DR. ALBERTO MONJE (Orcid ID : 0000-0001-8292-1927)
DR. SAMIR ABOU AYASH (Orcid ID : 0000-0003-1047-5571)
PROF. VIVIANNE CHAPPUIS (Orcid ID : 0000-0003-1227-7587)

Article type : Original Article

Long-term effectiveness of 6 mm micro-rough implants in various indications: A 4.5 to 18.2-year retrospective study

Running title:

Survival and success rates of 6 mm implants

Clemens RAABE, Alberto MONJE, Samir ABOU-AYASH, Daniel BUSER, Thomas VON ARX, Vivianne CHAPPUIS

Clemens Raabe, Dr. med. dent.

Resident, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland

Alberto Monje, DDS, MS, PhD

Assistant Lecturer, Department of Periodontology; University Internacional de Catalunya, Spain

Adjunct Clinical Assistant Professor, Department of Periodontology; The University of Michigan, USA

Samir Abou-Ayash, Dr. med. dent.

Senior Lecturer, Department of Reconstructive Dentistry and Gerodontology; School of Dental Medicine, University of Bern, Switzerland

Daniel Buser, Prof. em. Dr. med. dent.

Senior Surgeon, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland

Thomas von Arx, Prof. Dr. med. dent.

Vice-Chair, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland

Vivianne Chappuis, Prof. Dr. med. dent.

Chair, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland

Conflict of Interest

The authors declare that they have no conflict of interest.

Correspondence Address

Prof. Dr. med. dent. Vivianne Chappuis, Department of Oral Surgery & Stomatology; University of Bern, Freiburgstrasse 7, CH-3010 Bern, Switzerland.

E-mail: vivianne.chappuis@zmk.unibe.ch

Tel +41 31 632 25 63 | Fax +41 31 632 25 03

Acknowledgments

We are grateful to Lukas Martig for the statistical analysis.

Contributions

Vivianne Chappuis and Daniel Buser contributed to the study conception and design. Data acquisition, analyses and interpretation were performed by Clemens Raabe and Vivianne Chappuis with contributions from all authors. First draft was written by Clemens Raabe and Vivianne Chappuis, and all authors commented on previous versions of the manuscript. All authors approved the final manuscript.

ORCID:

Clemens Raabe ORCID 0000-0003-2659-3505

Alberto Monje ORCID 0000-0001-8292-1927

Thomas von Arx ORCID 0000-0002-3545-6468

Vivianne Chappuis ORCID 0000-0003-1227-7587

Conflict of Interest Statement

Clemens Raabe declares that he has no conflict of interest.

Alberto Monje declares that he has no conflict of interest.

Samir Abou-Ayash declares that he has no conflict of interest.

Daniel Buser declares that he has no conflict of interest.

Thomas von Arx declares that he has no conflict of interest.

Vivianne Chappuis declares that she has no conflict of interest.

Funding

This study was self-funded by the Department of Oral Surgery and Stomatology, University of Bern.

Abstract

Objectives:

To evaluate the long-term effectiveness of 6 mm implants in various indications with a micro-rough surface after 4.6-18.2 years in function and to assess key factors associated with implant survival, success and biological/technical complications.

Materials and Methods:

Fifty-five patients with seventy-four 6 mm implants placed from 2000 to 2013 attended the re-examination assessing well-established clinical and radiographic parameters, biologic and prosthetic complications, and patient-reported outcome measures.

Results:

Five implants were lost after a mean follow-up period of 9.1 years resulting in a survival rate of 93.2%. All losses occurred in free-end situations in the mandible. Smoking habit significantly reduced implant survival (hazard ratio 36.25). Two implants exhibited a history of peri-implantitis, and one implant showed progressive marginal bone loss (MBL) resulting in a success rate of 89.2%. The mean MBL amounted to 0.029 mm. Increased MBL was found for implants placed in the maxilla (0.057 mm) and for implants with a diameter of 4.1 mm (0.043 mm). Soft tissue thickness (1.39 mm) and width of keratinized mucosa (1.91 mm) had no effect on MBL. Patient-reported outcome measures showed high satisfaction (mean VAS scores 88%) and high quality of life (mean OHIP-G14 score 2.2).

Conclusion:

The present study demonstrated survival and success rates of 93.2 % and 89.2 % for 6 mm implants used in various indications. A factor leading to higher implant failure was smoking, whereas modulating factors increasing annual MBL included implants placed in the maxilla and implants with a diameter of 4.1 mm compared to 4.8 mm.

