was tested on 120 measurements (30 radiographs × 20 patients × 2 (mesial, distal) bone level assessments) of the first examiner and 120 measurements of the second examiner.

Clinical assessments

Preoperatively (T_{pre}), 1 month (T_{5m}) and 1 year (T_{16m}) after the placement of the implant crowns, the soft tissue around the implants and their neighbouring teeth were clinically examined using the following clinical parameters:

- Assessment of plaque accumulation with the modified Plaque Index (Mombelli et al. 1987);
- Assessment of bleeding tendency with the modified Sulcus Bleeding Index (Mombelli et al. 1987);
- Assessment of peri-implant inflammation with the Gingival Index (Loë & Silness 1963);
- Presence of dental calculus;
- Sulcus probing pocket depth: measured to the nearest millimetre using a manual periodontal probe (Williams Color-Coded Probe; Hu-Friedy, Chicago, IL, USA).

Before the incision was made, the mucosa thickness was assessed by applying a periodontal probe through the mucosa at the spot where the implant would be placed.

Microbiological assessments

To analyse the composition of the subgingival plaque, preoperatively an anaerobic culture test was conducted. In each quadrant of the dentition the deepest pocket was selected for microbiological sampling. After gentle air-drying, two consecutive sterile paper points were inserted to the depth of the pockets and left in place for 10 seconds. Paper points from all four selected periodontal sites were pooled in 2.0 ml of reduced transport fluid (RTF) (Syed & Loesche 1972). The presence and proportions of Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis, Prevotella intermedia, Bacteroides forsythus, Peptostreptococcus micros, Fusobacterium nucleatum and Campylobacter rectus were assessed. The analyses were performed by the laboratory of the department Oral Microbiology (UMCG, the Netherlands) as described in the study of Heydenrijk et al. (2002).

Patient's satisfaction

Patient's satisfaction was assessed using a self-administered questionnaire to be completed at T_{pre} and T_{5m}. The questionnaire compromised of questions or statements that could be answered on a five-point rating scale ranging from "very dissatisfied" and "not in agreement" (score 1) to "very satisfied" and "in agreement" (score 5). Topics were aesthetics, function and treatment procedure. Furthermore, patients were asked to mark their overall satisfaction about their mouth in which they missed teeth, which were replaced by implants, at T_{pre} and T_{5m} on 10-point rating scale from 0 to 10, in which 10 is the highest score.

Statistical analysis

Sample size was calculated using G*power version 3.1 (Faul et al. 2009). As there were no data in the literature of the mean marginal bone loss of short control implants with the platform-matched implant-abutment connection, it was assumed that a mean marginal bone loss of 1.0 ± 0.5 mm would occur, from implant placement to 16 months thereafter, as the maximum marginal bone loss is seen up to 1.5 mm to the first implant thread. We considered 0.5 mm of radiographic marginal bone loss as a relevant difference between study groups, with an expected standard deviation of 0.75 mm. With a one-sided significance level of 5% and a power of 95%, a minimum of 36 patients per group was required, if one implant per patient was placed. A total of 72 patients for both groups would be needed; the total number of patients was set to at least 80 to deal with withdrawal.

To assess the interobserver agreement for the continuous variables of the marginal bone-level changes (scored on peri-apical radiographs) two-way random models were used to calculate the intraclass correlation coefficient.

To see whether the data were normally distributed the frequency distribution was plotted in a histogram. To test whether the result from the frequency analyses differed significantly from a normal distribution Kolmogorov-Smirnov and Shapiro-Wilk tests were done. For between groups comparisons of normally distributed variables, *t*-tests were used. Variables that were not normally distributed were statistically explored using Mann-Whitney tests.

Fisher's exact test was used to assess whether there was a difference in implant survival rate. Pearson's correlation coefficients were used to assess whether the observed marginal bone loss was dependent on the possible confounders implant location, implant diameter, result of the microbiological culture, mucosal thickness before placement and type of bone (Lekholm & Zarb 1985). Wilcoxon signed-rank tests were used for changes in patient's satisfaction before and after the implant treatment.

In all analyses, a significance level of $p<0.05$ was chosen. Data were analysed using the Statistical Package for Social Sciences (version 16.0, SPSS Inc., Chicago, IL, USA).

Table 1. Baseline characteristics of the patients

Variable	Platform-matched implant-abutment connection (control group; n=47)	Platform-switched implant-abutment connection (test group; n=45)
Mean age ± SD and range (years):		
	50.2 ± 13.0 (18-70)	51.0 ± 10.4 (21-67)
Female/male ratio:		
	39/8	38/7
Implant position:		
Maxillary ($P_1/P_2/M_1/M_2$)	31 (5/9/14/3)	31 (5/9/14/3)
Mandibular ($P_1/P_2/M_1/M_2$)	45 (4/17/19/5)	42 (2/15/20/5)
Number of implants to be placed in a patient:		
1	20	19
≥2	27	26
Implant diameter:		
4.1 mm	60	52
5.0 mm	16	21
Microbiology (before implant placement):		
Within normal range	19	16
Aggregatibacter actinomycetemcomitans>0.0%	1	1
Porphyromonas gingivalis >0.0%	0	1
Prevotella intermedia >2.5%	1	1
Bacteroides forsythus >3.0%	1	0
Peptostreptococcus micros >3.0%	7	4
Fusobacterium nucleatum >3.0%	6	5
Combination of bacteria out of normal range	5	10
Culture non-conclusive	7	7
Cause of tooth loss:		
Persistent apical periodontitis	17	13
Combined periodontic-endodontic lesion	1	0
Periodontal disease	7	7
Fracture	4	6
Dental caries	10	9
Congenitally missing tooth	4	3
Unknown	3	4
Mucosal thickness at the implant site before placement (%):		
1 mm	0.0	0
2 mm	41.0	44.1
3 mm	47.5	47.5
4 mm	11.5	3.4
>4 mm	0.0	5.1
Bone type (Lekholm & Zarb, 1985):		
1	0.0	0.0
2	40.0	22.9
3	42.5	62.9
4	17.5	14.3
Implant dehiscence or fenestration:		
	2	1

Results

Patients

Between February 2006 and December 2009, a total of 92 (47 control group, 45 test group) patients were included in this trial. Baseline patients and treatment characteristics are listed in table 1. There was 1 dropout; a patient did not react on any kind of communication to invite the patient for follow-up; thus data from 91 patients were available for the intention-to-treat analysis.

Marginal bone-level changes

The intraclass correlation coefficient for average measures was 0.87 for the radiographic interobserver agreement (Cronbach's Alpha=0.87), which can be interpreted as almost perfect agreement (Viera & Garrett 2005).
Figure 2 shows the frequency distributions of the mean marginal bone loss of the control group with the platform-matched implant-abutment connection and the test group with the platform-switched implants. Overall, mean marginal bone loss was significantly less around platform-switched implants than around implants with platform-matched implant-abutments connections, both 1 month and 1 year after placing the crown (table 2). However, when comparing marginal bone loss in cases provided with one implant no difference is marginal bone loss was observed, while when 2 or more adjacent platform-switched implants were placed bone loss was significantly less comparing to platform-matched implants, 1 month and 1 year after placing the crown (table 2).

Implant survival

Six of 76 implants in the control group (platform-matched; implant survival rate 92.1%) were lost; 3 implants before loading and 3 implants 1-6 months after loading. Three of 73 implants in the test group (platform-switched implant-abutment connection; implant survival rate 95.9%) were lost; all 3 implants were lost before loading. The difference was not significant (p=0.33).

Clinical outcome

The mean probing pocket depth around the implants did not significantly increase between T_{5m} and T_{16m} (table 2). Also no between-group differences in clinical parameters plaque accumulation, bleeding tendency, gingiva index (table 3) were observed.

Confounders

Compared with bone loss around single implants, marginal bone loss was found to be significant (p=0.001) higher when two ore more adjacent implants were placed. The thought confounders implant location, implant diameter, microbiological status, mucosal thickness and type of bone apparently played no significant role.

Patient's satisfaction

Feelings of shame and of visibility of being partial edentulous clearly decreased as well as that patient's self-confidence increased (table 4). Patients were especially satisfied about their increased ability to chew, and about the colour and the form of the crown. No differences were observed between the groups.

Discussion

This randomized clinical trial showed that 16 months after implant placement, marginal bone loss was significantly less around short implants provided with a platform-switched implant-abutment connection, while with regard to implant survival, clinical parameters and patient's satisfaction both implant-abutment connections showed similar favourable results. A difference of 0.24 mm in radiographic bone preservation might not be clinical relevant, but a reduction in bone resorption of 33% is interesting, striving for perfection. The marginal bone loss around platform-switched implants resembled the marginal bone loss as reported in the systematic review and meta-analysis of Atieh et al. (2010) on longer implants. In the control group two patients had a dehiscence and in the test group one patient had a dehiscence, which were in need of GBR. No effect was shown when leaving these implants out of statistical analysis of marginal bone loss, so, also these implants were included in the analyis.

Besides, Atieh et al. (2010) also did not detect a statistically significant difference in implant survival between the two platform designs. Implant survival rates were lower than the survival rates reported for 8.5 mm implants (98.8%; 95% CI: 98.2-99.6%) in the systematic review of Telleman et al. (2011a). A reason for the lower survival rates in the study could be the number of implants placed in the maxilla as one of the conclusions of the review to short implants was that the failure rate of studies performed in the maxilla was 0.010 implants/year compared with 0.003 in the mandible. Another reason might be due to the fact that in the systematic review, also results of studies were included in which short implants could be splinted to longer implants. And a reason could be that the implants used had an extended platform for which the use of countersink was needed for implant placement, this might have led to less initial implant stability (Renouard & Nisand 2006).

The platform-switched implants applied in our trial had an implant-abutment diameter difference in horizontal dimension between 0.35 mm (implant diameter 4 mm) and 0.40 mm (implant diameter 5 mm). Atieh et al. (2010) reported that subgroup analyses showed that an implant-abutment difference ≥0.4 mm was associated with less marginal bone loss ($MD_{(\geq 0.4)}$: -0.50; 95% CI:-0.72 to -0.29 in comparing to $MD_{(< 0.4)}$: -0.10; 95% CI:-0.35 to 0.15). A bigger mismatch is often caused, as in the current study, by the use of a wider diameter. It has been speculated that the findings of reduced bone loss accompanying a

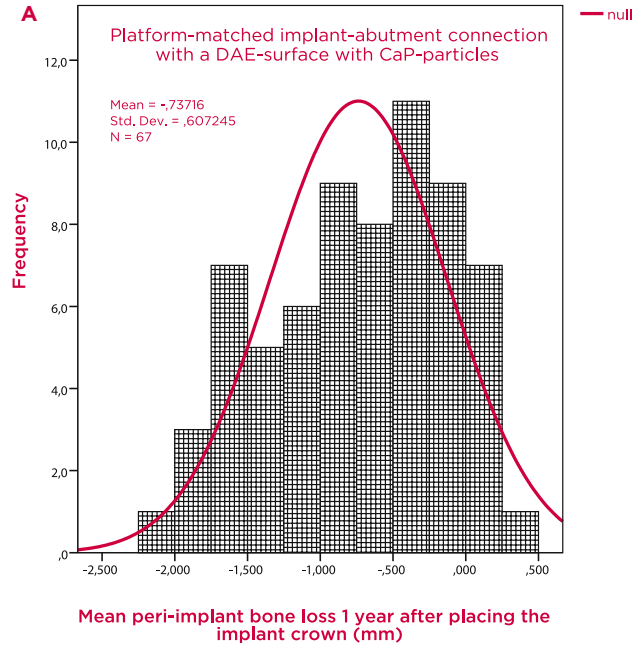


Figure 2. Frequency distributions of the mean marginal bone loss of the 67 control (A) and 70 test (B) implants supplied. Both distributions differ significantly from a normal distribution and show a negative kurtosis. (control implants: $D(67)=0.100$, $p=0.091$, $W(67)=0.950$, $p=0.009$; test implants: $D(70)=0.130$, $p=0.005$, $W(70)=0.899$, $p=0.000$).

Table 2. Changes in marginal bone level and pocket probing depths at implant and tooth sides from baseline to 16 months. Negative results in marginal bone-level changes indicate marginal bone loss and positive results in pocket probing depth changes indicate enlarged peri-implant pockets.

All implants	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=73)	Platform-switched (n=70)	Platform-matched (n=70)	Platform-switched (n=70)	Platform-matched (n=70)	Platform-switched (n=70)
Marginal bone-level changes (mm)	**-0.76**[*] (±0.60)	**-0.51**[*] (±0.56)	**0.03** (±0.30)	**0.02** (±0.30)	**-0.74**[§] (±0.61)	**-0.50**[§] (±0.53)
1 implant	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=18)	Platform-switched (n=19)	Platform-matched (n=15)	Platform-switched (n=19)	Platform-matched (n=15)	Platform-switched (n=19)
Marginal bone-level changes (mm)	**-0.42** (±0.56)	**-0.41** (±0.52)	**-0.02** (±0.24)	**0.05** (±0.26)	**-0.36** (±0.53)	**-0.36** (±0.43)
Pocket probing depth changes (mm)						
Implant	Not available	Not available	**-0.10** (±1.17)	**-0.09** (±0.66)	**-0.10** (±1.17)	**-0.09** (±0.66)
Tooth mesially of the implant	**0.06** (±0.53)	**0.07** (±0.40)	**-0.02** (±0.52)	**0.00** (±0.29)	**0.06** (±0.48)	**0.07** (±0.33)
Tooth distally of the implant	**-0.40** (±0.46)	**0.17** (±0.88)	**0.27** (±0.54)	**-0.13** (±0.65)	**-0.11** (±0.50)	**0.03** (±0.52)
2 or more implants	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=55)	Platform-switched (n=51)	Platform-matched (n=55)	Platform-switched (n=51)	Platform-matched (n=55)	Platform-switched (n=51)
Marginal bone-level changes (mm)	**-0.85**[♯] (±0.58)	**-0.56**[♯] (±0.57)	**0.05** (±0.31)	**0.01** (±0.31)	**-0.82**[†] (±0.60)	**-0.55**[†] (±0.56)
Pocket probing depth changes (mm)						
Implant	Not available	Not available	**-0.24** (±0.62)	**-0.28** (±0.60)	**-0.24** (±0.62)	**-0.28** (±0.60)
Tooth mesially of the implant	**0.08** (±0.54)	**0.04** (±0.58)	**-0.08** (±0.54)	**-0.16** (±0.51)	**0.00** (±0.44)	**-0.17** (±0.68)
Tooth distally of the implant	**-0.50** (±0.66)	**-0.46** (±0.33)	**-0.75** (±0.79)	**-0.28** (±0.56)	**-0.50** (±0.79)	**-0.50** (±0.47)

For between groups comparisons: * p=0.005, [§] p=0.0017, [♯] p=0.003, [†] p=0.015
Abbreviation: n=number of implants

Table 3. Clinical parameters of implants and adjacent teeth. No significant differences were found between control (platform-matched) and test (platform-switched) group before (T_{0m}), 1 month (T_{5m}) and 1 year (T_{16m}) in function.

