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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

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Key words: dental implant, surface roughness, nanoparticles, CaP, implant–abutment connection, platform switching, short implants, bone-level changes, survival, patient satisfaction

Abstract

Objective: 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 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 implant survival, radiographic peri-implant bone loss, clinical parameters, and patient's satisfaction.

Results: One year after loading, 6 of 76 implants in the control group (survival 92.1%) and 3 of 73 implants in the test group (survival 95.9%) were lost ($P = 0.33$). Radiographic bone loss around test implants (0.50 ± 0.53 mm) was significantly less than around control implants (0.74 ± 0.61 mm; $P < 0.005$). With regard to implant survival, clinical parameters, and patient's satisfaction, no significant differences were observed between test and control group.

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

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 the 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

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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; Kotsovilis 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 osteogenic 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, histologic 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, that is, placing a smaller-diameter abutment on a wider-diameter implant. The mismatch between the 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 and 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 crestal bone resorption by maintaining the inflammatory cell infiltrate within the implant-abutment connection (Ericsson et al. 1995, 1996; Brogini 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 peri-implant 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 peri-implant 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 10mm bone in vertical dimension and a minimum of 5mm bone in horizontal dimension available.

Exclusion criteria were as follows:

- medical and/or general contraindications for the surgical procedures (ASA score \geq III (Smeets et al. 1998));
- presence of active clinical periodontal disease in the dentition as expressed by probing pocket depths \geq 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 enrollment, 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 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 and 0.11 mm (for implants with a diameter of 4 and 5 mm, respectively) above the level of implant placement (Fig. 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 (Fig. 1b). The implant types used, which both were made of the same titanium alloy, had a dual-acid-etched (using hydrochloric and sulfuric acids) surface with a discrete crystalline deposition of nanometer-sized CaP particles. The CaP deposit on the dual-acid-etched

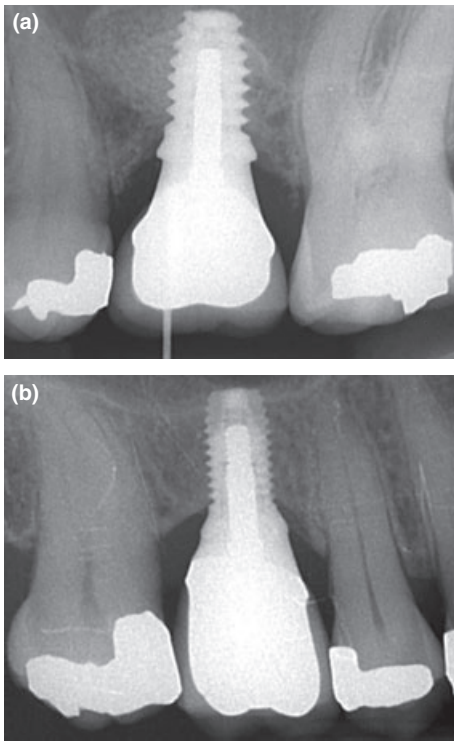


Figure 1. (a). Dental radiograph of a test implant (NanoTite Certain Prevail, Biomet 3i). (b) Dental radiograph of a control implant (NanoTite XP Certain, Biomet 3i).

(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, that is, 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 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 neighboring 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 boss (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 I, 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). One dental technician fabricated the metal-ceramic crowns.

Outcome measures

The primary outcome measure was the mean peri-implant 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 neighboring 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 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, Helsinki, Finland) were taken using a paralleling technique. For each patient, an individualized X-ray holder was made to standardize the peri-apical radiographs (Fig. 2). The radiograph taken before implant placement was only used for diagnostic reasons to detect any infection of abnormality. The radiographs were analyzed 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 \times 20 patients \times 2 (mesial, distal) bone level assessments)



Figure 2. Individualized X-ray holder to make standardized intra-oral dental radiographs.

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 neighboring 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 (L oe & Silness 1963);
- Presence of dental calculus;
- Sulcus probing pocket depth: measured to the nearest millimeter 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.

Patient's satisfaction

Patient's satisfaction was assessed using a self-administered questionnaire to be completed at T_{pre} and T_{5m} . The questionnaire comprised 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 esthetics, 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 a 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 clinically

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 peri-implant bone-level changes (scored on peri-apical radiographs), two-way random models were used to calculate the interclass 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 performed. As the variables were not normally distributed, Mann-Whitney tests were used for between groups comparisons.

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 peri-implant bone loss was dependent on the possible confounders numbers of implants placed, 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 analyzed using the Statistical Package for Social Sciences (version 16.0, SPSS Inc, Chicago, IL, USA).

