Clinical and radiographic evaluation of narrow- vs. regular-diameter dental implants: a 3-year follow-up. A retrospective study

Key words: bone resorption, mandible, narrow-diameter dental implants, overdenture

Abstract

Objectives: Narrow-diameter implants (NDIs) are used in severely resorbed mandibles. The reduced implant diameter means a reduction in the total contact surface between the implant and bone. The question arises whether the implant can be sufficiently osseointegrated to withstand loading forces. If not, marginal bone loss can result from overload. The aim of this retrospective study was to compare clinical and radiographic measurements and patient satisfaction of NDIs with those of regular-diameter implants (RDIs) placed in edentulous patients to support an overdenture via either a ball or a locator connection.

Material and Methods: Retrospectively over a 7-year period, a total 119 patients fulfilled the inclusion criteria and were selected for this study. The patients received two 3.3- or 4.1-mm-diameter standard titanium implants in the mandible to support an overdenture. At maintenance examinations after 1 and 3 years, clinical peri-implant and prosthetic conditions, marginal bone (MB) and patient satisfaction were investigated.

Results: None of the 238 implants were lost during the 3-year follow-up period. Overall MB loss was statistically higher in the NDI group when compared with the RDI group. At the site level, a greater MB loss was observed at the distal side of both implant types. Implants with a locator showed significantly greater MB loss (0.38 mm) compared with the implants with a ball attachment (0.14 mm) over the two-year evaluation period ($P = 0.006$). Patient satisfaction significantly favoured the NDI (8.3) and the locator attachment (8.6).

Conclusions: The results suggest that during the first three years after implantation, NDIs were associated with more marginal bone loss compared with RDIs. Regardless of implant diameter, the locator attachment showed more marginal bone loss over time compared with the ball attachment.

Osseointegration, the method of direct anchorage of endosseous oral implants in the jawbone, represents a breakthrough in oral rehabilitation. It is a well-documented modality for treating partially or completely edentulous patients (Brånemark et al. 1977). Oral implants of various designs have become highly predictable over the last decades. However, the geometry and volume of the available bone can limit their use.

Narrow implants

The choice of implant diameter depends on the type of edentulism, the volume of the residual bone, the amount of space available for the prosthetic reconstruction, the emergence profile and the type of occlusion. In general, it seems that the guidelines developed for the surgical placement and prosthetic restoration of regular-diameter implants (RDIs; diameter $\geq 3.5$ mm) can be applied to Narrow-diameter implants (NDIs; Degidi et al. 2008). Narrow-diameter implants (diameter <3.5 mm) have specific clinical indications, for example, they are used in areas where the ridge dimension is narrow and to replace teeth with a small cervical diameter. However, decreasing the diameter also means increasing the risk of implant fracture caused by lower mechanical stability and increasing the risk of overload (Schwarz 2000, Vigolo et al. 2004; Comfort et al. 2005).

The literature shows that a reduction in the implant diameter may decrease the osseointegrated surface and compromise the
mechanical properties of the implant body, screw and abutment components [Petrie & Williams 2005; Quck et al. 2006]. Wider implants have proven to be more mechanically resistant. It is reported that the removal of osseointegrated wide-diameter implants requires higher removal torque forces compared with smaller-diameter implants [Ivanoff et al. 1997; Degidi et al. 2007]. In addition, one might wonder whether a reduced diameter, which means a reduction in the contact surface between implant and bone, is sufficient to withstand the necessary loading forces [Zinsli et al. 2004].

In contrast to the natural tooth, the presence of a dental implant alters the strain and stress levels in the bone for several reasons, including the absence of cushioning provided by the periodontal ligament and morphological differences in the material properties of the implant vs. a natural tooth [Chou et al. 2010]. When the tooth is in use, vertical and horizontal occlusal loads are generated, and these loads develop stress gradients in the implant structure and surrounding bone. The manner in which an implant, the mesostructure and the prosthetic transfer these axial and off-axial forces and bending movements towards the supporting bone affects the survival and long-term stability of the crestal bone [Ormianer et al. 2012].

Alterations in loading conditions can result in bone remodelling [Chou et al. 2010]. A persistent overload may provoke micro-fractures in the alveolar bone, increasing stress and osteoclastic activity in the region [Anitua et al. 2010]. This biomechanical overload may lead to marginal bone resorption.