Clinical parameters	% at T_{0m}		% at T_{5m}		% at T_{16m}	
	Platform-matched (n=76)	Platform-switched (n=73)	Platform-matched (n=73)	Platform-switched (n=70)	Platform-matched (n=70)	Platform-switched (n=70)
Implant Plaque Index [1]						
score 0, no detection of plaque	-	-	89.6	88.6	78.8	73.9
score 1, plaque on probe	-	-	10.4	11.4	13.6	20.3
score 2, plaque seen by naked eye	-	-	0	0	7.6	5.8
score 3, abundance of soft matter	-	-	0	0	0	0
Implant Bleeding Index[1]						
score 0, no bleeding	-	-	70.1	68.1	69.7	64.7
score 1, isolated bleeding spots	-	-	29.9	30.4	27.3	33.8
score 2, confluent line of blood	-	-	0	1.4	3	1.5
score 3, heavy or profuse bleeding	-	-	0	0	0	0
Implant Gingival Index[2]						
score 0, normal mucosa	-	-	94.0	92.8	90.9	95.7
score 1, mild inflammation	-	-	6.0	7.2	9.1	4.3
score 2, moderate inflammation	-	-	0	0	0	0
score 3, severe inflammation	-	-	0	0	0	0
Implant dental calculus						
score 0, no dental calculus	-	-	100	100	100	100
score 1, dental calculus present	-	-	0	0	0	0
Adjacent teeth Plaque index[1]						
score 0, no detection of plaque	69.9	58.0	82.5	84.8	91.1	86.8
score 1, plaque on probe	28.8	37.7	15.8	15.2	8.9	11.8
score 2, plaque seen by naked eye	1.4	4.3	1.8	0	0.0	1.5
score 3, abundance of soft matter	0	0	0	0	0	0
Adjacent teeth Bleeding index[1]						
score 0, no bleeding	78.1	77.1	86.0	86.6	98.2	91.3
score 1, isolated bleeding spots	20.5	21.4	14.0	13.4	1.8	8.7
score 2, confluent line of blood	1.4	1.4	0	0	0	0
score 3, heavy or profuse bleeding	0	0	0	0	0	0
Adjacent teeth Gingival Index[2]						
score 0, normal mucosa	97.3	91.4	100	97.0	100	100
score 1, mild inflammation	2.7	8.6	0	3.0	0	0
score 2, moderate inflammation	0	0	0	0	0	0
score 3, severe inflammation	0	0	0	0	0	0
Adjacent teeth dental calculus						
score 0, no dental calculus	93.2	88.6	93.0	92.5	94.6	97.1
score 1, dental calculus present	6.8	11.4	7.0	7.5	5.4	2.9

[1] (Mombelli et al. 1987) [2] (Loë & Silness, 1963)
Abbreviation: n=number of implants

Table 4. Patient's satisfaction.

	T_{pre} % in agreement		T_{5m} % in agreement	
	Platform-matched (n=47)	Platform-switched (n=45)	Platform-matched (n=41)	Platform-switched (n=42)
Feelings				
presence of shame	50.0	42.3	0*	0*
self-confidence decreased	26.1	33.4	0*	0*
self-confidence increased	2.2	0	52.5*	47.8*
visible being partial edentulous	56.6	64.5	0*	0*
Function				
evade eating with the edentulous zone/implant	67.4	68.9	2.5*	2.3*
the ability to chew is decreased	67.4	71.1	12.5*	13.6*
the ability to chew is increased	6.5	0	85.0*	70.4*
implant does influence the speech	-	-	5.0	6.8
implant does influence the taste	-	-	2.5	2.3
Aesthetics				
satisfied with the colour of the crown	-	-	81.3	89.1
satisfied with the form of the crown	-	-	80.0	86.4
satisfied with the colour of the mucosa around the crown	-	-	71.9	75.6
satisfied with the form of the mucosa around the crown	-	-	56.2	70.2
Overall satisfaction (0-10)	**4.9 ± 1.7**	**4.6 ± 1.9**	**8.9 ± 1.0***	**8.7 ± 1.2***

significantly improved compared with pretreatment values (p=0.000)
Abbreviation: n=number of patients

larger implant-abutment difference may be due to an increased implant diameter rather than to the platform (Enkling et al. 2011). But the study of Canullo et al. (2011) on the impact of implant diameter of platform-switched implants clearly concluded no relation to bone resorption. This difference could not be found in the current RCT. Atieh et al. (2010), however, did not consider the vertical dimension of the platform-switched implant-abutment connection design, as most implant systems have only a diameter difference in horizontal dimension, resulting in a 90° angle between implant and abutment. In the platform-switched implants we used the implant-abutment connection that lies 0.09 mm (implant diameter 4 mm) and 0.11 mm (implant diameter 5 mm) above the outermost margin of the collar of the implant. So when the platform-switched implants are placed at crestal bone level the implant-abutment connection is slighty higher. From the study of Cochran et al. (2009) we know that the least bone resorption was shown with the platform-switch situated 1 mm above the alveolar crest. So, the design of our platform-switched implants in vertical dimension might have contributed to the favourable results. Conversely, Veis et al. (2010) reported the least bone resorption when implants were placed subcrestally. Obviously from these contrasting results, more comparative studies to the different designs (in horizontal and vertical dimension) and level of placement of platform-switched implants are needed.

It is clear from the current results that the nanometer-sized deposition of CaP on the DAE surface seems not to have an added value on the survival rate of short implants (8.5 mm in length) in the posterior zone. Some in vivo animal studies found significant more bone response to surfaces with particles of hydroxyapatite or CaP of different nanosizes after 2 to 4 weeks (Meirelles et al. 2008b, Lin et al. 2009, Jimbo et al. 2011). But other animal studies of maximum 6 weeks up to 3 months found no evidence of better bone responses (Schliephake et al. 2009, Vignoletti et al. 2009, Schouten et al. 2010, Schwarz et al. 2010, Svanborg et al. 2010). Human histologic and histomorphometric studies of mini-implants placed in the posterior maxilla found after 4 weeks to 2 months showed significant more bone-to-implant contact and bone volume on the surface with the nanoparticles CaP (Goené et al. 2007, Orsini et al. 2007). One study found after 3 months more old bone particles on dual acid-etched surface with the nanoparticles CaP as if a more active osteogenesis process was going on, which accelerates the osseointegration process (Telleman et al. 2010). Two prospective clinical studies were reported on implants with a dual acid-etched surface with nanoparticles CaP (Östman et al. 2010a,b). They concluded that the nanoroughned surface performed comparatively well to other surfaces.

Overall patient's satisfaction was high in both groups. But this study was not powered to do a subgroup analysis on patient's satisfaction, thus no definite conclusion could be drawn. It is striking to see that even in the posterior zone patients experience feelings of shame of being partially edentulous, because the patients have the feeling that other people can see they are missing a tooth or teeth. With replacing this missing tooth or teeth it was obvious that their self-confidence increased. This psychological distress was also reported by the quality of life report in partially edentulous patients by Nickenig et al. (2008), who revealed 24.2% dissatisfaction with appearance preoperative versus 2.3% postoperative. Patients were especially satisfied about the ability to chew, the colour and the form of the crown and more indifferent about the colour and form of the mucosa, as in the posterior region it is often quite difficult to see the mucosa around the crown.

In conclusion, for teeth replacements in the resorbed posterior region of partially dentate patients, short implants (8.5 mm in length) with a platform-switched implant-abutment connection showed significantly less marginal bone loss after 1 year in function, while implant survival, clinical parameters and patient's satisfaction were independent of the implant-abutment connection design.

References

Altman, D. G. (1991) Clinical trials. *Practical Statistics for Medical Research,* 1st edition, pp. 443-445. London: Chapmann & Hall.

Arvidsson, A., Franke-Stenport, V., Andersson, M., Kjellin, P., Sul, Y. T. & Wennerberg, A. (2007) Formation of calcium phosphates on titanium implants with four different bioactive surface preparations. An in vitro study. *Journals of Materials Science: Materials in Medicine* 18, 1945-1954.

Atieh, M. A., Ibrahim, H. M. & Atieh, A. H. (2010) Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis. *Journal of Periodontololgy* 81, 1350-1366.

Broggini, N., McManus, L. M., Hermann, J. S., Medina, R., Schenk, R.K., Buser, D. & Cochran, D. L. (2006) Peri-implant inflammation defined by the implant-abutment interface. *Journal of Dental Research* 85, 473-478.

Canullo, L., Iannello, G., Penarocha, M. & Garcia, B. (2011) Impact of implant diameter on bone level changes around platform switched implants: preliminary results of 18 months follow-up a prospective randomized match-paired controlled trial. *Clinical Oral Implants Research* 24, epub ahead of print.

Cochran, D. L., Bosshardt, D. D., Grize, L., Higginbottom, F. L., Jones, A. A., Jung, R. E., Wieland, M. & Dard, M. (2009) Bone response to loaded implants with non-matching implant-abutment diameters in the canine mandible. *Journal of Periodontology* 80, 609-617.

Davies, J. E. (2003) Understanding peri-implant endosseous healing. *Journal of Dental Education* 67, 932-949.

Davies, J. E. (2007) Bone bonding at natural and biomaterial surfaces. *Biomaterials* 28, 5058-5067.

Enkling, N., Jöhren, P., Klimberg, V., Bayer, S., Mericske-Stern, R. & Jepsen, S. (2011) Effect of platform switching on peri-implant levels: a randomized clinical trial. *Clinical Oral Implants Research* 22, 1185-1192.

Ericsson, I., Persson, L. G., Berglundh, T., Marinello, C. P., Lindhe, J. & Klinge, B. (1995) Different types of inflammatory reactions in peri-implant soft tissues. *Journal of Clinical Periodontology* 22, 255-261.

Ericsson, I., Nilner, K., Klinge, B. & Glantz, P.O. (1996) Radiographical and histological characteristics of submerged and non-submerged titanium implants. An experimental study in the Labrador dog. *Clinical Oral Implants Research* 7, 20-26.

Esposito, M., Grusovin, M. G., Felice, P., Karatzopoulos, G., Worthington, H. V. & Coulthard, P. (2009) Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. *Cochrane database Systematic Review* 7, CD003607.

Esposito, M., Grusovin, M. G., Rees, J., Karasoulos, D., Felice, P., Alissa, R. Worthington, H. V. & Coulthard, P. (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. *Cochrane database Systematic Review* 17, CD008397.

Faul, F., Erdfekder, E., Buchner, A. & Lang, A. G. (2009) Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behavior Research Methods* 41, 1149-1160.

Goené, R. J., Testori, T. & Trisi, P. (2007) Influence of a nanometer-scale surface enhancement on de novo bone formation on titanium implants: a histomorphometric study in human maxillae. *The International Journal Periodontics & Restorative Dentistry* 27, 211-219.

Hagi, D., Deporter, D. A., Pilliar, R. M. & Arenovich T. (2004) A targeted review of study outcomes with short (≤7 mm) endosseous dental implants in partially edentulous patients. *Journal of Periodontology* 75, 798-804.

Heydenrijk, K., Raghoebar, G. M., Meijer, H. J. A., van der Reijden, W., van Winkelhoff, A-J. & Stegenga, B. (2002) Two-part implants inserted in a one-stage or a two-stage procedure. A prospective comparative study. *Journal of Clinical Periodontology* 29, 901-909.

Hermann, J. S., Buser, D., Schenk, R. K., Schoolfield, J. D. & Cochran, D.L. (2001) Biologic width around one-and two- piece titanium implants. *Clinical Oral Implants Research* 12, 559-571.

Jimbo, R., Coelho, P. G., Vandeweghe, S., Schwartz-Filho, H. O., Hayashi M., Ono D., Andersson, M. & Wennerberg, A. (2011) Histological and three-dimensional evaluation of osseointegration into nanostructured calcium phosphate-coated implants. *Acta Biomaterialia* 7, 4229-4234.

Kikuchi, L., Park, J. Y., Victor, C. & Davies, J. E. (2005) Platelet interactions with calcium-phosphate-coated surfaces. *Biomaterials* 26, 5285-5295.

Kotsovilis, S., Fourmousis, I., Karoussis, I. K. & Bamia, C. (2009) A systematic review and meta-analysis on the effect of implant length on the survival of rough-surface dental implants. *Journal of Periodontology* 80,1700-1718.

Lang, N. P. & Jepsen, S. (2009) Implant surfaces and design. *Clinical Oral Implants Research* 20, 228-231.

Lee, J. H., Frias, V., Lee, K. W. & Wright, R.F. (2005) Effect of implant size and shape on implant success rates: A literature review. *The Journal of Prosthetic Dentistry* 94, 377-381.

Lekholm, U. & Zarb, G. A. (1985) Patient selection and preparation. In: Bränemark, P. I., Zarb G. A. & Albrektsson, T. (eds). *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*, 1st edition, pp. 199-209. Chicago: Quintessence Publishing.

Lin, A., Wang, C. J., Kelly, J., Gubbi, P. & Nishimura, I. (2009) The role of titanium implant surface modification with hydroxyapatite nanoparticles in progressive early bone-implant fixation in vibo. *The International Journal of Oral & Maxillofacial Implants* 24, 808-816.

Löe, H. & Silness, J. (1963) Periodontal disease in pregnancy. I. Prevalence and severity. *Acta Odontologica Scandinavica* 21, 533-551.

Maeda, Y., Miura, J., Taki, I. & Sogo, M. (2007) Biomechanical analysis on platform switching: Is there any biomechanical rationale? *Clinical Oral Implants Research* 18, 581-584

Meirelles, L., Albrektsson, T., Kjellin, P., Arvidsson, A., Franke-Stenport V., Andersson, M., Currie, F. & Wennerberg A. (2008a) Bone reaction to nano hydroxyapatite modified titanium implants placed in a gap-healing model. *Journal of Biomedical Materials Research. Part A.* 87, 624-631.

Meirelles, L., Arvidsson, A., Andersson, M., Kjellin, P., Albrektsson, T. & Wennerberg A. (2008b) Nano hydroxyapatite structures influence early bone formation. *Journal of Biomedical Materials Research. Part A.* 87, 299-307.

Mendes, V. C., Moineddin, R. & Davies, J. E. (2007) The effect of discrete calcium phosphate nanocrystals on bone-bonding to titanium surfaces. *Biomaterials* 28, 4748-4755.

Mombelli, A., van Oosten, M. A. C., Schürch, E. & Lang N. P. (1987) The microbiota associ-

ated with successful or failing osseointegrated titanium implants. *Oral Microbiology and Immunology* 2, 145-151.

Nickenig, H. K., Wichmann, M., Andreas, S.K. & Eitner, S. (2008) Oral health-related quality of life in partially edentulous patients: Assessment before and after implant therapy. *Journal of Cranio-Maxillofacial Surgery* 36, 477-480.

Orsini, G., Piatelli, M., Scarano, A., Petrone, G., Kenealy, J., Piatelli, A. & Caputi, S. (2007) Randomized, controlled histologic and histomorphometric evaluation of implants with nanometer-scale calcium phosphate added to the dual acid-etched surface in the human posterior maxilla. *Journal of Periodontology* 78, 209-218.

Östman, P. O., Wennerberg, A. & Albrektsson, T. (2010a) Immediate occlusal loading of NanoTite™ PREVAIL® Implants: A prospective 1-year clinical and radiographic study. *Clinical Implant Dentistry & Related Research* 12, 39-47.

Östman, P. O., Hupalo, M., del Castillo, R., Emery, R. W., Cocchetto, R., Vincenzi, G., Wagenberg, B., Vanassche, B., Valentin, A., Clausen, G., Hogan, P., Goené, R., Evans, C. & Testori, T. (2010b) Immediate provisionalization of NanoTite implants in suppport of single-tooth and unilateral restorations: One-year interim report of a prospective, multicenter study. *Clinical Implant Dentistry & Related Research* 12, supplement s1, e47-e55.

Park, J. Y., Gemmell, C. H. & Davies, J.E. (2001) Platelet interactions with titanium: modulation of platelet activity by surface topography. *Biomaterials* 22, 2671-2682.

Renouard, F. & Nisand, D. (2006) Impact of length and diameter on survival rates. *Clinical Oral Implants Research* **17**, 35-51.

Romeo, E., Bivio, A., Mosca, D., Scanferla, M., Ghisolfi, M. & Storelli, S. (2010) The use of short dental implants in clinical practice: literature review. *Minerva Stomatologica* 59, 23-31.

Schliephake, H., Aref, A., Scharnweber, D., Rösler, S. & Sewing, A. (2009) Effect of modifications of dual acid-etched implant surfaces on periimplant bone formation. Part II: calcium phsphate coatings. *Clinical Oral Implants Research* 20, 38-44.

Schouten, C., Meijer, G. J., van den Beucken J. J. J. P., Leeuwenburgh, S.C.G., de Jonge, L. T., Wolke, J. G. C., Spauwen, P. H. M. & Jansen, J. A. (2010) In vivo bone response and mechanical evaluation of electrosprayed CaP nanoparticle coatings using the iliac crest of goats as an implantation model. *Acta Biomaterialia* 6, 2227-2236.

Schwarz, F., Sager, M., Kadelka, I., Ferrari, D. & Becker, J. (2010) Influence of titanium implant surface characteristics on bone regeneration in dehiscence-type defects: an experimental study in dogs. *Journal of Clinical Periodontology* 37, 466-473.

Sewerin, I. P. (1990) Errors in radiographic assessment of marginal bone height around osseointegrated implants. *Scandinavian Journal of Dental Research* 98, 428-433.