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.

Peri-implant bone-level changes

The intraclass correlation coefficient for average measures was 0.867 for the radiographic interobserver agreement (Cronbach's $\alpha = 0.867$), which can be interpreted as

almost perfect agreement (Viera & Garrett 2005).

Fig. 3 shows the frequency distributions of the mean peri-implant bone loss of the control group with the platform-matched implant-abutment connection and the test group with the platform-switched implants. Overall, mean peri-implant bone loss 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 peri-implant bone loss in cases provided with one implant, no difference in peri-implant bone loss was observed; 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). The effect size of the total group of implants was -0.39 , of single implant placed 0 and of 2 or more adjacent implants -0.45 , respectively.

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 three 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, gingival index (Table 3) were observed.

Confounders

Compared with bone loss around single implants, peri-implant bone loss was found to be significantly ($P = 0.001$) higher when two or 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

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 (mm)		
4.1	60	52
5.0	16	21
Microbiology (before implant placement)		
Within normal range	19	16
<i>Aggregatibacter actinomycetemcomitans</i> > 0.0%	1	1
<i>Porphyromonas gingivalis</i> > 0.0%	0	1
<i>Prevotella intermedia</i> > 2.5%	1	1
<i>Bacteroides forsythus</i> > 3.0%	1	0
<i>Peptostreptococcus micros</i> > 3.0%	7	4
<i>Fusobacterium nucleatum</i> > 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 (%) (mm)		
1	0.0	0
2	41.0	44.1
3	47.5	47.5
4	11.5	3.4
>4	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
Guided bone regeneration applied	2	1

about the color 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, peri-implant 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 favorable results. A difference of 0.24 mm in radiographic bone preservation might not be clinical relevant, but a reduc-

tion in bone resorption of 33% is interesting, striving for perfection. The peri-implant bone loss around platform-switched implants resembled the peri-implant 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 peri-implant bone loss, so, also these implants were included in the analysis.

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

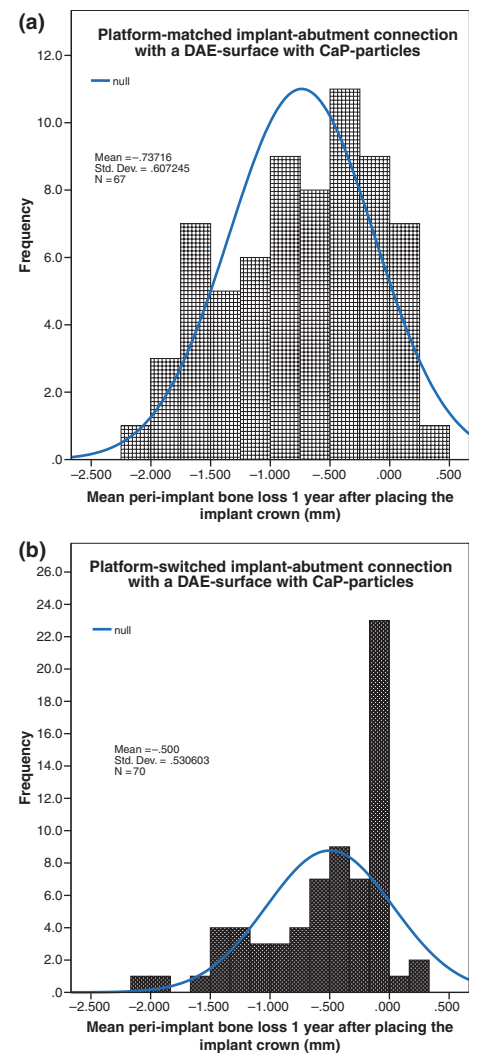


Figure 3. Frequency distributions of the mean peri-implant bone loss of the 67 control (panel a) and 70 test (panel b) implants. Both distributions differ significantly from a normal distribution (blue curve).

implants (98.8%; 95% CI: 98.2–99.6%) in the systematic review of Telleman et al. (2011a, b). 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 to 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