Full-body screw NDIs have shown success and survival rates comparable with those of RDI [Andersen et al. 2001; Romeo et al. 2006; Degidi et al. 2008] with the exception of implants in areas of low bone quality [Type 4; van Steenberghhe et al. 1990; Lekholm 1992]. The long-term (>10 years) results of moderately rough-surface NDIs have been reported by only a few authors [Zinsli et al. 2004; Arisan et al. 2010]. NDI placement can be a viable alternative when bone-augmented surgery is indicated in patients with thin posterior mandibular ridges. Under these conditions, NDIs have been used successfully in delayed-loading conditions [Vigolo et al. 2004; Zinsli et al. 2004; Comfort et al. 2005].

Aim of the study

The aim of this retrospective study was to compare over a 3-year period the clinical and radiographic measurements and patient satisfaction of narrow-diameter implants (NDIs) with those of RDI placed in edentulous patients using two types of retention systems.

Materials and methods

Study population

This retrospective study enrolled all patients treated with an implant-retained overdenture in the mandible in a private dental clinic in Drachten, the Netherlands, between 2004 and 2011.

The patients received an overdenture based on the following prerequisites:

- fully edentulous;
- suffering from insufficient lower denture retention and stability; and
- sufficient residual bone height (≥8 mm) for implant placement between the mental foramina, as assessed via panoramic usage and lateral cephalogram.

The patients included in this study were in good general health and included those with well-controlled diabetes and those using anti-coagulants. Excluded were those who had a history of radiotherapy in the head/neck region.

Patients were included if they had returned for their annual maintenance visits and had had radiographs taken 1 and 3 years post-implant placement.

The patients received an implant-retained lower overdenture on two implants with either a locator or a ball attachment using two standard Straumann implants at the 33–32 and 42–43 positions. The implant diameter was chosen by the operator according to the width of the patient’s residual jaw. The patients received either two regular-diameter implants (RDIs, 4.1 mm Straumann) or two narrow-diameter implants (NDIs, 3.3 mm Straumann).

Additional patient exclusion criteria included non-compliance with the annual follow-up (72%), one or more radiographs not suitable for radiographic assessments (7%), bone grafts of local GBR procedures performed before implant placement, missing data [e.g. insufficient medical history], different implant lengths or widths in the same patient or the use of an implant system other than Straumann (5%).

Over the review period, 810 patients were treated, and their data were screened to evaluate whether they met the abovementioned criteria. In total, 119 patients fulfilled the inclusion criteria (Table 1).

Surgical and prosthetic treatment

All of the implant surgeries were performed by three experienced implantologists (AVD, EAHH and GAW) recognised by the Dutch Society of Oral Implantology [NVOI]. A total of 238 sandblasted acid-etched SLA standard titanium implants [Institut Straumann AG, Basel, Switzerland] were included in the study.

All of the patients underwent the same surgical protocol. Peri-operative antimicrobial prophylaxis (amoxicillin [solutab], 500 mg three times daily) was provided 2 days before surgery and up to 5 days afterwards. The patients s with chlorhexidine [0.2%Corsodyl, Glaxo Smith Kline, Zeist, the Netherlands] for one minute twice daily for 2 weeks, starting the day of surgery. Local anaesthesia was induced by infiltration [Lignospan, 2% special, lidocaine hydrochloride 20 mg/ml [2%], ephinephrine tartarate (epinephrine 0.0125 mg/ml), Septodont nvs-a, Brussels, Belgium], and post-operative analgesia consisted of paracetamol [500 mg] tablets taken 30 min post-operation and as needed afterwards. To raise a full-thickness flap, a crestal incision with a vertical releasing incision in the midline was used. The recipient site was prepared, and bone tapping was included according to the manufacturer’s one-stage surgical protocol. The rough surface area of all implants was completely embedded in bone. A prefabricated surgical guide was used during implant placement. Standard non-submerged healing abutments (2–5 mm) were screwed onto the implants to ensure transmucosal positioning. Mattress and non-interrupted single sutures [3-0 Perma-Hand silk [EH7343H], Ethicon® division of Johnson & Johnson, Livingston, UK] were placed to close the flap. After surgery,