Shalabi, M. M., Gortemaker, A., van 't Hof, M. A., Jansen, J. A. & Creugers, N. H. J. (2006) Implant surface and bone healing: a systematic review. Journal of Dental Research 85, 496-500.

Smeets, E. C., de Jong, K. J. & Abraham-Inpijn, L. (1998) Detecting the medically compromised patient in dentistry by means of the medical risk-related history. A survey of 29,424 dental patients in the Netherlands. *Preventive Medicine* 27, 530-535.

Svanborg, L. M., Hoffman, M., Andersson, M., Currie, F., Kjellin, P. & Wennerberg, A. (2010) The effect of hydroxyapatite nanocrystals on early bone formation surrounding dental implants. *International Journal of Oral & Maxillofacial Surgery* 40, 308-315.

Syed, S. A. & Loesche, W. J. (1972) Survival of human dental plaque flora in various transport media. *Applied Microbiology* 24, 638-644.

Telleman, G., Albrektsson, T., Hoffman, M., Johansson, C. B., Vissink, A., Meijer, H. J. A. & Raghoebar, G. M. (2010) Peri-implant endosseous healing properties of dual acid-etched mini-implants with a nanometer-sized deposition of CaP: a histological and histomorphometric human study. *Clinical Implant Dentistry & Related Research* 12, 153-160.

Telleman, G., Raghoebar, G. M., Vissink, A., den Hartog, L., Huddleston Slater, J. J. & Meijer, H. J. A. (2011a) A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. *Journal of Clinical Periodontology* 38, 667-676.

Telleman, G., Raghoebar, G. M., Vissink, A. & Meijer H. J. A. (2011b) The use of a coded healing abutment as an impression coping to design and mill an individualized anatomic abutment: A clinical report. *Journal of Prosthetic Dentistry* 105, 282-285.

Veis, A., Parissis, N., Tsirlis, A., Papadeli, C., Marinis, G. & Zogakis, A. (2010) Evaluation of peri-implant marginal bone loss using modified abutment connections at various crestal level placements. *The International Journal of Periodontics & Restorative Dentistry* 30, 609-617.

Viera, A. J. & Garrett, J. M. (2005) Understanding interobserver agreement: The kappa statistic. *Family Medicine* 37, 360-363.

Vignoletti, F., Johansson, C. B., Albrektsson, T., De Sanctis, M., San Roman, F. & Sanz, M. (2009) Early healing of implants placed into fresh extraction sockets: an experimental study in the beagle dog. De novo bone formation. *Journal of Clinical Periodontology* 36, 265-277.

Wagenberg, B. & Froum, S. J. (2010) Prospective study of 94 platform-switched implants observed from 1992 to 2006. *The International Journal of Periodontics & Restorative Dentistry* 30, 9-17.

Wennerberg, A. & Albrektsson, T. (2009a) Structural influence from calcium phosphate coatings and its possible effect on enhanced bone integration. *Acta Odontologica Scandinavica* 67, 333-340.

Wennerberg, A. & Albrektsson, T. (2009b) Effects of titanium surface topography on bone integration: a systematic review. *Clinical Oral Implants Research* 20, 172-184,

Wennerberg, A. & Albrektsson, T. (2010) On Implant surfaces: A review of current knowledge and opinions. *The International Journal of Oral & Maxillofacial Implants* 25, 63-74.

This chapter is an edited version of the manuscript: Telleman, G., Raghoebar, G. M., Vissink, A. & Meijer, H. J. A. (2012). Impact of platform switching on peri-implant bone remodelling around short implants in the posterior region, 1-year results from a split-mouth clinical trial. Clinical Implant Dentistry and Related Research doi: 10.1111/j.1708-8208.2012.00461.x. (Epub ahead of print).

Chapter 6

Impact of platform switching on marginal bone levels around short implants in the posterior region: 1-year results from a split-mouth clinical trial

Abstract

Aim: To assess the effect of platform switching on peri-implant bone remodelling around short implants (8.5 mm in length) placed in the resorbed posterior mandibular and maxillary region of partially edentulous patients.

Materials and methods: Seventeen patients with one or more missing teeth at both sides in the posterior region were, according to a split-mouth design, randomly assigned to be treated with a platform-matched (control) implant on the one side and a platform-switched implant (test) on the other side. A total of 62 short implants (8.5 mm) with a dual acid-etched surface with nanometer-sized calcium phosphate particles was placed. Follow-up visits were conducted one month and one year after placing the implant crown. Outcome measures were marginal bone-level changes, implant survival and clinical parameters.

Results: One year after loading, peri-implant bone remodelling around test implants (0.53±0.54 mm) was significant less than around control implants (0.85±0.65 mm; p=0.003). With regard to implant survival and clinical parameters no significant differences were observed between test and control implants.

Conclusion: This study suggested that peri-implant bone remodelling is affected by platform switching. One year after loading, marginal bone levels were better maintained at implants restored according to the platform switching concept.

Introduction

From the moment the healing abutment is placed and the implant is exposed to the oral environment, biologic width formation starts. A mucosal attachment of a certain minimum vertical dimension (3-4 mm) is formed and, as a consequence, marginal bone loss may take place (Berglundh & Lindhe 1996, Hermann et al. 2001). Whether or not marginal bone loss will occur depends, amongst others, on the presence of a microgap between implant and abutment and on the location of this microgap in relation to level of the crestal bone. One-piece implants (no microgap) and implants placed above the alveolar crest have been show to prevent marginal bone loss (Hermann et al. 2001, Todescan et al. 2002, Broggini et al. 2006, Cochran et al. 2009). The implant-abutment connection is also thought to be an important factor regarding peri-implant bone remodelling as the highest number of inflammatory cells has been observed at the implant-abutment interface (Broggini et al. 2006).

The implant-abutment configuration itself is also thought to affect peri-implant remodelling of bone. In so called platform-switched implants the diameter of the abutment is less than the diameter of the implant, resulting in a horizontal offset at the top of the implant that separates the crestal bone and the connective tissue from the interface. Early results of these platform-switched implants showed no changes in peri-implant bone levels, contrary to standard platform-matched implants (Wagenbourg & Froum 2010). Next, several hypotheses were posed to explain the rationale behind the concept of platform switching for crestal bone preservation. The biomechanical rationale proposed that by platform switching the stress-concentration zone (from the forces of occlusal loading) is directed from the crestal bone-implant interface to the axis of the implant and so reduces the stress level in the cervical bone area (Maeda et al. 2007). Cochran et al. (2009) showed that placing the implant-abutment connection below the crestal bone level may cause bone resorption to re-establish the biologic width. Following this theory, platform switching medializes the microgap and the dimension of the biologic width. A horizontal mismatch of 0.3 mm was found to decrease the vertical dimension of the junctional epithelium (Becker et al. 2009, Farronato et al. 2012). Another hypothesis concerned the role of inflammatory cell infiltrate at the implant-abutment connection. The presence of peri-implant microbiota was suggested to influence marginal bone loss by maintaining the inflammatory cell infiltrate within the implant-abutment connection (Broggini et al. 2006, Ericsson et al. 1995, 1996) However, no association was found between marginal bone loss and peri-implant microbiota at platform-matched and platform-switched implants (Canullo et al. 2010a).

Preclinical data of Cochran et al. (2009) showed minimal histologic bone remodelling of platform-switched implant. Their data were in contrast to the preclinical data described by Becker et al. (2007, 2009), who concluded that

platform switching may not be of crucial importance for maintenance of the crestal bone level. From the systematic review of the literature, Atieh et al. (2010) concluded that marginal bone loss around platform-switched implants was significantly less compared with platform-matched implants (0.021-0.99 mm for platform-switched and 0.101-1.67 mm for platform-matched implants) (Hürzeler et al. 2007, Cappiello et al. 2008, Canullo et al. 2009, 2010b, Crespi et al. 2009, Kielbassa et al. 2009, Prosper et al. 2009, Tramell et al 2009, Vigolo & Givani 2009, Enkling et al. 2011). However, no long-term data are present. The large variation in results was thought to be due to the use of different implant diameters, mismatches and implant systems. Moreover, 3 of the 10 included studies reported no differences in bone-level changes between the platform concepts tested (Crespi et al. 2009, Kielbassa et al. 2009, Enkling et al. 2011).

Short implants (<10 mm in length) are increasingly used as there is fair evidence that short implants can be placed successfully in the partially edentulous patient, but with a tendency toward an increasing survival rate per implant length (Telleman et al. 2011a). Therefore it is important to preserve peri-implant bone, especially in short implants. However, short implants might be expected to develop a greater maximum compressive stress in their coronal region in comparison to longer implants, which could lead to bone microfracture and marginal bone loss (Hagi et al. 2004).

To our knowledge no study with a split-mouth design, has been reported about the effectiveness of platform switching. The rationale for a split-mouth design was to remove all components related to differences between subjects from the treatment comparisons. By making within-patient comparisons, rather than between-patient comparisons, the error variance (noise) of the experiment can be reduced, thereby obtaining a more powerful statistical test. As implant surface roughness affects bone response an implant with a relatively new implant surface was chosen; a dual acid-etched surface with a nanometer-sized deposition of calcium phosphate (CaP) (Lang & Jepsen 2009, Wennerberg & Albrektsson 2009a,b). Histological and histomorphometric studies showed acceleration of early peri-implant bone healing, but no long-term data are present (Goené et al. 2007, Orsini et al. 2007, Telleman et al. 2010). Therefore, the aim of this study was to assess the effect of platform switching on peri-implant bone remodelling around short implants (8.5 mm) placed in the resorbed posterior mandibular and maxillary region of partially edentulous patients.

Materials and methods

Patients

Partially edentulous patients referred for implant therapy in the posterior region, in the years 2007 until 2010, to the department of Oral and Maxillofacial Surgery of the University Medical Center Groningen (The Netherlands), were considered for inclusion if they fulfilled the following criteria:

- at least 18 years of age;
- capable of understanding and giving informed consent;
- one or more missing teeth being a premolar and/or molar in the maxilla right and left side or one or more missing teeth being a premolar and/or molar in the mandible right and left side;
- at the place of the future implant a maximum of 10 mm bone in vertical dimension and minimum of 8 mm in horizontal dimension available.

Exclusion criteria were:

- medical and/or general contraindications for the surgical procedures (ASA score ≥III) (Smeets et al. 1998);
- presence of active clinical periodontal disease in the dentition as expressed by probing pocket depths ≥5 mm and bleeding on probing;
- presence of peri-apical lesions or any other abnormalities or infections at the implant site as determined on a radiograph;
- smoking;
- a history of radiotherapy to the head and neck region.

Study Design

This study was approved by the Medical Ethical Committee of the University Medical Center Groningen. Before enrolment, written and verbal information was given to the patients and written informed consent was obtained.

Two different implant-abutment connections were studied on implants with a length of 8.5 mm. The platform-switched implants (NanoTite Certain Prevail, Biomet 3i, Palm Beach Gardens, FL, USA) used in the test group had a horizontal mismatch of 0.35 mm and 0.40 mm, respectively, for the implants with a diameter of 4 and 5 mm. In a vertical dimension, the implant-abutment connection is positioned 0.09 mm and 0.11 mm (for implants with a diameter of 4 and 5 mm, respectively), above the implant shoulder (figure 1a). The control implants (NanoTite XP Certain, Biomet 3i) had the same dimensions as the platform-switched implants except for the implant-abutment connection, which was platform-matched (figure 1b). Both implant types had an extended platform and a dual acid-etched (using hydrochloric and sulphuric acids) surface with a discrete crystalline deposition of nanometer-sized CaP particles (NanoTite, Biomet 3i). Implants with a platform-matched (control) or a platform-switched implant-abutment connection (test) were randomly assigned to the left or right side of the jaw. An investigator with no clinical involvement in the trial informed the surgeon, who inserted the implants, about the allocation result on the day of surgery, just before implant surgery was started. The prosthodontist was informed about the allocation result before the impression of the healing abutment was made. The surgeon and prosthodontist

could not be blinded for the allocation result as they could see by the inner color of the implant whether the implant placed was a test or control implant.

Figure 1a. Dental radiograph of two adjacent test implants (NanoTite Certain Prevail, Biomet 3i)

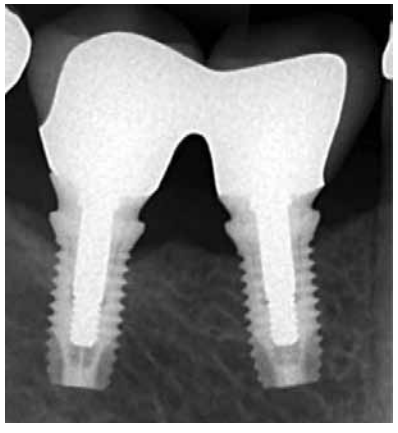
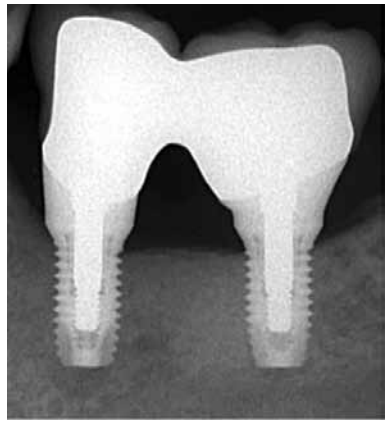


Figure 1b. Dental radiograph of two adjacent control implants (NanoTite XP Certain, Biomet 3i)



Interventions

All patients were treated at the department of Oral and Maxillofacial Surgery of the University Medical Center Groningen. All implants (left and right side) were placed in the same surgery, in healed sites, i.e., at least 3-4 months after tooth removal allowing the extraction site to have healed. Implants were placed and restored according to the protocol described in detail previously (Telleman et al. 2011b). Briefly, the incision was made on the top of the alveolar crest and a surgical template was used. The implant shoulder was placed at bone level, both mesial and distal even with the alveolar crest, if necessary the bone was flattened. The distance between the implant and the neighbouring teeth was at least 1.5 mm, and the distance between two implants was at least 3 mm. On this implant, a coded healing abutment (Encode®, Biomet 3i) with a height of 4 mm was placed to develop an emergence profile. Next, if any, implant dehiscences or fenestrations at the buccal side of the implant were covered with autogenous bone chips collected during implant bed preparation and anorganic bovine bone (Bio-oss®, Geistlich Pharma AG, Wolhusen, Switzerland) overlaid with a collagen membrane (Bio-Gide®, Geistlich Pharma AG). Finally, the wound was closed with sutures (Vicryl 3-0, Johnson & Johnson, Brunswick, NJ, USA). Two weeks following implant surgery the sutures were removed. Three months after implant placement, seating of the healing abutment was evaluated and impressions were made. The healing abutment was scanned from the cast and an individualized abutment was milled according to the procedure described by Telleman et al. (2011b). The abutment was placed with 20 Ncm and the metal ceramic crown was cemented (GC Fuji 1, GC Europe NV, Leuven, Belgium).

A single experienced oral and maxillofacial surgeon performed all surgical procedures. Six experienced prosthodontics performed the prosthetic procedure.

Outcome measures

The primary outcome measure was the mean marginal bone-level change (mesial and distal sides combined) from the time of implant placement (baseline) to 1 year after placing the crown on the implant; which is 16 months after placing the implant (T_{16m}) as measured on standardized digital radiographs. Secondary outcome measures were implant survival and changes in marginal soft tissue level of the implant and the neighbouring teeth. One and the same examiner performed all measurements. To assess the reliability of the radiographic examination, this examiner was assisted by a second examiner. The operationalization of the variables is described as follows.

Radiographic assessments

After implant placement (T_{0m}), 1 month (T_{5m}) and 1 year after placing the implant crown (T_{16m}), standardized digital intra-oral radiographs were taken according to a long-cone paralleling technique as described by Meijndert et al. (2004). Marginal bone-level changes were measured using specifically designed computer software (Dicomworks, version 1.0, Department of Biomedical Engineering, University Medical Center Groningen, The Netherlands). The calibration was carried out in the vertical plane for each radiograph, by using the known distance of several threads. This calibration ensured a correct measurement (Sewerin 1990). The outermost margin of the implant shoulder was used as the reference point to assess the marginal vertical bone-level change. To assess the reliability of the radiographic examination 30 radiographs of 10 patients were assessed by two examiners. The interobserver agreement was tested on 60 measurements (3 radiographs × 10 patients × 2 (mesial, distal) bone level assessments) of the first examiner and 60 measurements of the second examiner.