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

	$T_{0m}-T_{5m}$		$T_{5m}-T_{16m}$		$T_{0m}-T_{16m}$	
	Platform-matched (n = 76)	Platform-switched (n = 73)	Platform-matched (n = 76)	Platform-switched (n = 73)	Platform-matched (n = 76)	Platform-switched (n = 73)
All implants (n=number of implants)						
Implant bone-level changes (mm)	-0.76 (\pm 0.60)*	-0.51 (\pm 0.56)*	0.03 (\pm 0.30)	0.02 (\pm 0.30)	-0.74 (\pm 0.61) [†]	-0.50 (\pm 0.53) [†]
1 implant (n = number of patients)						
	$T_{0m}-T_{5m}$		$T_{5m}-T_{16m}$		$T_{0m}-T_{16m}$	
	Platform-matched (n = 20)	Platform-switched (n = 19)	Platform-matched (n = 20)	Platform-switched (n = 19)	Platform-matched (n = 20)	Platform-switched (n = 19)
Implant bone-level changes (mm)	-0.42 (\pm 0.56)	-0.41 (\pm 0.52)	-0.02 (\pm 0.24)	0.05 (\pm 0.26)	-0.36 (\pm 0.53)	-0.36 (\pm 0.43)
Pocket probing depth changes (mm)						
Implant	-	-	-0.10 (\pm 1.17)	-0.09 (\pm 0.66)	-0.10 (\pm 1.17)	-0.09 (\pm 0.66)
Tooth mesially of the implant	0.06 (\pm 0.53)	0.07 (\pm 0.40)	-0.02 (\pm 0.52)	0.00 (\pm 0.29)	0.06 (\pm 0.48)	0.07 (\pm 0.33)
Tooth distally of the implant	-0.40 (\pm 0.46)	0.17 (\pm 0.88)	0.27 (\pm 0.54)	-0.13 (\pm 0.65)	-0.11 (\pm 0.50)	0.03 (\pm 0.52)
2 or more implants (n=number of patients)						
	$T_{0m}-T_{5m}$		$T_{5m}-T_{16m}$		$T_{0m}-T_{16m}$	
	Platform-matched (n = 27)	Platform-switched (n = 26)	Platform-matched (n = 27)	Platform-switched (n = 26)	Platform-matched (n = 27)	Platform-switched (n = 26)
Implant bone-level changes (mm)	-0.85 (\pm 0.58) [‡]	-0.56 (\pm 0.57) [‡]	0.05 (\pm 0.31)	0.01 (\pm 0.31)	-0.82 (\pm 0.60) [§]	-0.55 (\pm 0.56) [§]
Pocket probing depth changes (mm)						
Implant	-	-	-0.24 (\pm 0.62)	-0.28 (\pm 0.60)	-0.24 (\pm 0.62)	-0.28 (\pm 0.60)
Tooth mesially of the implant	0.08 (\pm 0.54)	0.04 (\pm 0.58)	-0.08 (\pm 0.54)	-0.16 (\pm 0.51)	0.00 (\pm 0.44)	-0.17 (\pm 0.68)
Tooth distally of the implant	-0.50 (\pm 0.66)	-0.46 (\pm 0.33)	-0.75 (\pm 0.79)	-0.28 (\pm 0.56)	-0.50 (\pm 0.79)	-0.50 (\pm 0.47)
For between-group comparisons: * $P = 0.005$, [†] $P = 0.017$, [‡] $P = 0.003$, [§] $P = 0.015$.						

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 peri-implant 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 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 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 favorable 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 the 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 significantly more bone response to surfaces with particles of hydroxyapatite or CaP of different nanosizes after 2–4 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 significantly more bone to implant 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 nanoroughened 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 patients' satisfaction, thus no conclusive conclusion could be drawn.

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 in single or 2 or more adjacent implants placed