<table>
<thead>
<tr>
<th>Table 1. Number of included and excluded patients and distribution of reasons for exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total number of patients treated between 2004 and 2011</strong></td>
</tr>
<tr>
<td>Number of included patients</td>
</tr>
<tr>
<td>Number of excluded patients</td>
</tr>
<tr>
<td>Reasons for exclusion</td>
</tr>
<tr>
<td>Follow-up did not comply with protocol</td>
</tr>
<tr>
<td>One or more radiographs were not suitable for assessments</td>
</tr>
<tr>
<td>Missing data (e.g. insufficient retrievable medical history), different implant diameters or lengths used in the same patient</td>
</tr>
</tbody>
</table>
the lower prosthesis was kept by the operator for 2 weeks to allow optimal wound healing and prevent implant loading. After a 2-week healing period, the sutures were removed and the old dentures were adapted, so that they did not touch the healing abutments during use. After an additional 2-month healing period, a routine full-denture prosthetic procedure was followed to allow the patient with a new set of dentures, with the lower denture supported with a ball attachment (Straumann Retentive Anchor H3, 4 mm, Ti; REF 048.439).

Assessments
During the annual maintenance visits, the peri-implant conditions, prosthetic complications and patient satisfaction (scale: 0–10) were investigated. A clinical assessment of the peri-implant tissues was performed by measuring the probing pocket depth (PPD) with a pressure-sensitive probe (Click-Probe®, Kerr Hawe scale: 3–5–7–10 mm). The measurements were rounded off to the nearest millimetre at 4 sites per implant (disto-vestibular, vestibular, mesio-vestibular and lingual). When necessary at these recall visits, calculus and plaque were professionally removed with carbon fibre hand instruments, and when indicated, oral hygiene instructions were given. One year after implant placement and every 24 months thereafter, intra-oral radiographs (Siemens heliodent, 60 kV, 7 ma, 0.25 s) of the individual implants were taken if the patient consented. A commercially available radiograph holder device was used to control the projection geometry (Dentsply Rinn, XCP Evolution 2000, anterior bite block, anterior ring). The device was used to position the X-ray tube at a 90° angle to the long axis of the dental implant and to ensure that the implant threads were visible on the X-ray both mesially and distally. The digitised periapical X-rays were transferred to a personal computer equipped with image analysis software (Dimaxis, Plandent, Helsinki, Finland). The measurements were performed in a dark room. The maximum width of the standardised implant neck was used to calibrate the image analysis software.

The marginal bone (MB) level was measured at the mesial and distal sides of all RDI and NDI (Fig. 1). To assess the MB around the RDI and NDI, Point (a) (as indicated in Fig. 1) was used. The distance from Point (a) to the most coronal point of contact between the bone and the implant surface, Point (b), was measured (c). The measurements were rounded off to the nearest tenth of a millimetre.

Statistical analysis
The mean values of the different variables were calculated for each implant and patient. The patient was the statistical unit. The Kolmogorov–Smirnov test was used to confirm the normality of the data sets. In cases of normal distribution, an independent sample t-test was used to analyse the radiographic differences between the two implants, and within-patient comparisons were performed with dependent samples t-test. The Mann–Whitney U-test was used to compare PPD and patient satisfaction. An analysis of covariance was used to test PPD and MB at 3 years, with the year as a covariate. Although non-parametric tests use medians for comparisons, means are provided. The level of significance was set at $P = 0.05$. All tests were performed using a statistical software package (SPSS Statistics 20; IBM, Chicago, IL, USA).

Results
Up till February 2011, 119 patients who had received two implants in the mandible to support an overdenture were selected for this retrospective study. The descriptive data are presented in Table 2.

Fifty-nine per cent of the patients were female, and the average age of the population at implant insertion was 69 years (range: 34–93 years). The anchoring system used for the overdenture was either a locator (46%) or a ball attachment (54%). The majority of the inserted implants had a length of 12 mm, including 58 (48%) in the 3.3-mm implant (NDI) group and 30 (25%) in the 4.1-mm implant (RDI) group. Only two patients received NDI with a length of 8 mm (2%).

None of the 238 implants were lost during the 3-year follow-up period. The most frequent prosthetic complication was healing abutment loosening (1%). Loosening of the locator/ball attachment (0.4%) or complicated wound healing (0.8%) was seldom reported.