Clinical assessments

Preoperatively (T_{pre}), 1 month (T_{5m}) and 1 year (T_{16m}) after the placement of the implant crowns, the soft tissue around the implants and their neighbouring teeth were clinically examined using the following clinical parameters:

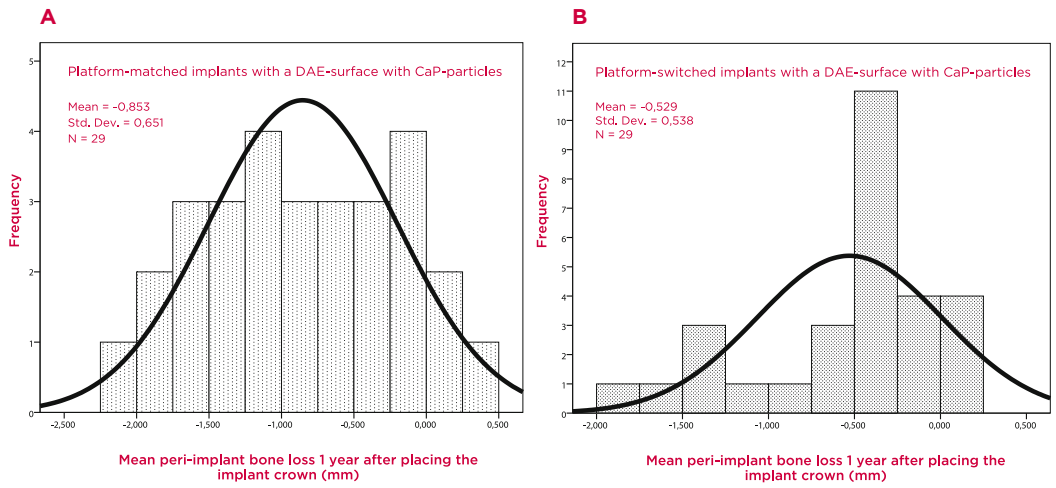
- Assessment of plaque accumulation with the modified Plaque Index (Mombelli et al. 1987);
- Assessment of bleeding tendency with the modified Sulcus Bleeding Index (Mombelli et al. 1987);
- Assessment of peri-implant inflammation with the Gingival Index (Loë & Silness 1963);

- Presence of dental calculus;
- Sulcus probing pocket depth: measured to the nearest millimetre using a manual periodontal probe (Williams Color-Coded Probe; Hu-Friedy, Chicago, IL, USA).

Statistical analysis

To assess the interobserver agreement for the continuous variables of the peri-implant bone-level changes (scored on peri-apical radiographs) two-way random models were used to calculate the intraclass correlation coefficient. To see whether the data were normally distributed the frequency distribution was plotted in a histogram (figure 2). To test whether the result from the frequency analyses differed significantly from a normal distribution Kolmogorov-Smirnov and Shapiro-Wilk tests were done. For between-groups comparisons of normally distributed variables, *t*-tests were used. Variables that were not normally distributed were statistically explored using Mann-Whitney tests. In all analyses, a significance level of $p<0.05$ was chosen. Data were analysed using the Statistical Package for Social Sciences 16.0 (SPSS Inc., Chicago, IL, USA).

Figure 2. Frequency distributions of the mean peri-implant bone remodelling of the 29 platform-matched (A) and 29 platform-switched (B) implants supplied. The platform-matched implants show a normal distribution ($D(29)=0.121$, $p=0.200$, $W(29)=0.968$, $p=0.498$). The frequency distribution of the platform-switched implants differ significantly from a normal distribution and show a negative kurtosis ($D(29)=0.201$, $p=0.004$, $W(29)=0.893$, $p=0.007$).



Results

Patients

Between May 2007 and December 2009, a total of 17 patients fulfilled the inclusion criteria. Baseline patients and treatment characteristics are listed in table 1. There was no drop-out; all patients attended the follow-up visits.

Table 1. Baseline characteristics of the patients

Variable	Platform-matched implant-abutment connection (n=17; control))	Platform-switched implant-abutment connection (n=17; test)
Mean age ± SD and range (years):		
	53.7 ± 11.7 (21-67)	53.7 ± 11.7 (21-67)
Female/male ratio:		
	17/0	17/0
Implant position:		
Maxillary ($P_1/P_2/M_1/M_2$)	12 (2/3/4/3)	12 (3/2/5/2)
Mandibular ($P_1/P_2/M_1/M_2$)	19 (1/9/8/1)	19 (1/8/8/2)
Number of implants to be placed in a patient:		
1	4	4
≥2 adjacent implants	13	13
Implant diameter:		
4.1 mm	27	26
5.0 mm	4	5

Peri-implant bone remodelling

The intraclass correlation coefficient for average measures was 0.87 for the radiographic interobserver agreement (Cronbach's Alpha=0.87), which can be interpreted as almost perfect agreement (Viera & Garrett 2005).
Overall, mean peri-implant bone remodelling was significantly less around platform-switched implants than around implants with platform-matched implant-abutment connections, both 1 month and 1 year after placing the crown (table 2). However, when comparing bone remodelling in cases provided with one implant no difference between the two platform designs was observed, while when two or more adjacent platform-switched implants were placed bone remodelling was significantly less comparing to platform-matched implants, 1 month and 1 year after placing the crown (table 2).

Implant survival

Two of 31 platform-matched implants and 2 of the 31 platform-switched implants were lost, both resulting in a survival rate of 93.6%. All implants were lost before loading, three in the maxilla and one in the mandible.

Table 2. Changes in marginal bone level and pocket probing depths at implant and tooth sides from baseline to 16 months after placement of the implant. Negative results in marginal bone-level changes indicate marginal bone loss and positive results in pocket probing depth changes indicate enlarged peri-implant pockets.

All implants	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=31)	Platform-switched (n=31)	Platform-matched (n=31)	Platform-switched (n=31)	Platform-matched (n=29)	Platform-switched (n=29)
Marginal bone-level changes (mm)	**-0.82*** (±0.59)	**-0.44*** (±0.57)	**-0.01** (±0.34)	**-0.09** (±0.36)	**-0.85§** (±0.65)	**-0.53§** (±0.54)
1 implant	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=4)	Platform-switched (n=4)	Platform-matched (n=4)	Platform-switched (n=4)	Platform-matched (n=4)	Platform-switched (n=4)
Marginal bone-level changes (mm)	**-0.41** (±0.31)	**-0.15** (±0.36)	**0.08** (±0.15)	**-0.20** (±0.38)	**-0.33** (±0.36)	**-0.35** (±0.19)
Pocket probing depth changes (mm)						
Implant	Not available	Not available	**-0.06** (±0.85)	**-0.44** (±1.00)	**-0.06** (±0.85)	**-0.44** (±1.00)
Tooth mesially of the implant	**0.13** (±0.52)	**0.31** (±0.31)	**-0.13** (±0.25)	**-0.06** (±0.31)	**0.00** (±0.35)	**0.25** (±0.46)
Tooth distally of the implant	**-0.42** (±0.29)	**0.50** (±0.35)	**0.42** (±0.52)	**0.25** (±0.65)	**0.00** (±0.66)	**0.75** (±0.00)
2 or more implants	T_{0m} – T_{5m}		T_{5m}-T_{16m}		T_{0m} - T_{16m}	
	Platform-matched (n=27)	Platform-switched (n=27)	Platform-matched (n=27)	Platform-switched (n=27)	Platform-matched (n=25)	Platform-switched (n=25)
Marginal bone-level changes (mm)	**-0.89♯** (±0.60)	**-0.49♯** (±0.59)	**-0.02** (±0.36)	**-0.07** (±0.36)	**-0.94†** (±0.65)	**-0.56†** (±0.57)
Pocket probing depth changes (mm)						
Implant	Not available	Not available	**-0.19** (±0.72)	**-0.36** (±0.61)	**-0.19** (±0.72)	**-0.36** (±0.61)
Tooth mesially of the implant	**-0.02** (±0.54)	**0.00** (±0.51)	**-0.06** (±0.41)	**-0.06** (±0.54)	**-0.08** (±0.37)	**-0.06** (±0.45)
Tooth distally of the implant	Not available	Not available	Not available	Not available	Not available	Not available

For between groups comparisons: * p=0.003, § p=0.066, ♯ p=0.005, † p=0.040
Abbreviation: n=number of implants

Table 3. Clinical parameters of implants and adjacent teeth. No significant differences were found between control (platform-matched) and test (platform-switched) group before (T_{0m}), 1 month (T_{5m}) and 1 year (T_{16m}) in function.

Clinical parameters	% at T_{0m}		% at T_{5m}		% at T_{16m}	
	Platform-matched	Platform-switched	Platform-matched	Platform-switched	Platform-matched	Platform-switched
Implant Plaque Index[1]						
score 0, no detection of plaque	-	-	89.7	93.1	65.5	82.8
score 1, plaque on probe	-	-	10.3	6.9	17.2	6.9
score 2, plaque seen by naked eye	-	-	0	0	17.2	10.3
score 3, abundance of soft matter	-	-	0	0	0	0
Implant Bleeding Index[1]						
score 0, no bleeding	-	-	69.0	79.3	65.5	75.9
score 1, isolated bleeding spots	-	-	31.0	20.7	27.6	20.7
score 2, confluent line of blood	-	-	0	0	6.9	3.4
score 3, heavy or profuse bleeding	-	-	0	0	0	0
Implant Gingival Index[2]						
score 0, normal mucosa	-	-	93.1	100	82.8	93.1
score 1, mild inflammation	-	-	6.9	0	17.2	6.9
score 2, moderate inflammation	-	-	0	0	0	0
score 3, severe inflammation	-	-	0	0	0	0
Implant dental calculus						
score 0, no dental calculus	-	-	100	100	100	100
score 1, dental calculus present	-	-	0	0	0	0
Adjacent teeth Plaque index[1]						
score 0, no detection of plaque	82.6	72.7	90.5	95.2	100	90.5
score 1, plaque on probe	17.4	27.3	4.8	4.8	0	4.8
score 2, plaque seen by naked eye	0	0	4.8	0	0	4.8
score 3, abundance of soft matter	0	0	0	0	0	0
Adjacent teeth Bleeding index[1]						
score 0, no bleeding	91.3	86.4	81.0	95.2	95.5	90.5
score 1, isolated bleeding spots	8.7	13.6	19.0	4.8	4.5	9.5
score 2, confluent line of blood	0	0	0	0	0	0
score 3, heavy or profuse bleeding	0	0	0	0	0	0
Adjacent teeth Gingival Index[2]						
score 0, normal mucosa	100	100	100	100	100	100
score 1, mild inflammation	0	0	0	0	0	0
score 2, moderate inflammation	0	0	0	0	0	0
score 3, severe inflammation	0	0	0	0	0	0
Adjacent teeth dental calculus						
score 0, no dental calculus	100	100	95.2	95.2	100	100
score 1, dental calculus present	0	0	4.8	4.8	0	0

[1] (Mombelli et al. 1987) [2] (Loë & Silness 1963)
Abbreviation: n=number of implants

Clinical outcome

The mean probing pocket depth around the implants did not significantly increase between T_{5m} and T_{16m} (table 2). Also no between-group differences in clinical parameters plaque accumulation, bleeding tendency, gingiva index (table 3) were observed.

Discussion

After 1 year in function, the results of our split-mouth study showed significantly less peri-implant bone remodelling around short platform-switched implants compared with platform-matched implants placed in the resorbed posterior region of partially dentate patients. This effect was only observed when two or more implants were placed, and did not count for single tooth replacement. A reason could be the low numbers of single tooth replacements in this study. Three of the 10 studies in the systemic review of Atieh et al. (2010) to platform switching reported also no differences in bone-level changes between the two platform designs (Crespi et al. 2009, Kielbasa et al. 2009, Enkling et al. 2011). Although Atieh et al. (2010) concluded that platform-switched implants show less marginal bone loss. The large variation in peri-implant bone remodelling reported in the review was thought to be due to the use of different implant diameters, mismatches, and implant systems. Clearly, the concept of platform switching is not sufficiently verified yet and thus not solid evidence based, as long-term data about the effect of platform switching and about the different platform switching designs are lacking. Furthermore, not much is written about the difference in bone remodelling around single or multiple adjacent platform switching implants. Athieh et al. (2010) stated that these implants may preserve inter-implant bone height, but they could not confirm the validity of that concept.

This trial showed similar implant survival rates for both platform designs, comparable to the survival rates reported by Atieh et al. (2010). However, the survival rates of the current study were lower than the rates reported for 8.5 mm implants (98.8%; 95% CI: 98.2-99.6%) in the systematic review to short implants (Telleman et al. 2011a). A reason for the lower survival rates in the current study could be the number of implants placed in the maxilla as one of the conclusions of the review to short implants was that the failure rate of studies performed in the maxilla was 0.010 implants/year compared with 0.003 implants/year in the mandible.

Also, no between-group significant differences in the clinical parameters plaque accumulation, bleeding tendency and gingiva index was observed. However, there was a tendency for platform-matched implants to have slightly more plaque and signs of mild inflammation. Considering the small difference, coming up with possible causes for this clinical observation would be pure speculation. The overall results of the clinical parameters are in accordance with the results of the histological study of Canullo et al. (2011a), who concluded that switching and traditional platform implants had similar histological and soft tissue features, despite different bone-level changes. Furthermore, Dellavia et al. (2011) concluded that platform switching apparently did not affect the inflammatory cellular and molecular pattern around the implant-abutment connection.

The platform-switched implants applied in our trial had an implant-abutment diameter difference in horizontal dimension of 0.35 or 0.40 mm (depending on the diameter of the implant). Atieh et al. (2010) reported that subgroup analyses showed that an implant-abutment difference ≥0.4 mm was associated with a more favourable response. A bigger mismatch is often caused, as in the current study, by the use of a wider diameter. It has been speculated that the findings of reduced bone remodelling accompanying a larger implant-abutment difference may be due to an increased implant diameter rather than to the platform (Enkling et al. 2011). However, the study of Canullo et al. (2011b) on the impact of implant diameter of platform-switched implants clearly concluded no relation between implant diameter and extent of bone remodelling.

In the platform-switched implants we used, the implant-abutment connection is 0.09 and 0.11 mm (depending on the diameter of the implant) above the outermost margin of the collar of the implant, so when placed a bone level, as in the current study, the implant-abutment connection is slightly higher. From the study of Cochran et al. (2009) we now know that the least bone remodelling was shown with the platform-switch situated 1 mm above the alveolar crest. Conversely, Veis et al. (2010) reported the least bone remodelling when implants were placed subcrestal. These contrasting results points to the need of additional comparative studies to the different designs (in horizontal and vertical dimension) and level of placement of platform-switched implant-abutment connections.

Generally spoken about split-mouth designs, comparisons made on a within-patient basis may have potential disadvantages (Lesaffre et al. 2009). One treatment concept may effect another treatment (carry-across effects). To what extent this is the case in the current study, is difficult to say. But with only a small difference between the two implant-abutment connections, placed in one and the same surgical treatment, is probably of minor influence. Another disadvantage is the recruitments of patients, which is hampered by the need for symmetrical edentulism in the posterior region. This restriction might bias the selection of patients towards those with a higher risk for cavities and possibly poorer brushing and dietary behaviour.

In conclusion, this study suggested that peri-implant bone remodelling is affected by platform switching. One year after loading, marginal bone levels were better maintained at implants restored according to the platform switching concept.

References

Atieh, M. A., Ibrahim, H. M. & Atieh, A. H. (2010) Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis. *Journal of Periodontology* 81, 1350-1366.

Becker, J., Ferrari, D., Herten, M., Kirsch, A., Schaer, A. & Schwarz, F. (2007) Influence of platform switching on crestal bone changes at non-submerged titanium implants: a histomorphometrical study in dogs. *Journal of Clinical Periodontology* 34, 1089-1096.

Becker, J., Ferrari, D., Mihatovic, I., Sahm, N., Schaer, A. & Schwarz, F. (2009) Stability of crestal bone level at platform-switched non-submerged titanium implants: a histomorphometrical study in dogs. *Journal of Clinical Periodontology* 36, 532-539.

Berglundh, T. & Lindhe, J. (1996) Dimension of the periimplant mucosa. Biological width revisited. *Journal of Clinical Periodontology* 23, 971-973.