Clinical parameters	% at T _{0m}				% at T _{5m}				% at T _{16m}			
	Platform-matched		Platform-switched		Platform-matched		Platform-switched		Platform-matched		Platform-switched	
	1	≥2	1	≥2	1	≥2	1	≥2	1	≥2	1	≥2
(n = number of patients)	(n = 20)	(n = 27)	(n = 19)	(n = 26)	(n = 20)	(n = 27)	(n = 19)	(n = 26)	(n = 20)	(n = 27)	(n = 19)	(n = 26)
Implant Plaque Index*												
Score 0, no detection of plaque	–	–	–	–	84.2	90.2	84.6	90.7	84.2	70.6	91.7	75.9
Score 1, plaque on probe	–	–	–	–	15.8	9.8	15.4	9.3	15.8	21.6	0	14.8
Score 2, plaque seen by naked eye	–	–	–	–	0	0	0	0	0	7.8	0	9.3
Score 3, abundance of soft matter	–	–	–	–	0	0	0	0	0	0	0	0
Implant Bleeding Index*												
Score 0, no bleeding	–	–	–	–	52.6	74.5	69.2	70.4	63.2	65.3	83.3	66.7
Score 1, isolated bleeding spots	–	–	–	–	42.1	25.5	30.8	29.6	36.8	32.7	16.7	29.6
Score 2, confluent line of blood	–	–	–	–	5.3	0	0	0	0	2.0	0	3.7
Score 3, heavy or profuse bleeding	–	–	–	–	0	0	0	0	0	0	0	0
Implant Gingival Index†												
Score 0, normal mucosa	–	–	–	–	89.5	94.1	100	92.6	94.7	96.1	91.7	90.7
Score 1, mild inflammation	–	–	–	–	10.5	5.9	0	7.4	5.3	3.9	8.3	9.3
Score 2, moderate inflammation	–	–	–	–	0	0	0	0	0	0	0	0
Score 3, severe inflammation	–	–	–	–	0	0	0	0	0	0	0	0
Implant dental calculus												
Score 0, no dental calculus	–	–	–	–	100	100	100	100	100	100	100	100
Score 1, dental calculus present	–	–	–	–	0	0	0	0	0	0	0	0
Adjacent teeth Plaque index*												
Score 0, no detection of plaque	50.0	66.7	73.7	65.7	76.5	93.9	88.0	78.1	85.3	88.2	91.3	90.9
Score 1, plaque on probe	41.2	33.3	23.7	34.3	23.5	6.1	12.0	18.8	14.7	8.8	8.7	9.1
Score 2, plaque seen by naked eye	8.8	0	2.6	0	0	0	0	3.1	0	2.9	0	0
Score 3, abundance of soft matter	0	0	0	0	0	0	0	0	0	0	0	0
Adjacent teeth Bleeding index*												
Score 0, no bleeding	76.5	77.8	76.3	80.0	82.4	90.9	88.0	84.4	94.1	88.6	100	97.0
Score 1, isolated bleeding spots	20.6	22.2	23.7	17.1	17.6	9.1	12.0	15.6	5.9	11.4	0	3.0
Score 2, confluent line of blood	2.9	0	0	2.9	0	0	0	0	0	0	0	0
Score 3, heavy or profuse bleeding	0	0	0	0	0	0	0	0	0	0	0	0
Adjacent teeth Gingival Index†												
Score 0, normal mucosa	91.2	91.7	100	94.3	100	93.9	100	100	100	100	100	100
Score 1, mild inflammation	8.8	8.3	0	5.7	0	6.1	0	0	0	0	0	0
Score 2, moderate inflammation	0	0	0	0	0	0	0	0	0	0	0	0
Score 3, severe inflammation	0	0	0	0	0	0	0	0	0	0	0	0
Adjacent teeth dental calculus												
Score 0, no dental calculus	88.2	88.9	92.1	94.3	91.2	93.9	92.0	93.8	94.1	100	100	91.2
Score 1, dental calculus present	11.8	11.1	7.9	5.7	8.8	6.1	8.0	6.3	5.9	0	0	8.8

*Mombelli et al. (1987).

†Löe & Silness (1963).

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 vs. 2.3% postoperative. Patients were especially satisfied about the ability to chew, the color

and the form of the crown and more indifferent about the color and the 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 den-

Table 4. Patients' satisfaction before and after the implant therapy

	Patients in agreement with an item at T _{pre}		Patients in agreement with an item at T _{sm}	
	Platform-matched (n = 47)	Platform-switched (n = 45)	Platform-matched (n = 47)	Platform-switched (n = 45)
Feelings				
Presence of shame	23/47	19/45	0/45*	0/45*
Self-confidence decreased	12/47	15/45	0/45*	0/45*
Self-confidence increased	1/47	0/45	21/47*	21/45*
Visible being partial edentulous	26/47	29/45	0/45*	0*
Function				
Evade eating with the edentulous zone/ implant	31/47	32/45	1/47*	1/45*
The ability to chew is decreased	31/47	32/45	5/47*	6/45*
The ability to chew is increased	3/47	0/45	34/47*	31/45*
Implant does influence the speech	–	–	2/47	3/45
Implant does influence the taste	–	–	1/47	1/45
Esthetics				
Satisfied with the colour of the crown	–	–	26/47	33/45
Satisfied with the form of the crown	–	–	32/47	38/45
Satisfied with the colour of the mucosa around the crown	–	–	23/47	28/45
Satisfied with the form of the mucosa around the crown	–	–	18/47	26/45
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 ($P = 0.000$).

tate patients, short implants (8.5 mm in length) with a platform-switched implant–abutment connection showed significantly less peri-implant bone loss after 1 year in function, while implant survival, clinical parameters, and patient's satisfaction were

independent of the implant–abutment connection design.

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