The PPD, MB and patient satisfaction were recorded for the NDI and RDI groups with two different types of retention systems. There was a statistically significant difference between the NDI and RDI groups in the overall mean PPD change between 1 and 3 years (Table 3). The average PPD at Year 1 was 1.7 mm in the NDI group and 1.9 mm in the RDI group. At Year 3, the mean PPDs were 1.6 and 1.7 mm, respectively. Over time, a tendency for decreasing PPD in the two groups was found and was slightly higher for the RDI group.

The bone loss between the two time points was regarded to be within the limits for acceptable progression (Table 4). The MB between years 1 and 3 for both NDI and RDI showed a statistically significant difference, both for overall marginal bone loss and by site ($P < 0.001$). In general, the bone loss was double in the NDI group (0.32 mm for the 3.3-mm implants and 0.14 mm for the 4.1-mm implants). At site level, a greater MB difference was observed at the distal aspect of both NDI and RDI compared with the mesial side.

The findings of a greater marginal bone loss in the NDI and RDI groups with locator attachments are shown in Table 5, in which the total population is divided by whether they received ball ($n = 64$) or locator...
those with the ball retention system (more marginal bone loss compared with retention systems and NDIs showed significantly
change by retention system between 1 and cumulative distribution of the bone-level
significant (t controlling for MB at 1 year, this value remained
0.026; 0.43 vs. 0.21 mm; Table 6). After con-
Table 4.
Analysis of overall mean (SD) and median marginal bone (MB) level by implant diameter and site at 1 and 3 years

Table 2. Patient and implant demographics

<table>
<thead>
<tr>
<th>Mean age (SD)</th>
<th>69 (9.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age range</td>
<td>34-93</td>
</tr>
<tr>
<td>No. of male patients</td>
<td>48 (41%)</td>
</tr>
<tr>
<td>No. of female patients</td>
<td>71 (59%)</td>
</tr>
<tr>
<td>No. of patients with 3.3-mm implants (NDIs)</td>
<td>75 (63%)</td>
</tr>
<tr>
<td>8-mm</td>
<td>2</td>
</tr>
<tr>
<td>10-mm</td>
<td>6</td>
</tr>
<tr>
<td>12-mm</td>
<td>58</td>
</tr>
<tr>
<td>14-mm</td>
<td>9</td>
</tr>
<tr>
<td>No. of patients with 4.1-mm implants (RDIs)</td>
<td>44 (37%)</td>
</tr>
<tr>
<td>10-mm</td>
<td>9</td>
</tr>
<tr>
<td>12-mm</td>
<td>30</td>
</tr>
<tr>
<td>14-mm</td>
<td>5</td>
</tr>
<tr>
<td>No. of patients with ball attachments</td>
<td>64 (54%)</td>
</tr>
<tr>
<td>No. of patients with locators</td>
<td>55 (46%)</td>
</tr>
</tbody>
</table>

Annual bone loss

Annual marginal bone measurements revealed that marginal bone loss predominantly occurred during the first year of loading. The study by Adell et al. [1981] observed that during the first year of function, a vertical marginal bone loss of 1 mm could be anticipated. On X-rays, the so-called sauceration effect was minimal during the second year, indicating the establishment of biological width, as described by Hermann et al. [1997, 2001]. In this study, the first examination was conducted 1 year after implantation to overcome the anticipated bone resorption.

In the present study, the subsequent annual bone losses were 0.16 mm with the NDI and 0.07 mm with the RDI. For the NDIs, these findings are not in agreement with the findings of Verschuysen et al. [2010], who showed an annual bone loss of 0.08 mm between the first and third year in an edentulous population. Although different implants of different lengths were taken into consideration in this study, a clearly lower annual bone loss was associated with the RDI compared with the NDI used in this study. Another study in an edentulous population with a ball-supported overdenture showed an

Table 3. Clinical data and analysis of overall mean (SD) and median probing pocket depth (PPD) at 1 and 3 years

Table 4. Analysis of overall mean (SD) and median marginal bone (MB) level by implant diameter and site at 1 and 3 years

<table>
<thead>
<tr>
<th>Implant diameter (mm)</th>
<th>1 year</th>
<th>3 years</th>
<th>Difference (3 years–1 year)</th>
<th>P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 (n = 75)</td>
<td>1.7 (0.58)</td>
<td>1.6 (0.50)</td>
<td>−0.15 (0.69)</td>
<td>0.002</td>
</tr>
<tr>
<td>4.1 (n = 44)</td>
<td>1.9 (0.59)</td>
<td>1.7 (0.65)</td>
<td>−0.22 (0.67)</td>
<td></td>
</tr>
</tbody>
</table>

PPD, probing pocket depth.
1Univariate analysis, PPD after 3 years with baseline PPD as covariate.
2Wilcoxon signed-rank test, within-group comparison. P < 0.05.


did not show any bone loss compared with 51% of those in the RDI group with ball attachments. A comparison of patient satisfaction [Table 7] with the ball or locator attachment showed a significant difference (P = 0.013) in favour of the locator attachment in the first year only [patient satisfaction score: 8.6].