Broggini, N., McManus, L. M., Hermann, J. S., Medina, R., Schenk, R. K., Buser, D. & Cochran, D. L. (2006) Peri-implant inflammation defined by the implant-abutment interface. *Journal of Dental Research* 85, 473-478.

Canullo, L., Goglia, G., Iurlare, G. & Ianello, G. (2009) Short-term bone level observations associated with platform switching in immediately placed and restored single maxillary implants: a preliminary report. *The International Journal of Prosthodontics* 22, 277-282.

Canullo, L., Quaranta, A. & Teles, R. P. (2010a) The microbiota associated with implants restored with platform switching: a preliminary report. *Journal of Periodontology* 81, 403-411.

Canullo, L., Fedele, G. R., Ianello, G. & Jepsen, S. (2010b) Platform switching and marginal bone-level alterations: the results of a randomized-controlled trial. *Clinical Oral Implants Research* 21, 115-121.

Canullo, L., Pellegrini, G., Allievi, C., Trombelli, L, Annibali, S. & Dellavia, C. (2011a) Soft tissues around long-term platform switching implant restorations: a histological human evaluation. Preliminary results. *Journal of Clinical Periodontology* 38, 86-94.

Canullo, L., Iannello, G., Penarocha, M. & Garcia, B. (2011b) Impact of implant diameter on bone level changes around platform switched implants: preliminary results of 18 months follow-up a prospective randomized match-paired controlled trial. *Clinical Oral Implants Research* 24, epub ahead of print.

Cappiello, M., Luongo, R., Di Iorio, D., Bugea, C., Cocchetto, R. & Celletti, R. (2008) Evaluation of peri-implant bone loss around platform-switched implants. *The International Journal of Periodontics & Restorative Dentistry* 28, 347-355.

Cochran, D. L., Bosshardt, D. D., Grize, L., Higginbottom, F. L., Jones, A. A., Jung, R. E., Wieland, M. & Dard, M. (2009) Bone response to loaded implants with non-matching implant-abutment diameters in the canine mandible. *Journal of Periodontology* 80, 609-617.

Crespi, R., Capparè, P. & Gherlone, E. (2009) Radiographic evaluation of marginal bone level around platform-switched and non-platform-switched implants used in an immediate loading protocol. *The International Journal of Oral & Maxillofacial Implants* 24, 920-926.

Dellavia, C., Canullo, L., Allievi, C., Lang, N. P. & Pellegrini, G. (2011) Soft tissue surrounding switched platform implants: an immunohistochemical evaluation. *Clinical Oral Implants Research* 29, epub ahead of print.

Enkling, N., Jöhren, P., Klimberg, V., Bayer, S., Mericske-Stern, R. & Jepsen, S. (2011) Effect of platform switching on peri-implant levels: a randomized clinical trial. *Clinical Oral Implants Research* 22, 1185-1192.

Ericsson, I., Persson, L. G., Berglundh, T., Marinello, C. P., Lindhe, J. & Klinge, B. (1995) Different types of inflammatory reactions in peri-implant soft tissues. *Journal of Clinical Periodontology* 22, 255-261.

Ericsson, I., Nilner, K., Klinge, B. & Glantz, P. O. (1996) Radiographical and histological characteristics of submerged and non-submerged titanium implants. An experimental study in the Labrador dog. *Clinical Oral Implants Research* 7, 20-26.

Farronato, D., Santoro, G., Canullo, L., Botticelli, D., Maorana, C. & Lang, N. P. (2012) Establishment of the epithelial attachment and connective tissue adaptation to implants installed under the concept of “platform-switching”: a histologic study in mini-pigs. *Clinical Oral Implants Research* 23, 90-94.

Goené, R. J., Testori, T. & Trisi, P. (2007) Influence of a nanometer-scale surface enhancement on de novo bone formation on titanium implants: a histomorphometric study in human maxillae. *The International Journal Periodontics & Restorative Dentistry* 27, 211-219.

Hagi, D., Deporter, D. A., Pilliar, R. M. & Arenovich, T. (2004) A targeted review of study outcomes with short (≤ 7 mm) endosseous dental implants placed in partially edentulous patients. *Journal of Periodontology* 75, 798-804.

Hermann, J. S., Buser, D., Schenk, R. K., Schoolfield, J. D. & Cochran, D. L. (2001) Biologic width around one-and two- piece titanium implants. *Clinical Oral Implants Research* 12, 559-571.

Hürzeler, M., Fickl, S., Zuhr, O. & Wachtel, H. C. (2007) Peri-implant bone level around implants with platform-switched abutments: preliminary data from a prospective study. *Journal of Oral and Maxillofacial Surgery* 65, 33-39.

Kielbassa, A. M., Martinez-de Fuentes, R., Goldstein, M., Arnhart, C., Barlattani, A., Jackowski, J., Knauf, M., Lorenzoni, M., Maiorana, C., Mericske-Stern, R., Rompen, E. & Sanz, M. (2009) Randomized controlled trial comparing a variable-thread novel tapered and a standard tapered implant: one-year results. *The Journal of Prosthetic Dentistry* 101, 293-305.

Lang, N. P. & Jepsen, S. (2009) Implant surfaces and design. *Clinical Oral Implants Research* 20, 228-231.

Lesaffre, E., Philstrom, B., Needleman, I. & Worthington, H. (2009) The design and analysis of split-mouth studies: What statisticians and clinicians should know. *Statistics in Medicine* 28, 3470-3482.

Löe, H. & Silness, J. (1963) Periodontal disease in pregnancy. I. Prevalence and severity. *Acta Odontologica Scandinavica* 21, 533-551.

Maeda, Y., Miura, J., Taki, I. & Sogo, M. (2007) Biomechanical analysis on platform switching: Is there any biomechanical rationale? *Clinical Oral Implants Research* 18, 581-584.

Meijndert, L., Meijer, H. J. A., Raghoebar, G. M. & Vissink, A. (2004) A technique for standardized evaluation of soft and hard peri-implant tissues in partially edentulous patients. *Journal of Periodontology* 75, 646-651.

Mombelli, A., van Oosten, M. A. C., Schürch, E. & Lang, N. P. (1987) The microbiota associated with successful or failing osseointegrated titanium implants. *Oral Microbiology and Immunology* 2, 145-151.

Orsini, G., Piatelli, M., Scarano, A., Petrone,

G., Kenealy, J., Piatelli, A. & Caputi, S. (2007) Randomized, controlled histologic and histomorphometric evaluation of implants with nanometer-scale calcium phosphate added to the dual acid-etched surface in the human posterior maxilla. *Journal of Periodontology* 78, 209-218.

Prosper, L., Redaelli, S., Pasi, M., Zarone, F., Radaelli, G. & Gherlone, E. (2009) A randomized prospective multicenter trial evaluating the platform-switching technique for the prevention of postrestorative crestal bone loss. *The International Journal of Oral & Maxillofacial Implants* 24, 299-308.

Shalabi, M. M., Gortemaker, A., van 't Hof, M. A., Jansen, J. A. & Creugers, N. H. J. (2006) Implant surface and bone healing: a systematic review. *Journal of Dental Research* 85, 496-500.

Sewerin, I. P. (1990) Errors in radiographic assessment of marginal bone height around osseointegrated implants. *Scandinavian Journal of Dental Research* 98, 428-433.

Smeets, E. C., de Jong, K. J. & Abraham-Inpijn, L. (1998) Detecting the medically compromised patient in dentistry by means of the medical risk-related history. A survey of 29,424 dental patients in the Netherlands. *Preventive Medicine* 27, 530-535.

Telleman, G., Albrektsson, T., Hoffman, M., Johansson, C. B., Vissink, A., Raghoebar, G. M. & Meijer, H. J. A. (2010) Peri-implant endosseous healing properties of dual acid-etched mini-implants with a nanometer-sized deposition of CaP: A histological and histomorphometric human study. *Clinical Implant Dentistry & Related Research* 12,153-160.

Telleman, G., Raghoebar, G. M., Vissink, A., den Hartog, L., Huddleston Slater, J. J. R. & Meijer, H. J. A. (2011a) A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. *Journal of Clinical Periodontology* 38, 667-676.

Telleman, G., Raghoebar, G. M., Vissink, A. & Meijer, H. J. A. (2011b) The use of a coded healing abutment as an impression coping to design and mill an individualized anatomic abutment: A clinical report. *The Journal of Prosthetic Dentistry* 105, 282-285.

Todescan, F. F., Pustiglioni, F. E., Imbronito, A. V., Albrektsson, T. & Gioso, M. (2002) Influence of the microgap in the peri-implant hard and soft tissues: A histomorphometric study in dogs. *International Journal of Oral Maxillofacial Implants* 17, 467-472.

Trammell, K., Geurs, N. C., O'Neal, S. J., Liu, P. R., Haigh, S. J., McNeal, S., Kenealy, J. N. & Reddy, M. S. (2009) A prospective, randomized, controlled comparison of platform-switched and matched-abutment implants in short-span partial denture situations. *The International Journal of Periodontics & Restorative Dentistry* 29, 599-605.

Veis, A., Parissis, N., Tsirlis, A., Papadeli, C., Marinis, G. & Zogakis, A. (2010) Evaluation of peri-implant marginal bone loss using modified abutment connections at various crestal level placements. *The International Journal of Periodontics & Restorative Dentistry* 30, 609-617.

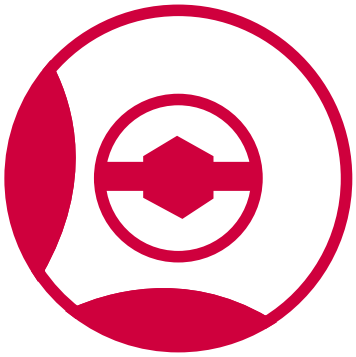
Viera, A. J. & Garrett, J. M. (2005) Understanding interobserver agreement: The kappa statistic. *Family Medicine* 37, 360-363.

Vigolo, P. & Givani, A. (2009) Platform-switched restorations on wide-diameter implants: a 5-year clinical prospective study. *The International Journal of Oral & Maxillofacial Implants* 24, 103-109.

Wagenberg, B. & Froum, S. J. (2010) Prospective study of 94 platform-switched implants observed from 1992 to 2006. *The International Journal of Periodontics & Restorative Dentistry* 30, 9-17.

Wennerberg, A. & Albrektsson, T. (2009) Effects of titanium surface topography on bone integration: a systematic review. *Clinical Oral Implants Research* 20, 172-184.

Wennerberg, A. & Albrektsson, T. (2010) On Implant surfaces: A review of current knowledge and opinions. *The International Journal of Oral & Maxillofacial Implants* 25, 63-74.



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Chapter 7

The use of a coded healing abutment as an impression coping to design and mill an individualized anatomic abutment: a clinical report

Abstract

A coded implant healing abutment makes an impression at the implant level no longer necessary. An impression is made of the healing abutment, which is placed onto the implant directly after implant placement. The codes embedded in the occlusal surface of the healing abutment provide essential information for the computer software to place the implant analogue in the definitive cast and to design and mill the definitive abutment.

Introduction

An implant impression is the negative copy of the dental implant platform and surrounding tissues needed to fabricate the prosthesis. Two different implant impression techniques are commonly applied, the open tray technique, using impression copings that have to be screwed on and off the implants, and the transfer or closed tray impression technique, in which the copings are placed back into the impression after removal. The authors of a systematic review indicated that, when an impression of 3 or fewer implants is made, there is no difference between the open and closed tray techniques; whereas for 4 or more implants, there is a higher accuracy with the open tray technique (Lee et al. 2008).

To combine the principles of the open and closed tray impression techniques, some implant manufacturers have developed snap-on plastic impression caps or press-fit metal copings (Walker et al. 2008, Nissan & Ghelfan 2009). With this technique, a closed tray is used, but the copings are removed along with the impression. An advantage of the plastic impression copings is the opportunity to modify the copings when implants converge or are placed too close together (Selecman & Wicks 2009). However, several authors stated that metal impression copings are more accurate than plastic impression caps (Walker et al. 2008, Selecman & Wicks 2009).

A disadvantage of all the previously described impression techniques is that the healing abutments have to be removed and the impression copings placed. All of this takes time and introduces the possibility of incorrectly placing the impression copings. To shorten chair time and to minimize the chance of impression coping-implant misfit, the coded healing abutment (Encode®; Biomet 3i, Palm Beach Gardens, FL, USA) was designed. With this system, implant impressions can be made of the healing abutments when making implant-level impressions. The manufacturer states that special codes embedded in the occlusal surface of the healing abutment provide information (implant depth, hex orientation, implant angulation, platform diameter, and internal connection or external interface) that is essential to seat the implant analogue in the definitive cast, as well as to design and mill the definitive individualized abutment (figure 1). Preliminary clinical results of CAD/CAM-fabricated individualized abutments of this restorative system indicate better tissue response and reduced clinical chair time when compared with prefabricated abutments (Priest 2005, Drago 2006, Grossmann et al. 2006, Fuster-Torres et al. 2009, Selecman & Wicks 2009).

Until recently, it was not possible to place the individualized abutment on the implant analogue in the definitive cast. As a result, a second implant-level impression was necessary to place the implant analogue in the definitive cast. Recently, a technique was developed using CAD to drill a hole in the definitive cast, and create a space into which the implant analogue is placed. Figure 2 shows the device that drills the hole and places the implant analogue (Robo-

Figure 1. Coded healing abutment consists of 2 pieces; screw and abutment (lateral view in upper figure). Special notches on occlusal surface are shown in lower part of figure.

Figure 2. Device that drills hole in definitive cast and places implant analogue. Device is connected to computer, which has information from coded healing abutment.

cats Technology; Biomet 3i). This technique makes it no longer necessary to make a second implant-level impression. This article describes the treatment of a congenitally missing second mandibular premolar with an implant and a CAD/CAM-fabricated individualized abutment with an optimal emergence profile using a coded healing abutment.

Clinical Report

A healthy, non-smoking 23-year-old woman presented for correction of the vertical overlap and crowding of the maxillary anterior teeth, as well as the replacement of a congenitally missing second mandibular premolar.

Extraoral examination revealed a mandibular retrognathia, profound plica mentalis and a relatively prominent chin. Intraoral examination revealed a healthy, well-maintained dentition. Because of the missing second mandibular premolar, the molars had shifted mesially. Radiographically, no pathology of bone or teeth was noted.

As an adult, the patient's mandibular retrognathia and crowding could not be corrected by orthodontic treatment alone. Therefore, the patient was subjected to combination surgery (bilateral sagittal split osteotomy) and pre- and postorthodontic treatment. There remained several treatment options for the missing second mandibular premolar. The first and second left molars could be orthodontically moved mesially into the diastema related to the missing premolar. Space could be created orthodontically to place an adhesive or conventional fixed partial denture, or an endosseous implant could be placed in the left mandible to complete the treatment. For reasons of symmetry, tooth preservation and predictable treatment, the option of an implant placement was chosen. The patient agreed with the suggested treatment and began orthodontic therapy. After one year of orthodontic treatment, the bilateral sagittal split osteotomy was performed. Meanwhile the left mandibular molars were distalized orthodontically, creating space for placement of a dental implant. As there was insufficient bone in the horizontal dimension to place an implant, the patient was scheduled for an augmentation procedure at the same time as the bilateral sagittal split osteotomy. The augmentation procedure was performed with bone from the left retromolar region (Raghoebar et al. 2007). The autogenous bone graft was stabilized with a titanium screw (Gebrüder Martin GmbH & Co. KG, Tuttlingen, Germany). After a 3-month healing period, a diagnostic cast was made with a diagnostic waxing representing the future implant crown in ideal position. A transparent acrylic resin (Orthocryl; Dentaurum GmbH & Co. KG, Ispringen, Germany) template of the diagnostic cast was fabricated for use as a surgical guide. One day before implant placement, the patient began the use of an aqueous 0.2% chlorhexidine mouth rinse (Corsodyl, GlaxoSmithKline, Zeist, The Netherlands) (1 minute, 3 times daily for 2 weeks) for oral disinfection. One hour before surgery, the patient took antibi-

otics (amoxicillin 500 mg, 6 tablets). After the administration of local anesthesia (Ultracaine D-S Forte; Aventis Pharma Deutschland GmbH, Frankfurt, Germany) an incision was made crestally. A mucoperiosteal flap was elevated to expose the alveolar crest and the fixation screw. The screw used to fixate the bone graft was removed and the implant (Osseotite Certain Prevail; Biomet 3i), diameter 4.1 mm/ length 8.5 mm, was placed using the template, according to the procedure advocated by the manufacturer. The shoulder of the implant was placed at bone level. A coded healing abutment (Encode®; Biomet 3i) with a height of 4 mm was placed to develop an emergence profile. The surgical site was closed with sutures (Vicryl 3-0; Johnson & Johnson, Brunswick, NJ, USA). After 2 weeks the sutures were removed.