<u>MeSH term keywords:</u>

Dental Implants, Alveolar Bone Loss, Patient Reported Outcome Measures, Clinical Trial, Osseointegration

<u>Word count:</u>

250

Introduction

Short 6 mm dental implants have become a safe treatment option for patients with reduced bone height in order to avoid complex vertical bone augmentation procedures. Short 6 mm implants enable minimally invasive surgical treatment concepts using standard implant placement protocols with low risks for intra- and post-operative complications and are particularly suitable for implant rehabilitations of older patients (≥75 years) or in compromised systemic medical conditions (Jung et al., 2018; Schimmel, Srinivasan, McKenna, & Müller, 2018). In addition, short 6 mm implants are associated with reduced treatment times and costs compared to the placement of longer implants in combination with complex vertical augmentative interventions (Monje et al., 2013). Data on long-term success rates of 6 mm implants considering the risk of complications and patient-reported outcome measures (PROMs) is limited (Lai et al., 2013; Romeo et al., 2014; Rossi et al., 2018; Naenni et al., 2018) in comparison to the well-documented use of standard length implants (Buser et al., 2012; Jung, Zembic, Pjetursson, Zwahlen, & Thoma, 2012; Chappuis et al., 2018).

Advances in material sciences and implant surface technology increased the predictability of short dental implants with a micro-rough implant surface. Nevertheless, differences in surface characteristics resulted in a wide variation of survival rates between 86.7–100 % for 6 mm implants (Papaspyridakos et al., 2018). Several modulating factors influencing the survival and success rate of short implants have been addressed in the literature: first, the influence of the bone density and bony structure on the survival rate of short implants was discussed. Recent reviews reported more failures of short implants in the maxilla compared to the mandible due to differences in bone density (Srinivasan et al., 2014; Ravidà et al., 2019). Second, the reduced length might also result in higher susceptibility for mechanical stress caused by overloading (Petrie & Williams 2005). No association between occlusal overload and loss of osseointegration was only confirmed for standard length implants (Heitz-Mayfield et al., 2004; Isidor, 2006; Naert, Duyck, & Vandamme, 2012). Finally, an unfavorable crown-to-implant ratio (CIR) of 6 mm implants facilitated more stress to crestal bone levels (Petrie & Williams, 2005; Morand & Irinakis, 2007) and increased marginal bone loss (Villarinho et al., 2017; Di Fiore et al., 2019). In contrast, other authors reported, that high CIR is not associated with increased marginal bone loss or implant failures (Nunes et al., 2016; Naenni et al., 2018).

In summary, poor bone structure of atrophic alveolar ridges, posterior locations with high occlusal forces, and unfavorable CIRs may represent risk factors jeopardizing the long-term survival and success rate of 6 mm implants. One restricting factor for the broad use of short implants remains the lack of long-term evidence. In order to optimize the long-term effectiveness of 6 mm short dental implants, there is a need to identify key modulating factors for implant survival and success to facilitate comprehensive treatment planning and enhance treatment outcomes.

The present study aimed to assess the long-term effectiveness of 6 mm implants after 4.6-18.2 years in place. The primary objective was the survival and success rate of 6 mm implants with a micro-rough surface including the evaluation of modulating factors. As secondary objectives, the annual marginal bone loss (MBL), the biological and technical complications, and patient's quality of life were investigated.

Material and Methods

Study design

The study was approved by the local institutional review board (KEK-BE: 2017-00019, Cantonal Ethics Commission [Kantonale Ethikkomission], Bern, Switzerland), is in accordance with the Declaration of Helsinki (2013), was registered on clinicaltrials.gov (NCT04017026), and is compliant with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

The records of all patients who had received an implant from 2000 to 2013 at the Department of Oral Surgery at the University of Bern were browsed electronically for the following inclusion criteria. Partially and fully edentulous patients treated with 6 mm implants and an age ≥ 18 years were eligible to be included in this investigation. The implant design included a tissue-level implant (Straumann AG, Basel, Switzerland) with a micro-rough surface (SLA or SLActive®) and an implant diameter of 4.1 or 4.8 mm. The implant sites required at least six weeks of healing after tooth extraction, sufficient bone height of ≥ 6 mm (including lateral and vertical bone augmenting procedures except sinus floor elevation) and 2 mm of keratinized mucosa prior to implant placement. The exclusion criteria were compromised general health contraindicating surgical interventions, insufficient oral hygiene, unwillingness to participate in the present study and pregnancy.