Discussion
This retrospective study analysed NDI and RDIs placed in fully edentulous patients by experienced clinicians in a private clinic over a follow-up period of 3 years. This study was conducted to examine the hypothesis that NDIs, in comparison with RDIs, show more bone loss over time as a result of increased stress distribution in the bony tissue around these implants.

The present study showed a 100% implant survival rate in the study population over the 3-year evaluation period. In addition, a minimum of technical and/or biological complications were noted. No adverse effects were observed. In general, a high patient satisfaction was present after 3 years irrespective of the retention system.

Annual bone loss

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<table>
<thead>
<tr>
<th>Implant diameter (mm)</th>
<th>Year 1</th>
<th>Year 3</th>
<th>MB difference (3 years–1 year)</th>
<th>P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>3.53 (0.54)</td>
<td>3.84 (0.49)</td>
<td>0.32 (0.43)</td>
<td>0.002</td>
</tr>
<tr>
<td>4.1</td>
<td>3.61</td>
<td>3.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial</td>
<td>3.59 (0.55)</td>
<td>3.73 (0.65)</td>
<td>0.14 (0.50)</td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>3.59 (0.53)</td>
<td>3.80 (0.56)</td>
<td>0.21 (0.49)</td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>3.66 (0.59)</td>
<td>3.71 (0.98)</td>
<td>0.05 (0.56)</td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>3.73</td>
<td>3.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>3.46 (0.61)</td>
<td>3.89 (0.49)</td>
<td>0.43 (0.48)</td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>3.47</td>
<td>3.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>3.52 (0.56)</td>
<td>3.75 (0.69)</td>
<td>0.22 (0.55)</td>
<td></td>
</tr>
</tbody>
</table>

*Univariate analysis, MB at 3 years with baseline MB as covariate.
†Dependent sample t-test; within-group comparison. P < 0.05.
‡Dependent sample t-test; within group, comparing mesial vs. distal in NDI and RDI.
overall bone loss of 0.29 mm over a 10-year follow-up period after excluding the first year of bone remodelling (Naert et al. 2004). Comfort et al. (2005) showed a very low annual bone loss of 0.01 mm after the first year of loading for NDIs in a 5-year follow-up of machine-surfaced implants. A good comparison of clinical and radiographic parameters remains difficult because of variation in the clinical and radiographic parameters. In addition, discussions of marginal bone loss rarely distinguish between narrow and regular implants. Compared with the aforementioned studies, the bone loss in the NDI group of our study appears to be above average, but without clinical patterns related to PPD.

The distinctly higher bone loss rate at the distal side in the NDI and RDI groups is in agreement with Elsyad et al. (2012), who studied a population of conventionally and immediately loaded implants supporting a bar-retained mandibular overdenture over a 3-year period. This randomised controlled trial showed distinctly higher bone resorption at the distal and labial sites around implants. These findings were confirmed in patients with a bar-retained prosthesis, who had significantly more bone loss at the distal side after the first year post-implantation (Semper et al. 2010).

### Implant diameter

Assunção et al. (2008) showed that in patients with an implant-supported denture, the von Mises stress values can rise to 52.6 MPa around the neck area. Pathological overload and secondary bone resorption have been reported at 50 MPa (Sugiura et al. 2000). The stress and strain levels in the bone surrounding the implant are influenced by implant design, load [magnitude and direction], bone quality, boundary conditions, mechanical properties and the cortical thickness of the bone. Using finite element analysis (FEA), a method for predicting the biomechanical performance of various dental implant designs and the effect of clinical factors on the success of implantation, a number of studies have attempted to assess the distribution of stress in bone. Ormianer et al. (2012) used cylindrical bone block models to investigate the stress and strain properties of 1- and 2-phase implants under applied loading conditions. They showed that implant diameter and peri-implant bone thickness influence the stress distribution in bone. Bone stress increased when bone thickness decreased for all implant designs and diameters. Another study found similar findings related to strain level and implant diameter with 3.3-, 4.1- and 4.8-mm-diameter ITI implants (Yu et al. 2009). However, from a biomechanical view, the authors advocate using wider implants in anatomically accessible narrow ridges to overcome the peak stress created in the cervical area.