After three months, seating of the healing abutment was evaluated (figure 3). A closed tray impression of the healing abutment was made with a polyether impression material (Impregum Penta; 3M ESPE, St. Paul, MN, USA) and a custom acrylic resin impression tray (Lightplast base plates; Dreve Dentamid GmbH, Unna, Germany). An irreversible hydrocolloid impression (Cavex Holland BV, Haarlem, The Netherlands) was made of the opposing arch. The impressions were poured in die stone (GC Fujirock EP; GC Europe NV, Leuven, Belgium) and the casts were mounted in maximal intercuspal position in a semi-adjustable articulator (Ivoclar Stratos 100 articulator; Ivoclar Vivadent, Schaan, Liechtenstein). The casts were sent to the manufacturer (Biomet 3i) with a prescription indicating the design and contour. The healing abutment was scanned and an individualized abutment was designed (figure 4). The abutment was milled from a solid titanium alloy block and polished (figure 5). Using CAD, a hole was drilled in the definitive cast to create space for the implant analogue, followed by the placement of the implant analogue (figure 2) (Robocats Technology; Biomet 3i). The individualized abutment with appropriate margin heights and natural emergence contours was placed on the implant analogue and shipped back to the laboratory where the metal ceramic crown was made.

The healing abutment was removed and the titanium individualized abutment was placed with 20 Ncm using a torque device and a large hex driver tip (figure 6). The screw access hole was filled with a cotton pellet and the metal (Estetic concorde; Cendres + Metaux, Biel, Switzerland) ceramic (Duceragold Kiss, DeguDent, Hanau-Wolfgang, Germany) crown was cemented with a glass ionomer luting cement (GC Fuji 1; GC Europe NV). Because of the precise fit between the individualized abutment and the metal ceramic crown, only a minimal amount of cement was needed to place the crown. To date, the restoration has been in service for 24 months without complications (figures 7, 8).

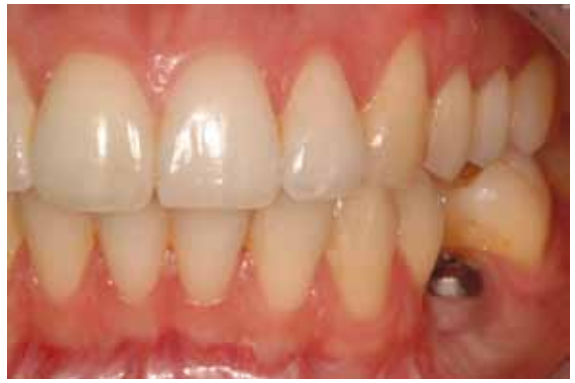

Figure 3. Buccal view of healing abutment

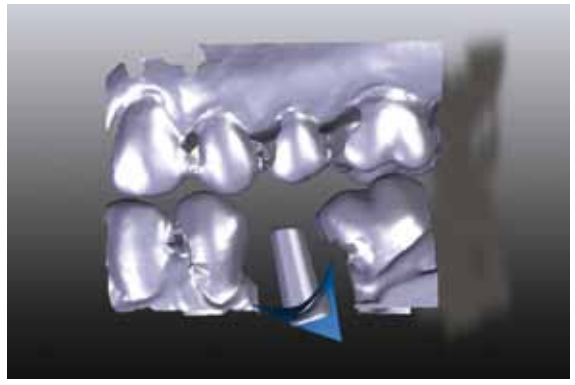

Figure 4. Computer-assisted design image of abutment to design in scanned casts. Anatomical shape with an optimal emergence profile was designed using computer software.

Figure 5. Individualized abutment seated on implant analogue

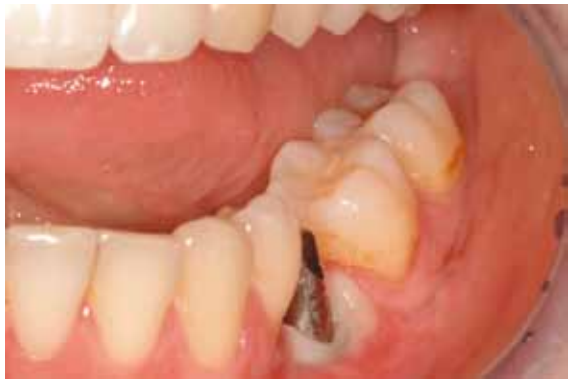

Figure 6. Titanium individualized abutment placed

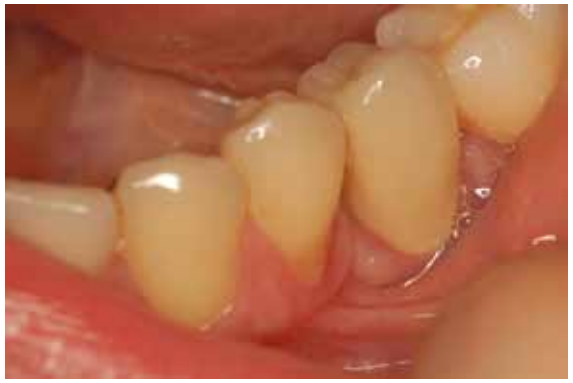

Figure 7. Restoration after service for 24 months

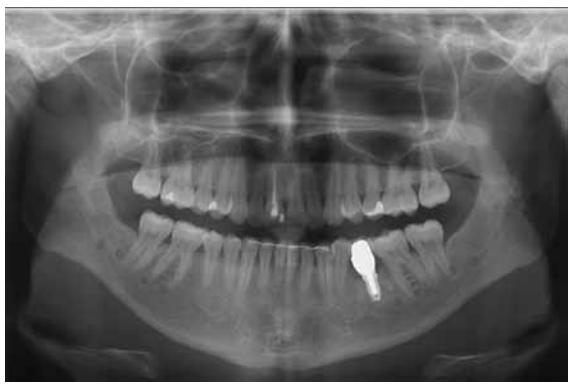

Figure 8. Panoramic radiograph of final result. Note horizontal bone loss due to congenitally missing mandibular left premolar. Implant was placed at bone level.

Discussion

This report demonstrates a technical procedure in which an abutment level impression was used to fabricate an individualized abutment with an optimal emergence profile. This new restorative system, consisting of a coded healing abutment and a CAD/CAM titanium abutment, is purported to have numerous advantages: 1) it provides an anatomical emergence profile for the definitive abutment; 2) it provides the ability to correct an implant angle of up to 30 degrees; 3) it is available in titanium and zirconium 4) there is no need to fabricate a cast or waxing, therefore reducing the laboratory time and costs; 5) it represents a simplified impression technique as there is no need to remove the healing abutment; 6) it is convenient technique for the patient as it shortens chair time; 7) it is easy to see the correct connection between the implant and the coded healing abutment when a mucoperiosteal flap is elevated during implant placement.

However, this system also has its disadvantages: 1) the use of the system is limited to a specific implant system; 2) when using a titanium abutment, the crown has to be cemented; screw-retained implant crowns are only an option with zirconium abutments; 3) because of the precise fit between the crown and the titanium abutment, only a minimal amount of cement can be used or the crown may not be fully seated. In addition, the restorative system has some 3-dimensional limitations, such as a need for at least 6 mm of interarch space, 2 mm of space between the implants, and at least 1 mm soft tissue around the implant (Priest 2005). However, these 3 disadvantages are encountered in almost all abutment systems. The restorative system described is one method to obtain an optimal implant suprastructure with an anatomical emergence profile.

Summary

This clinical report describes a patient with a congenitally missing mandibular premolar, replaced with a dental implant and restored with an individualized abutment. With the restorative system described, an impression is made of the healing abutment, which has codes embedded in its occlusal surface. The codes provide essential information for the computer software to place the implant analogue in the definitive cast, and to design and mill the definitive abutment.

References

Drago, C. J. (2006) Two new clinical/laboratory protocols for CAD/CAM implant restorations. *Journal of the American Dental Association* 137, 794-800.

Fuster-Torres, M. A., Albalat-Estela, S., Alcaniz-Ray, M. & Penarrocha-Diago, M. (2009) CAD/CAM dental systems in implant dentistry: Update. *Medicina oral, patología oral y cirugía bucal* 14, E141-145.

Grossmann, Y., Pasciuta, M. & Finger, I. M. (2006) A novel technique using a coded healing abutment for the fabrication of a CAD/CAM titanium abutment for an implant-supported restoration. *The Journal of Prosthetic Dentistry* 95, 258-261.

Lee, H., So, J. S., Hochstedler, J. L. & Ercoli, C. (2008) The accuracy of implant impressions: a systematic review. *The Journal of Prosthetic Dentistry* 100, 285-291.

Nissan, J. & Ghelfan, O. (2009) The press-fit implant impression coping technique. *The Journal of Prosthetic Dentistry* 101, 413-414.

Priest, G. (2005) Virtual-designed and computer-milled implant abutments. *Journal of Oral and Maxillofacial Surgery* 63, 22-32.

Raghoebar, G. M., Meijndert, L., Kalk, W. W. & Vissink, A. (2007) Morbidity of mandibular bone harvesting: a comparative study. *The International Journal of Oral & Maxillofacial Implants* 22, 359-365.

Selecman, A. M. & Wicks, R. A. (2009) Making an implant-level impression using solid plastic-press-fit, closed-tray impression copings: a clinical report. *The Journal of Prosthetic Dentistry* 101, 158-159.

Walker, M. P., Ries, D. & Borello, B. (2008) Implant cast accuracy as a function of impression techniques and impression material viscosity. *The International Journal of Oral & Maxillofacial Implants* 23, 669-674.

Chapter 8

General discussion and conclusions

General discussion and conclusions

The PhD research described in this thesis was performed to provide evidence for the application of the widely used short implants (<10 mm in length) and to analyse whether the concept of platform switching and a nanorough surface resulted in less marginal bone loss and higher survival rates of these implants.

What is known from the literature

A systematic review (Chapter 2) was performed to systematically assess the clinical outcome of short implants (<10 mm) in partially edentulous patients and to assess the sources of heterogeneity between studies by subgroup analyses (viz., length and surface topography of the implant, smoking, implant location (mandible versus maxilla) and bone augmentation procedure). It was shown, that there is fair evidence for high survival rates of short (<10 mm) implants in the partially edentulous patients, although with a tendency towards an increasing survival rate per implant length as well as a higher survival in mandibular than in maxillary bone, particularly in non smoking patients. So, placing short implants can be considered to be a sound alternative to placing implants after vertical bone grafting of resorbed mandibles or augmentation procedures of the maxillary sinus. Furthermore, surface topography and whether an augmentation procedure had been performed preceding the implant installation apparently did not affect the failure rate of short implants. Unfortunately, in the systematic review only the estimated survival rate could be used as an outcome measure, as in many studies no or insufficient data were available about peri-implant health and marginal bone loss, to allow for an analysis of the association between short implants and peri-implant health and bone loss. Furthermore, only one randomized-controlled trial could be included in our systematic review. Thus additional randomized-controlled trials are needed assessing peri-implant health and marginal bone loss as particularly these outcome parameters will provide essential information about the actual and aesthetic success of short implants. We know that a high number of implants survive, but is the condition of the surviving implant and the aesthetic result to the satisfaction of both the clinician and patient? Factors that might affect the latter outcome parameters need further study.

Marginal bone loss

The concept of platform switching was introduced to prevent marginal bone loss (Atieh et al. 2010), which has been thought to be relevant for short implants in particular as these implants might be exposed to greater compressive stress in their coronal region (Hagi et al. 2004). Therefore, a randomized-controlled trial with short implants was performed to assess whether platform switching had a beneficial effect on marginal bone loss (Chapter 3). Indeed marginal bone loss was significantly less around short implants provided with a platform-switched implant-abutment connection than around implants provided with a platform-matched connection. A mean difference of 0.24 mm in radiographic bone preservation might be only a minor difference, but a reduction in marginal bone loss of 33% (42% around single implants, 21% around 2 adjacent implants) is interesting, especially around single implants striving for perfection. In addition, one must keep in mind that the concept of platform switching is part of a number of changes in implant design to diminish marginal bone loss. As a better implant-abutment connection is suggested to decrease leakage of microbiological products from the implant and so reduces the inflammatory cell infiltrate within the implant-abutment connection (Weng et al. 2010, Pieri et al. 2011). And an optimal surface roughness up to the neck of the implant, without presence of inflammatory connective tissue, gives the possibility for bone to persist in the peri-implant region (Lang & Jepsen 2009). Furthermore, although the design of the implant neck in the peri-implant mucosa is completely different no differences could be observed in clinical parameters between platform-matched or –switched implant. It will be interesting whether this changes over a longer period of time.

Osseointegration

To enhance osseointegration and implant survival a new nanorough implant surface was introduced, viz. a dual acid-etched surface (DAE) with a nanometer-sized deposition of calcium phosphate (DAE+CaP) (Goené et al. 2007, Orsini et al. 2007). To assess the effect of the new DAE+CaP surface on bone healing, a double blind, randomized histological and histomorphometric study was performed (Chapter 4). The results of this study showed that peri-implant endosseous healing was better around mini-implants with a DAE+CaP surface than with a DAE surface in native maxillary bone, but not in bone areas reconstructed with iliac crest bone during healing and early remodelling (the mini-implants were used to fixate a bone graft form the anterior iliac crest). Apparently the DAE+CaP surface exert some properties that facilitates bone healing in existing bone, which might have some advantages when placing implants in compromised sites. However, a recently published histologic study in dogs reported higher bone-to-implant percentages (BIC%) of implants with a DAE comparing to a DAE + CaP surface (Abrahmsson et al. 2012). So, before applying implants for such an indication further study is needed to judge whether the new DAE+CaP has any benefit on implant survival and marginal bone loss in addition to the observed gain in endosseous healing in the osseointegration phase.

As a first step to elucidate the, as mentioned above, beneficial effect of the DAE+CaP surface for clinical application, two trials (Chapters 5 and 6) were performed. In these trials it was shown that, when combined with platform switching marginal bone loss around platform-switched implants with either a DAE (0.50±0.51 mm, chapter 3) or DAE+CaP surface (0.50±0.53 mm, chapter 5) was comparable one year after loading. Also the bone loss of platform-matched implants with either a DAE surface (0.74±0.48 mm, chapter 3) or

DAE+CaP surface (0.74±0.61 mm, chapter 5) was comparable. In other words, the observed reduction in marginal bone loss was mainly due to the platform switching concept and seemed irrespective of the surface of the applied implants. Our clinical observations of this nanorough surface are in line with other clinical studies (Östman et al. 2010a,b). The implants of the split mouth study (Chapter 6) showed slightly more marginal bone loss, a reason for this could be mostly 2 adjacent implants were placed. From the RCT's of chapter 3 and 5 was concluded when two or more adjacent implants were placed, marginal bone loss was slightly higher when compared with single implants.
Thus, the promising data from the histological study (Chapter 4) concerning improved early bone healing around implants with a DAE+CaP surface could not be confirmed in our clinical studies (Chapter 5 and 6).

Implant survival

The implant survival rates of the studies reported in chapter 3, 5 and 6 (92.1-95.9%) were lower than the survival rates reported for 8.5 mm implants (98.8% (95% CI: 98.2%-99.6%) in the literature (Chapter 2). The lower implant survival rates observed in our studies might be due to the higher numbers of implants placed in the maxilla than in the other studies reported in the literature and the use of a countersink. Countersinking, which had to be used according to the protocol of the manufacturer, as the applied implants had an extended platform, is known to reduce the primary stability of the implants as the outer cortical bone is removed (Renouard & Nisand 2005, 2006). The extended platform was introduced, because at the introduction of the implant, clinicians were afraid that by platform switching the implant neck would be a weak point for fracture. Today, as no fractures were reported, platform-switched implants can be straight or have an expanded platform.