The patients were contacted and invited by phone or letter to attend a clinical re-examination between May 2018 and April 2019. For patients with lost or removed implants, the patient records were analyzed or further information was gathered from their private dentist to include them in the investigation. Written informed consent was obtained from all patients of this investigation after a thorough explanation of the study's objectives and after answering arising questions.

Surgical and Restorative Procedure

The implant surgeries were performed by trained and board-certified oral surgeons working as full-time faculty members in the department. The implants were inserted according to a standardized protocol established at the University of Bern (Buser & von Arx, 2000) with the margin between machined and micro-rough surface being placed slightly sub-crestal (1 mm). If necessary, bone augmentation was performed prior to (autogenous block graft harvested from an intraoral donor site such as the chin or the ramus of the mandible) or simultaneous with implant placement (guided bone regeneration using autogenous bone chips, deproteinized bovine bone material (Bio-Oss) and a noncrosslinked collagen membrane (Bio-Gide); both Geistlich Pharma, Wolhusen, Switzerland). The prosthodontic treatment was carried out by the referring dentist or clinic after a healing period of at least 8 weeks using either screw or cement retained fixed dental prostheses (FDPs: single crowns, splinted crowns, bridges, or bridges with extensions) or removable dental prostheses (RDPs: bar or attachment supported complete dentures).

Follow-up Examinations

1) Clinical evaluation

After recording the general health status (smoking habit, medical risk factors, medication), the patients underwent clinical and radiographic re-examinations. The assessed clinical parameters included the modified plaque index (mPLI) (Mombelli, Oosten, Schürch, & Lang, 1987), the modified sulcus bleeding index (mSBI) (Mombelli et al., 1987), probing depths (PD), the width of keratinized mucosa (KM) around the implant, and the distance from the implant shoulder to the mucosal margin (DIM) at three buccal and one oral site of each implant. Subsequently, the soft tissue thickness at the buccal aspect was assessed by an ultrasonic device (PIROP G-Scan, ECHO-SON S.A., Krancowa, Poland). Finally, biological, technical, and mechanical complications were recorded or past episodes retrieved from the patients' charts.

2) Radiographic evaluation

Digital periapical radiographs (Soredex Minray, Helsinki, Finland) were taken using stock film holders (XCP film holder, Dentsply Sirona, Bensheim, Germany) and the parallel technique. The datasets were evaluated independently by two examiners (V.C., C.R.) with the image-processing software ImageJ2, including an evaluation of interrater agreement.

After calibrating the software by measuring the implant length and thread distance, the annual marginal bone loss was assessed by measuring the distance from the implant shoulder to the first bone-to-implant contact (DIB) (Buser, Weber, & Lang, 1990) at the mesial and distal sites of the implant on both the closest to 1-year postoperative and follow-up radiographs. The annual MBL was then calculated by the difference obtained postoperatively and at the follow-up divided by the period between the two radiographs.

3) Patient-reported outcome measures

The individual patient's satisfaction was assessed using patient-reported outcome measures. Each patient was asked to fill in the oral health impact profile (OHIP G-14) questionnaire. Six additional questions addressed the patient's satisfaction regarding the incorporation, esthetics and hygiene in a 100 mm visual analog scale (

Figure 1). All questionnaires were self-completed.

4) Classification of implant survival, success and complications

Implant survival was classified as the implant still present at re-examination. Implant success was defined according to the criteria of Buser et al. (1990) and Albrektsson et al. (1986) (Table 1) also accounting for any findings in the past (e.g. resolved infections).

Biologic complications were defined as inflammation of the peri-implant mucosal and/or osseous tissue with progressive loss of supporting bone (Schwarz, Derks, Monje, & Wang, 2018). Mechanical complications included failures of prefabricated components, whereas technical complications consisted of failures of the laboratory fabricated crowns (Salvi & Brägger, 2009).