To overcome the limitations of a bone block, one study used a mandible model to assess the stress and strain distribution with 10-mm-long ITI implants with diameters of 3.3, 4.1 and 4.8 mm (Ding et al. 2009a,b). Similar findings were reported for implant diameter and stress distribution in this immediate loading protocol. A significantly lower ($P < 0.05$) MPa was found with the 4.1-mm implants compared with the 3.3-mm implants. In particular, buccolingual forces created stress levels well above normal values; therefore, the authors recommend avoiding the use of 3.3-mm-diameter implants with a length of 10 mm. In this study, a subgroup comparison between 10-mm NDIs and RDIs did not show a significant difference in MB after 1 and 3 years (data not shown).

In the present study, NDIs were associated with greater bone loss over a 2-year period compared with RDI. This result is in concordance with the findings of the previously mentioned FEA, and it confirms the findings of Degidi et al. (2008), who found more marginal bone loss with narrow-diameter implants ($\leq 3.0$ mm). Romeo et al. (2006) found similar mean marginal bone loss scores for narrow- and standard-diameter ITI implants in a (partially) dentate population.

However, NDIs are very often indicated when the residual width of the crest is limited. Therefore, a possible explanation for the less favourable outcome regarding bone height around NDIs could be the compromise between width restriction and reluctance to perform a bone graft procedure to increase the width of the crest.

### Implant length

A study by Anitua et al. (2010) concluded that the impact of implant diameter is more significant than that of implant length or geometry. The stress was concentrated around the neck of the implant, and the majority of the stress was distributed around the first six threads of the implant. Various authors (Ding et al. 2009a,b; Yu et al. 2009) have concluded that diameter had a more significant effect than length in terms of

Table 5. Analysis of overall mean (SD) and median marginal bone (MB) level in locator vs. ball attachments at 1 and 3 years

<table>
<thead>
<tr>
<th>Mesostructure</th>
<th>Mean (SD) MB at 3 years</th>
<th>Median MB at 3 years</th>
<th>MB difference (3 years-1 year)</th>
<th>P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball (n = 64)</td>
<td>3.69 (0.53)</td>
<td>3.83 (0.62)</td>
<td>0.14 (0.47)*</td>
<td>0.001</td>
</tr>
<tr>
<td>Locator (n = 55)</td>
<td>3.39 (0.52)</td>
<td>3.77 (0.48)</td>
<td>0.38 (0.43)*</td>
<td></td>
</tr>
</tbody>
</table>

*Univariate analysis, MB at 3 years with baseline MB as covariate.

Table 6. Analysis of overall mean (SD) and median marginal bone (MB) level by retention system (locator or ball attachment) at 1 and 3 years

<table>
<thead>
<tr>
<th>Implants (mm)</th>
<th>Mean (SD) MB at 3 years</th>
<th>Median MB at 3 years</th>
<th>MB difference (3 years-1 year)</th>
<th>P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>3.72 (0.49)</td>
<td>3.92 (0.58)</td>
<td>0.21 (0.38)*</td>
<td>0.001</td>
</tr>
<tr>
<td>4.1</td>
<td>3.65 (0.60)</td>
<td>3.71 (0.65)</td>
<td>0.05 (0.57)</td>
<td>-0.000</td>
</tr>
</tbody>
</table>

*Univariate analysis, MB at 3 years with baseline MB as covariate.

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relieving the crestal stress and strain concentration. Therefore, the present observations are presented irrespective of implant length.

Survival rate
The high (100%) survival rate of the implants used in this study could be explained by their location in the mandible. In general, the mandible has a thicker and denser cortical layer than the maxilla, especially at the interforaminal region. Poor bone quality and density has a great influence on the success rate of dental implant treatment (Renouard & Nisand 2006). A greater bone density is one of the important factors related to better implant treatment outcomes (Vigolo & Givani 2000). The survival (probability) of small-diameter implants is shown to be higher in the mandible than in the maxilla (Arisan et al. 2010), although Degidi et al. (2008) did not find any difference between the maxilla and mandible in the long-term survival rate of 510 narrow-diameter implants. A possible explanation could be the relatively short median follow-up period of 20 months.