Conclusions and future perspectives

From this thesis it can be concluded that short (<10 mm) implants can be placed successfully in the partially edentulous patients. But it remains important to select your cases and inform the patient, as the implant survival rate is higher in mandibular than in maxillary areas as well as that the survival rate is higher in non-smokers than in smokers.
The platform switching concept has some promise in reducing marginal bone loss. Although clinically not yet highly relevant at the 1 year post implant placement, it has to be assessed whether this beneficial effect will hold or even might increase on intermediate and long term. Furthermore, although histologically promising in enhancing peri-implant bone healing, the introduced DAE+CaP surface could not be shown to exert such a beneficial effect in clinical trials performed thus far. It has, however, still to be assessed whether the introduced DAE+CaP surface has some promise when applying in compromised cases, e.g., in patients with osteoporosis or a history of radiotherapy.

The crown implant (CI) ratio is often increased when shorter implants are placed, which has been presumed to result in greater crestal stresses on dental implants, increased marginal bone loss and prosthetic complications (Bidez & Misch 1992a,b). However, several retrospective studies could not find an association between CI ratios and marginal bone loss (Birdi et al. 2010, Gómez-Polo et al. 2010, Urdaneta et al. 2010, Schneider et al. 2012), while a prospective study showed that higher CI ratios were associated with less marginal bone loss (Blanes et al. 2007). Thus, there is a need for a clinical study to assess to the association between CI ratio and marginal bone loss and prosthetic complication. Finally, as the design of platform-switched implants has been changed over the time (e.g., no expanded platform) additional randomized clinical trials are needed applying a variety of platform switching designs to find the perfect dimensions for a platform switch.

References

Abrahmsson, I., Linder, E., Larsson, L. & Berglundh, T. (2012) Deposition of nanometer scaled calcium-phosphate crystals to implants with a dual acid-etched surface does not improve early tissue integration. *Clinical Oral Implants Research* 9, epub ahead of print.

Atieh, M. A., Ibrahim, H. M. & Atieh, A. H. (2010) Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis. *Journal of Periodontology* 81, 1350-1366.

Bidez, M. W. & Misch, C. E. (1992a) Force transfer in implant dentistry. Basic concepts and principles. *The Journal of Oral Implantology* 18, 264-274.

Bidez, M. W. & Misch, C. E. (1992b) Issues in bone mechanics related to oral implants. *Implant Dentistry* 1, 289-294.

Birdi, H., Schulte, J., Kovacs, A., Weed, M. & Chuang, S. (2010) Crown-to-implant ratios of short-length implants. *Journal of Oral implantology* 6, 425-432.

Blanes, R. J., Bernard, J. P., Blanes, Z. M. & Belser, U. C. (2007) A 10-year prospective study of ITI dental implants placed in the posterior region. II: influence of the crown-to-implant ratio and different prosthetic treatment modalities on crestal bone loss. *Clinical Oral Implants Research* 18, 707-714.

Goené, R. J., Testori, T. & Trisi, P. (2007) Influence of a nanometer-scale surface enhancement on de novo bone formation on titanium implants: a histomorphometric study in human maxillae. *The International Journal Periodontics & Restorative Dentistry* 27, 211-219.

Gómez-Polo, M., Bartens, F., Sala, L., Tamini, F., Celemín, A. & del Rio, J. (2010) The correlation between crown-implant ratios and marginal bone resorption: a preliminary clinical study. *The International Journal of Prosthodontics* 23, 33-37.

Hagi, D., Deporter, D. A., Pilliar, R. M. & Arenovich, T. (2004) A targeted review of study outcomes with short (≤ 7 mm) endosseous dental implants placed in partially edentulous patients. *Journal of Periodontology* 75, 798-804.

Lang, N. P. & Jepsen, S. (2009) Implant surfaces and design. *Clinical Oral Implants Research* 20, 228-231.

Orsini, G., Piatelli, M., Scarano, A., Petrone, G., Kenealy, J., Piatelli, A. & Caputi, S. (2007) Randomized, controlled histologic and histomorphometric evaluation of implants with nanometer-scale calcium phosphate added to the dual acid-etched surface in the human posterior maxilla. *Journal of Periodontology* 78, 209-218.

Östman, P. O., Wennerberg, A. & Albrektsson, T. (2010a) Immediate occlusal loading of NanoTite™ PREVAIL® Implants: A prospective 1-year clinical and radiographic study. *Clinical Implant Dentistry & Related Research* 12, 39-47.

Östman, P. O., Hupalo, M., del Castillo, R., Emery, R. W., Cocchetto, R., Vincenzi, G., Wagenberg, B., Vanassche, B., Valentin, A., Clausen, G., Hogan, P., Goené, R. J., Evans, C. & Testori, T. (2010b) Immediate provisionalization of NanoTite implants in suppport of single-tooth and unilateral restorations: One-year interim report of a prospective, multicenter study. *Clinical Implant Dentistry & Related Research* 12, supplement 1, e47-e55.

Pieri, F., Aldini, N. N., Marchetti, C. & Corinaldesi, G. (2011) Influence of implant-abutment interface design on bone and soft tissue levels around immediately placed and restored single-tooth implants: a randomized controlled clinical trial. *The International Journal of Oral & Maxillofacial Implants* 26, 169-178.

Renouard, F. & Nisand, D. (2005) Short implants in the severely resorbed maxilla: a 2-year retrospective clinical study. *Clinical Implant Dentistry and Related Research* 7, S104-110.

Renouard, F. & Nisand, D. (2006) Impact of implant length and diameter on survival rates. *Clinical Oral Implants Research* 17, 35-51.

Schneider, D., Witt, L. & Hämmerle, C. H. F. (2012) Influence of the crown-to-implant length ratio on the clinical performance of implants supporting single crown restorations: a cross-sectional retrospective 5-year investigation. *Clinical Oral Implants Research* 23, 169-174.

Urdaneta, R. A., Rodriguez, S., McNeil, C., Weed, M. & Chuang, S. (2010) The effect of increased crown-to-implant ratio on single-tooth locking-taper implants. *The International Journal of Oral & Maxillofacial Implants* 25, 729-743.

Weng, D., Nagata, M. J., Bell, M., de Melo, L. G. & Bosco, A. F. (2010) Influence of microgap location and configuration on peri-implant bone morphology in non-submerged implants: an experimental study in dogs. *The International Journal of Oral & Maxillofacial Implants* 25, 540-547.

Summary

Nowadays, short (<10 mm in length) implants are increasingly used for the prosthodontic rehabilitation of the partially edentulous posterior mandible or maxilla. Short implants have been associated with lower survival rates when compared to longer implants, for which are several presumed reasons. First, compared to longer implants with a comparable diameter, the available area for bone to implant contact is less when short implants are used. Secondly, in partially edentulous patients short implants are mostly placed in the posterior zone where the quality of the alveolar bone is poorer than in the anterior zone, especially in the maxilla. Thirdly, often a very outsized crown has to be made to reach occlusion, because of the extensive resorption in the posterior region, which results in a higher crown to implant ratio. To avoid the use of short implants, the alveolar bone can be augmented before implant placement using a grafting technique. This modification in the patient's anatomy makes it possible to insert a longer implant, but an extra surgical intervention also leads to greater patient's morbidity, higher costs and a longer treatment period.

There is no consensus in the literature on the definition of a short implant, however. Several authors have reviewed the literature of applying short implants in the prosthodontic rehabilitation of (partial) edentulous patients. Reviewers concluded that important confounders (e.g., length, surface topography, smoking, implant location (mandible vs. maxilla), bone augmentation procedure) needed to be addressed in future studies, as they might be a key factor for the success in the use of short implants. No systematic review with meta-analyses to determine the role of these possible predictors was yet performed on short implants in the partially edentulous patients.

Furthermore, to aim for less marginal bone resorption and even higher implant survival rates, the search for refining implant design and surface topography is continuing. This search has included the rather recent introduction of the concept of platform switching (placing a smaller-diameter abutment on a wider-diameter implant) and a changed surface topography and chemistry of the implant (nanometer-sized irregularities and deposits of calcium phosphate (CaP) on the implant surface).

It is unknown, however, whether platform switching and the changed surface and chemistry of the implant resulted in higher bone to implant contact, higher implant survival rates and less resorption of marginal bone around implants, at least with regard to short implants. Therefore, the general aim of the in this thesis described PhD research was to analyse short implants placed in the resorbed posterior region of partially dentate patients with regard to marginal bone resorption, survival rate, clinical performance and patient's satisfaction.

In **chapter 2,** a systematic review of the literature is described assessing the estimated implant survival rate of short (<10 mm) dental implants installed in partially edentulous patients as well as that sources of heterogeneity between studies by subgroup analyses were assessed (length, surface topography, smoking, implant location (mandible vs. maxilla), bone augmentation procedure). The systematic search was conducted in the electronic databases of MEDLINE (1980-October 2009) and EMBASE (1980-October 2009) to identify eligible studies. Two reviewers independently assessed the methodological quality of the articles using specific study design-related quality assessment forms. Twenty-nine methodologically acceptable studies were selected. A total of 2611 short implants (lengths 5-9.5 mm) was analysed.

The results showed that an increase in implant length was associated with an increase in implant survival within the range of 5 to 8.5 mm (93.1 – 98.8%), while further increasing the length did not result in a significantly higher implant survival. The cumulative estimated failure rate of studies performed in the maxilla was 0.010 implants/year, compared with 0.003 implants/year for implants placed in the mandible. For studies that included smokers the failure rate was 0.008 implants/year compared with 0.004 implants/year for studies that excluded smokers (combined failure rate for implants placed in the maxilla and/or mandible). Surface topography and augmentation procedure could not be shown as sources of heterogeneity.

The findings from this systematic review add to the growing evidence that short (<10 mm) implants can be placed successfully in the partially edentulous patients, though with an increasing survival rate per implant length and the prognosis may be better in the mandible of non-smoking patients.

In **chapter 3** a study is described in which was assessed whether the concept of platform switching preserved peri-implant bone around short implants (8.5 mm in length), by comparing implants with a conventional platform-matched implant-abutment connection to a platform-switched design. Eighty patients with one or more missing teeth in the posterior zone were randomly assigned to be treated with implants with either a conventional (control) or a platform-switched (mismatch 0.35-0.40 mm) implant-abutment connection (test). Follow-up visits were conducted 1 month and 1 year after placing the implant crown. Outcome measures were marginal bone loss, using standardized peri-apical radiographs, implant survival, clinical parameters and patient's satisfaction. One year after loading, marginal bone loss around test implants (0.50±0.51 mm) was significantly less than around control implants (0.74±0.48 mm) (p=0.006). Moreover, bone loss was less around 1 versus 2 adjacent implants (p=0.001), in both the test (0.29±0.36 vs. 0.70±0.54 mm) and control (0.50±0.45 vs. 0.88±0.45 mm) group. Four of 59 implants in the control group (survival 93.2%) and three of 56 implants in the test group (survival 94.6%) were lost (p>0.05). With regard to clinical parameters and patient's satisfaction no differences were observed between the test and control group. In conclusion, 1 year after loading marginal bone levels were better maintained around short implants restored according to the platform switching concept. This study suggested that marginal bone loss may be reduced by platform

switching. However, to find the perfect platform switching design comparative studies to the different designs and level of placement are needed.

In **chapter 4** a histological and histomorphometric study is described in which the early peri-implant endosseous healing properties of a dual acid-etched (DAE) surface were compared to those of a DAE surface modified with nanometer-sized calcium phosphate (CaP) particles in grafted and mature maxillary bone. Fifteen patients received two mini-implants, 1 with DAE surface (control) and 1 with a DAE + CaP surface (test) to fixate an iliac crest bone graft used for a sinus floor augmentation procedure to the maxilla. A part of each mini-implant was in contact with the grafted bone and a part extended into the native maxillary bone. After a healing period of 3 months, the specimens were harvested and analysed. Overall, a trend was seen for stronger bone response around the test mini-implants in the native bone of the maxilla. However, only the old bone particles measured by percentages of bone-to-implant contact and bone area were statistically significant (p=0.025 and p=0.042, respectively). From this chapter, it can be concluded that the DAE surface with CaP particles improved the peri-implant endosseous healing properties in the native bone of the maxilla when compared to the DAE surface, but the test surface did not improve the healing properties in the bone graft area. We assume that this might be a result of the lower remodelling process of the bone graft area, which is still in progress 3 months after grafting.

In **chapter 5** a study is described assessing the performance of short nanorough implants (8.5 mm in length) provided with either a platform-matched or a platform-switched implant-abutment connection, placed in the resorbed posterior region of partially dentate patients. A total of 149 implants with a DAE surface and a discrete crystalline deposition of nanometer-sized CaP particles, with either a platform-matched (control) or a platform-switched implant-abutment connection (test) were placed (randomly assigned) in 92 patients. Follow-up visits were conducted 1 month and 1 year after placing the implant crown. Outcome measures were marginal bone loss, using standardized peri-apical radiographs, implant survival, clinical parameters and patient's satisfaction. One year after loading, marginal bone loss around test implants (0.50±0.53 mm) was significantly less than around control implants (0.74±0.61 mm; p<0.005). Six of 76 implants in the control group (survival 92.1%) and three of 73 implants in the test group (survival 95.9%) were lost (p>0.05). With regard to clinical parameters and patient's satisfaction no significant differences were observed between test and control group.
In conclusion, for teeth replacements in the resorbed posterior region of partially dentate patients, short implants (8.5 mm in length) with a platform-switched implant-abutment connection showed significantly less peri-implant bone loss after one year in function, while implant survival, clinical parameters and patient's satisfaction were independent of the implant-connection design.

In **chapter 6** also a study is described assessing the performance of short nanorough implants (8.5 mm in length) provided with either a platform-matched or a platform-switched implant-abutment connection. The implants were placed in the resorbed posterior mandibular and maxillary region of partially edentulous patients. Seventeen patients with one or more missing teeth at both sides in the posterior region were, according to a split-mouth design, randomly assigned to be treated with a platform-matched (control) implant on the one side and a platform-switched implant (test) on the other side. A total of 62 short implants (8.5 mm) with a DAE surface with nanometer-sized CaP particles was placed. Follow-up visits were conducted 1 month and 1 year after placing the implant crown. Outcome measures were marginal bone-level changes, using standardized peri-apical radiographs, implant survival and clinical parameters. One year after loading, peri-implant bone remodelling around test implants (0.53±0.54 mm) was significant less than around control implants (0.85±0.65 mm; p=0.003). Two of 31 platform-matched and 2 of the 31 platform-switched implants were lost, both resulting in a survival rate of 93.6%. With regard to clinical parameters no significant differences were observed between test and control implants.
In conclusion, this study suggested that peri-implant bone remodelling is affected by platform switching. One year after loading, marginal bone levels were better maintained at implants restored according to the platform switching concept.

In **chapter 7** the surgical and prosthetic treatment protocol applied in **chapters 3, 5 and 6** is illustrated by a clinical report as well as that the concept of using a coded healing abutment is explained. The advantage of using a coded healing abutment is that taking an impression at the implant level is no longer necessary. In short, an impression is made of the healing abutment, which is placed onto the implant directly after implant placement. The codes embedded in the occlusal surface of the healing abutment provide essential information for the computer software to place the implant analogue in the final cast and to design and mill the individualized abutment.

The main research outcomes are discussed and general conclusions are drawn in **chapter 8**. From the PhD research described in this thesis it can be concluded that short (<10 mm) implants can be placed successfully in the partially edentulous patients. It remains important, however, to select your cases suitable for this approach and to inform the patient about the benefits and disadvantages of this treatment. Amongst others it has to be mentioned that the implant survival rate is higher in mandibular than in maxillary areas as well as that the survival rate is higher in non-smokers than in smokers.

Furthermore, it was shown that the platform switching concept has some promise in reducing peri-implant bone loss. Although clinically not yet highly relevant at the 1 year post implant placement, it has to be assessed whether the observed beneficial effect of less peri-implant bone loss will hold or even might increase on intermediate and long term. In addition, although histologically promising in enhancing peri-implant bone healing, the introduced DAE+CaP surface could not be shown to exert such a beneficial effect in clinical trials performed thus far. It has, however, still to be assessed whether the introduced DAE+CaP surface has some promise when applying in compromised cases, e.g., in patients with osteoporosis or a history of radiotherapy.