Retention system
In this study, either a ball or a locator attachment was used. No bar attachments were considered because of the solistic forces applied to the implant structure and to improve the reproducibility of the probing measures. Therefore, a bias related to the applied suprastructure is possible, although Naert et al. (2004) did not show any difference in the applied suprastructure and peri-implant parameters. A clear difference was found in single or splinted attachment types, whereas bone loss rates were statistically higher in cantilever situations (Bilhan et al. 2011). This study showed that regardless of the implant diameter, the ball attachment was clearly preferable in terms of marginal bone loss after 3 years of follow-up. Hypothetically, the degrees of freedom in ball attachments have a positive effect in the stress distribution under peri-implant conditions, leading to a less bone resorption compared with the rigid connection in locator attachments.

Limitations
- The descriptive data in this study show that the majority of the implants placed were 12 mm in length and only a small percentage were 10 or 8 mm in length (Table 2). This is in line with the review by Pommer et al. (2011), who showed that the majority of the implants placed were 10 mm or longer. This could be partially explained by operator preference. Therefore, additional bone augmentation should precede the placement of implants with the preferred length of 12 mm. Another hypothetical reason for the distribution of implant lengths is a bias towards excluding of patients with shorter implants in low mandibles because they did not provide radiographs that were suitable for assessment. For instance, the deep placement of a film holder with a parallel alignment is restricted in a shallow lingual area in a vertically reduced mandible. The use of a panoramic radiograph could partially overcome this problem (Arisan et al. 2010). Film holder placement and correct adjustment may vary radiographic assessment, which may have affected bone-level measurements.

- Another limitation of this study is that no data regarding bleeding on probing (BOP) or suppuration are available because of the retrospective nature of this study. Consequently, peri-implantitis, as characterised by BOP and/or suppuration through probing and marginal bone loss detection in radiographs, could not be detected (Zitzmann & Berglundh 2008). However, progressive bone loss and deep probing measurements could be indicative of the onset and progression of peri-implant disease. In this study, the average PPD and MB did not indicate peri-implant disease. The regular maintenance performed by the dentist or oral hygienist and the relatively short follow-up period

Table 7. Patient satisfaction. Statistical analysis comparing locator or ball attachment at 1 and 3 years

<table>
<thead>
<tr>
<th></th>
<th>1 year</th>
<th>P-value*</th>
<th>3 years</th>
<th>P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball attachment</td>
<td>7.4</td>
<td>0.013</td>
<td>8.5</td>
<td>0.609</td>
</tr>
<tr>
<td>Locator attachment</td>
<td>8.6</td>
<td></td>
<td>8.3</td>
<td></td>
</tr>
</tbody>
</table>

*Mann-Whitney U-test; between-group comparison.

Fig. 2. Scatterplot distribution of the subjects according to mean marginal bone (MB)-level difference between 1 and 3 years.
could be responsible for this positive outcome.

• One of the lessons learned from this structured maintenance protocol was introduced in 2004 as part of the treatment protocol, patients do not appear to be strictly following this protocol. In fact, only 15% of the patients adhered to the protocol, which requires yearly evaluations of the clinical parameters and radiographs at least during the 1st year and 3rd year. It is possible that the selected patient group was highly motivated, and this may have introduced a bias in the results. In the light of this possibility, one should interpret that findings of this study represent the results of patients with adequate motivation to follow through with yearly professional evaluations and maintenance care.

Future research should evaluate whether the difference in bone loss between NDIs and RDIs and between the locator and ball attachments remains significant after 5 or 10 years.

Conclusion

Within the limitations of this retrospective study, the authors can conclude that in the first 3 years after implantation, NDIs are associated with more marginal bone loss over time compared with RDIs. Regardless of implant diameter, the locator attachment was associated with more bone loss over time compared with the ball attachment.

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Conflict of interest and source of funding statement

This study was funded by the authors. The authors can report that they have no conflict of interest with any commercial brand or entity mentioned in this study.

References


**Supporting Information**

Additional Supporting Information may be found in the online version of this article:

**Appendix S1.** STARD checklist for reporting of studies of diagnostic accuracy [version January 2003].