Samenvatting

Korte implantaten (<10 mm lengte) worden steeds vaker gebruikt ten behoeve van het prothetisch herstel van verloren gegane kiezen in de boven- en/of onderkaak van patiënten die voor de rest nog alle tanden en kiezen hebben (partieel dentate patiënten). In het verleden werden korte implantaten geassocieerd met meer implantaatverlies in vergelijking tot langere implantaten (>10 mm lengte), waarvoor meerdere redenen bestaan. In de eerste plaats heeft een kort implantaat minder oppervlak beschikbaar voor contact tussen bot en implantaat dan een langer implantaat met eenzelfde diameter. Ten tweede worden korte implantaten voornamelijk geplaatst in de zijdelingse delen van de boven- en onderkaak, waar, zeker in de bovenkaak, de botkwaliteit beduidend slechter is dan in de frontregio. In de derde plaats wordt, wanneer de kaak in hoogte is geslonken (resorptie), vaak een zeer grote kroon vervaardigd op een relatief kort implantaat om het kauwvlak te bereiken, wat tot een grotere kroon-implantaatratio leidt (d.w.z. dat de lengte van de kroon erg groot wordt t.o.v. de lengte van het implantaat). Bij natuurlijke elementen wordt een relatief grote kroon-wortelratio als een ongunstige belasting beschouwd voor het element.
Om het gebruik van korte implantaten te vermijden, kan het kaakbot worden opgebouwd met een bottransplantaat voordat het implantaat wordt geplaatst. Deze aanpassing in de anatomie van de patiënt maakt het mogelijk een langer implantaat te plaatsen. Maar deze extra chirurgische behandeling leidt tevens tot een grotere morbiditeit, hogere kosten en een langere behandelperiode. Aangetekend moet worden dat in de literatuur geen consensus bestaat betreffende de definitie van een kort implantaat. In dit proefschrift wordt een implantaat met een lengte van minder dan 10 mm als een kort implantaat beschouwd.

Een belangrijke factor voor het welslagen van een behandeling met korte implantaten is het minimaliseren van peri-implantair botverlies, wat dikwijls als gevolg van botresorptie optreedt, rond de hals van het implantaat (marginaal botverlies). Om minder marginaal botverlies en hogere slagingspercentages te realiseren is enige tijd geleden het zogenaamde platform-switching concept (het plaatsen van een opbouw (abutment) met een diameter kleiner dan die van het implantaat) geïntroduceerd. Daarnaast is een nieuw implantaatoppervlak op de markt gekomen, waarbij op nanoniveau middels depositie van calciumfosfaat (CaP) op het implantaatoppervlak is getracht een verfijnde oppervlakteruwheid te bereiken. Het was echter niet bekend of bij de toepassing van korte implantaten platform switching en het nanoruwe implantaatoppervlak zouden resulteren in minder resorptie van marginaal bot, in een hogere implantaatoverleving, en in, op histologisch niveau, meer bot-implantaatcontact. Daarom is in dit promotieonderzoek nagegaan wat het effect is van de toepassing van korte implantaten, met en zonder het platform-switching concept en met en zonder het nanoruwe oppervlak, in de geresorbeerde zijdelingse delen van partieel dentate patiënten op de implantaatoverleving, het bot-implantaatcontact en de conditie van de peri-implantaire harde en zachte weefsels is.

Omdat onvoldoende bekend was, wat de uitkomsten waren van de tot dusverre verrichte onderzoeken naar de toepassing van korte implantaten in de zijdelingse delen van de partieel dentate patiënt, werd een systematisch literatuuronderzoek verricht naar het overlevingspercentage van korte implantaten (lengte 5 tot 9,5 mm) (**hoofdstuk 2**). Bij dit systematisch literatuuronderzoek werd ook gekeken naar mogelijk bronnen die heterogeniteit tussen de studies zouden kunnen veroorzaken (lengte, topografie van implantaatoppervlak, roken, implantaat locatie (onderkaak versus bovenkaak), botopbouwprocedure). Het systematisch literatuuronderzoek werd uitgevoerd in de elektronische databases van MEDLINE (1980-oktober 2009) en EMBASE (1980-oktober 2009). Twee beoordelaars analyseerden onafhankelijk van elkaar de methodologische kwaliteit van de artikelen aan de hand van daartoe ontwikkelde studieopzet-gerelateerde beoordelingsformulieren. Negenentwintig methodologisch aanvaardbare studies konden worden geselecteerd waarin de resultaten van 2611 korte implantaten (lengte 5 tot 9,5 mm) werd geanalyseerd.
Uit het literatuuronderzoek kwam naar voren dat het overlevingspercentage van korte implantaten tot een lengte van 8,5 mm toenam naarmate de lengte van het implantaat opliep (van 93,1% naar 98,8%). Verder toename van implantaatlengte resulteerde niet in significant hogere overlevingspercentages van de implantaten. Voorts bleken meer implantaten in de bovenkaak (0,010 implantaat/jaar) verloren te gaan dan in de onderkaak (0,003 implantaat/jaar). Ook lijkt roken een slechte invloed te hebben op de implantaatoverleving; studies die rokers includeerden, rapporteerden een hoger implantaatverlies (0,008 implantaat/jaar) dan studies waarin rokers waren geëxcludeerd (0,004 implantaat/jaar). De oppervlakteruwheid en de botopbouwprocedure bleken geen heterogeniteit te veroorzaken.
De bevindingen uit dit systematisch literatuuronderzoek ondersteunen het groeiende bewijs dat korte implantaten (<10 mm) met succes kunnen worden geplaatst in de partieel dentate patiënt, maar met een hogere implantaatoverleving wanneer een langer implantaat (tot 8,5 mm) wordt geplaatst en met de beste prognose in de onderkaak van de niet-rokende patiënt.

In **hoofdstuk 3** wordt een studie beschreven waarin is nagegaan of toepassing van het platform–switching concept leidt tot beter behoud van het marginale bot rondom korte implantaten (8,5 mm). Tachtig patiënten met één of meer ontbrekende kiezen in de zijdelingse delen werden na randomisatie behandeld met een implantaat met een platform-switch (verschil in diameter tussen breedte van het implantaat en het abutment: 0.35-0.40 mm; testgroep) of een conventioneel/platform-match (diameter van het implantaat en het abutment zijn gelijk; controlegroep) implantaat-abutmentconnectie. Na zowel één maand

als na één jaar na het plaatsen van de kroon op het implantaat werd het marginale peri-implantaire botverlies beoordeeld aan de hand van gestandaardiseerde röntgenfoto's. Tevens werd gekeken naar de implantaatoverleving, klinische peri-implantaire parameters en patiënttevredenheid.
Eén jaar na het plaatsen van de kroon bleek het marginale peri-implantaire botverlies in de testgroep (0,50±0,51 mm) significant geringer te zijn dan in de controlegroep (0,74±0,48 mm) (p=0,006). Het botverlies rond twee aangrenzende implantaten bleek voorts, zowel in de test- als controlegroep groter te zijn dan bij toepassing van één enkel implantaat (testgroep: 0,70±0,54 versus 0,29±0,36 mm; controlegroep: 0,88±0,45 versus 0,50±0,45 mm; p=0,001). Vier van 59 implantaten in de controlegroep (overleving 93,2%) en drie van 56 implantaten in de testgroep (overleving 94,6%) gingen verloren (p>0,05). Met betrekking tot de klinische parameters en patiënttevredenheid konden geen verschillen tussen de test- en controlegroep worden aangetoond.
Uit deze studie word de conclusie getrokken dat na één jaar in functie het marginale bot rondom korte implantaten, geplaatst in de zijdelingse delen van de partieel dentate patiënt, beter behouden blijft wanneer een platform-switch implantaat-abutmentconnectie wordt toegepast. Implantaatoverleving, klinische parameters en patiënttevredenheid blijken niet afhankelijk te zijn van het ontwerp van deze connectie.

In **hoofdstuk 4** wordt een histologische en histomorfometrische studie beschreven waarin de osseointegratiefase (vastgroeifase van het implantaat) van een dubbel geëtst implantaatoppervlak (dual acid-etched=DAE) is vergeleken met een dubbel geëtste oppervlak waarop tevens nanopartikeltjes van CaP zijn afgezet (DAE+CaP). Bij 15 patiënten werden twee mini-implantaten, één met een DAE-oppervlak (controle) en één met een DAE+CaP-oppervlak (test), aangebracht om een bottransplantaat, geoogst uit de crista iliaca, te fixeren tegen het bot van de bovenkaak. Elk mini-implantaat was deels in contact met het getransplanteerde bot en deels met het bot van de bovenkaak. Na 3 maanden werden de mini-implantaten met een 'appelboor' verwijderd, hierbij werd het implantaat tezamen met het bot dat in direct contact staat met dit implantaat verwijderd.
De meeste botvorming, gemeten als het percentage bot-implantaatcontact en het botvolume dat aanwezig is in één implantaatwinding, werd waargenomen rond de test mini-implantaten in het oorspronkelijke bot van de bovenkaak.
Uit dit hoofdstuk kan worden geconcludeerd dat een DAE-oppervlak waarop CaP nanopartikeltjes zijn afgezet de peri-implantaire botgenezing bevordert in die kaakdelen waarin het implantaat in contact staat met het oorspronkelijke bot. In botdelen die zich in de eerste drie maanden na de transplantatie nog sterk aan het ombouwen zijn (dat zijn de delen van de bovenkaak waarin het bottransplantaat werd aangebracht om een voldoende botvolume voor het aanbrengen van implantaten te creëren), wordt een dergelijk positief effect van het DAE+CaP-oppervlak niet waargenomen.

In **hoofdstuk 5** wordt een studie beschreven waarin korte implantaten (8,5 mm met het bovengenoemde DAE+CaP-oppervlak) enerzijds met een platform-switch (testgroep) en anderzijds met een platform-match (controlegroep) implantaat-abutmentconnectie werden toegepast. Een totaal van 149 implantaten werd in de geresorbeerde zijdelingse delen geplaatst van 92 partieel dentate patiënten. Na zowel één maand als na één jaar na het plaatsen van de kroon op het implantaat werd het marginale peri-implantaire botverlies beoordeeld aan de hand van gestandaardiseerde röntgenfoto's. Tevens werd gekeken naar de implantaatoverleving, klinische peri-implantaire parameters en de patiënttevredenheid.
Eén jaar na het plaatsen van de kroon bleek het marginale peri-implantaire botverlies in de testgroep (0,50±0,53 mm) significant geringer te zijn dan in de controlegroep (0,74±0,61 mm) (p <0,005). Zes van de 76 implantaten in de controlegroep (overleving 92,1%) en drie van de 73 implantaten in de testgroep (overleving 95,9%) gingen verloren (p> 0,05). Met betrekking tot de klinische parameters en patiënttevredenheid konden geen significante verschillen tussen test- en controlegroep worden aangetoond.
Uit deze studie wordt de conclusie getrokken dat na één jaar in functie het marginale bot rondom korte implantaten, geplaatst in de zijdelingse delen van de partieel dentate patiënt, beter behouden blijft wanneer een platform-switch implantaat-abutmentconnectie wordt toegepast. Implantaatoverleving, klinische parameters en patiënttevredenheid blijken niet afhankelijk te zijn van het ontwerp van deze connectie.

In **hoofdstuk 6** wordt een zogenaamde split-mouth studie beschreven, waarin de prestaties van het korte implantaat (8,5 mm) met een DAE+CaP-oppervlak, enerzijds met een platform-switch (testgroep) en anderzijds met een platform-match (controlegroep) implantaat-abutmentconnectie werden vergeleken. De implantaten werden geplaatst in de geresorbeerde zijdelingse delen van óf de onderkaak óf de bovenkaak van partieel dentate patiënten. Zeventien patiënten met één of meer ontbrekende kiezen in beide zijden van de zijdelingse delen werden geïncludeerd. Aan de ene zijde werd een implantaat met een platform-switch geplaatst (test), aan de andere zijde een implantaat met een platform-match connectie (controle). In totaal werden 62 korte implantaten (8,5 mm) geplaatst. Na zowel één maand als na één jaar na het plaatsen van de kroon op het implantaat werd het marginale peri-implantaire botverlies beoordeeld aan de hand van gestandaardiseerde röntgenfoto's. Tevens werd gekeken naar de implantaatoverleving en naar klinische peri-implantaire parameters.
Eén jaar na het plaatsen van de kroon bleek het marginale peri-implantaire botverlies in de testgroep (0,53±0,54 mm) significant geringer te zijn dan in de controlegroep (0,85±0,65 mm; p=0,003). Twee van de 31 implantaten in de controlegroep en twee van de 31 implantaten in de testgroep gingen verloren, wat in beide groepen in een overlevingspercentage van 93,6% resul-

teerde. Met betrekking tot de klinische parameters konden geen verschillen tussen de test- en controlegroep worden aangetoond.
Kortom, ook uit deze studie komt naar voren dat de peri-implantaire botniveau positief wordt beïnvloed door platform switching, in de zin dat minder verlies van marginaal peri-implantair bot optreedt.

In **hoofdstuk 7** wordt het chirurgische en prothetische behandelprotocol beschreven dat in de klinische studies van **hoofdstuk 3, 5 en 6** is toegepast, inclusief het concept van het gebruik van een gecodeerd abutment tijdens de inhelingsfase van het implantaat. Het voordeel van het toepassen van een gecodeerd abutment is dat het nemen van een afdruk op implantaatniveau, d.w.z. een niveau dat gewoonlijk onder het tandvlees ligt, niet meer nodig is. Er kan namelijk worden volstaan met het maken van een afdruk gemaakt van het gecodeerde abutment. Dit abutment is al direct na plaatsen van het implantaat op het implantaat geschroefd. De op de bovenzijde van het abutment aanwezige codering voorziet in de benodigde informatie voor de computer om op de juiste wijze het implantaatanaloog te plaatsen in het gipsmodel en het definitieve, individuele abutment te ontwerpen.

In **hoofdstuk 8** worden de belangrijkste onderzoeksresultaten in een groter verband besproken en algemene conclusies getrokken. Geconcludeerd kan worden dat korte (<10 mm) implantaten met succes kunnen worden geplaatst in de zijdelingse delen van partieel dentate patiënten, waarbij moet worden aangetekend dat de overlevingskans van korte implantaten in de onderkaak hoger is dan in de bovenkaak en dat de overlevingskans van de implantaten negatief wordt beïnvloed door roken.
Voorts kon worden aangetoond dat het platform-switching concept een gunstig effect lijkt te hebben op het behoud van het niveau van het peri-implantaire bot. Omdat de 1-jaars resultaten klinisch nog niet allesbepalend zijn, moet in 5- of 10-jaars studies worden beoordeeld of het waargenomen gunstige effect van minder marginaal botverlies blijvend is op de middellange en lange termijn. Bovendien moet verder worden gezocht naar het ideale ontwerp van de platform-switch en het niveau waarop het implantaat moet worden geplaatst.
Hoewel op histologisch niveau een betere botgenezing werd gezien rond implantaten met een DAE+CaP-oppervlak, kon dit positieve effect klinisch (nog) niet worden aangetoond. Wellicht kan het DAE+CaP-oppervlak klinisch wel een gunstig effect hebben op de peri-implantaire botgenezing in gecompromitteerde patiënten, bijvoorbeeld in patiënten met osteoporose of in patiënten met een voorgeschiedenis van radiotherapie in het gebied waar het implantaat moet worden geplaatst.

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Dankwoord

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Curriculum Vitae

Gerdien Telleman was born on May 5th 1980 in Amsterdam, the Netherlands. During secondary school (gymnasium; Kandinsky College Nijmegen), she followed two years of preparatory courses in violin at the School of Music in Arnhem. After finishing the secondary school in 1998, she went for one year to Israel to work as a volunteer in kibbutz Nes Ammim. In 1999 she started her study Dentistry at the University of Groningen. During her study she went for elective courses in oral pathology and oral oncology (with prof. J.J. Hille) to the Groote Schuur Hospital, Cape Town, South Africa. She obtained her dental degree in 2004. In 2005 she started her PhD research project at the department of Oral and Maxillofacial Surgery and Maxillofacial Prosthetics of the University Medical Center Groningen. She is also working as a dentist in a private practice 'van Asperen Tandheelkunde' in Bolsward and at the Centre for Dentistry and Oral Hygiene, University Medical Center Groningen, Groningen. Gerdien is married to René Jacques de Vries. Together they have a son, Douwe Olivier, who was born on January 12th 2011. On the first of December this year they are expecting their second child.

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