Statistical analysis

Patient data were first analyzed descriptively. Implant survival rates were assessed univariately and in an explorative way by using Cox proportional hazard regression models and assuming all implant data to be independent. Hazard Ratios were calculated and assessed, but only for dichotomous and numeric covariates so that the ratio of "dropouts" vs. "estimated parameters" is 5/1 = 5. Note that this ratio is adequate in an explorative context, but has its limitations as the computed models lack statistical power due to the limited number of failed implants – leading to larger CIs for hazard ratios and masking potential significances. The inter-rater agreement was assessed for radiographic measurements with the help of the intraclass correlation coefficient. A preliminary multiple regression analysis was performed to screen for twelve potential risk factors on bone loss. Thereby, a backward stepwise selection minimizing the Akaike Information Criterion (AIC) was used. The resulting five risk variables were then assessed with the help of a linear mixed model, correcting for the impact of the patient. Goodness-of-fit for the linear mixed model was tested using the Shapiro-Wilk test on both residuals and random effects. Also, the residuals were visually assessed for possible patterns. The number of estimated fixed parameters in the final mixed model was seven in a sample size of 69, yielding a ratio of 69/7 = 9.9. For all analyses, p-values less than 0.05 were considered statistically significant. All analyses were performed with the statistics software R, version 3.5.0 (R Core Team, 2018).

Results

Study sample

Seventy-eight individuals met the search criteria after thoroughly reviewing the patient records. Fifteen of those patients were not willing to participate in a clinical investigation, four patients lived in a foreign country or had moved away, two patients suffered from severe illness and two patients had passed away. Fifty-five patients were evaluated consisting of 18 men (32.7 %) and 37 women (67.3 %) with a mean age of 60.8 years (26 – 87 y) at implant surgery and a mean follow-up period of 9.1 years (4.6 - 18.2 y). Fifty patients were non-smokers at the timepoint of reexamination, two were light smokers (< 10 cigarettes per day) and three were heavy smokers (≥ 10 cigarettes per day). In all these patients, 74 tissue-level implants with a length of 6 mm (Straumann AG, Basel, Switzerland) and a micro-rough SLA® (n=16) or SLActive® (n=58) surface were inserted.

Surgical and Restorative Procedure

The majority (91.9 %) of surgical interventions used a standard implant placement protocol of at least 6 months following tooth extraction. A simultaneous bone augmentation was necessary in 10.8 % of procedures; a staged augmentation was necessary also in 10.8 % of procedures. Postoperative healing was uneventful in all except one patient, who suffered from an early peri-implant infection on two 6 mm implants one month postoperatively. These implants were regrafted successfully and healed. 93.2 % of the implants were restored with FDPs. 86.5 % of all restorations provided splinting to at least one adjacent implant (length 6 – 12 mm) (Table 2).

Survival Rate and Incidence of Biologic, Technical and Mechanical Complications

In total, five implants were lost resulting in a survival rate of 93.2 % after a mean follow-up period of 9.1 years (Figure 2). Two implants were lost in one smoker after 6.8 years due to periimplantitis, whereas three implants were lost due to spontaneous non-inflammatory loss of osseointegration after 4.8 years (n=2 in one smoker) and 11.6 years (n=1 in a non-smoker). All of the implant losses appeared in free-end situations of the mandible and in implants being restored with splinted restorations. A history of biologic complications evolved in two implants of a single patient as a peri-implant infection one month postoperatively, that was resolved by a peri-implant augmentative procedure. At the last clinical follow-up examination, no biologic complications were present in any of the short implants. History of peri-implantitis occurred in a rate of 5.4 % at implant-level. Only minor technical complications were recorded (8.1 %). Chipping was the most frequent, occurring in five restorations. Additionally, the framework of a bridge fractured and required a new restoration. Mechanical complications only presented as screw-loosening in three cases (4 %) (

Table 3).

Clinical Parameters

Overall, 94 % of patients attended a regular dental maintenance care program at least once a year. Patients presented good oral hygiene showing low plaque and bleeding indices (mean mPLI 0.25 ± 0.48, mean mSBI 0.11 ± 0.37). Mean PD amounted to 3.01 ± 1.03 mm whilst the mean DIM of -0.65 ± 1.31 mm indicated the location of the implant shoulder slightly submucosal. Mean amount of KM at the buccal implant shoulder was 1.91 ± 1.76 mm with a mean soft tissue thickness of 1.39 ± 0.70 mm (

Table 3). Representative clinical images and PAs are shown in Figure 3.

Radiographic Parameters

Sixty-nine surviving implants in 52 patients were evaluated by two independent examiners to assess the annual MBL as well as anatomical and clinical crown-to-implant ratios. High intraclass correlation coefficients (0.77 – 0.93) were found for all their measurements, except fair values for the annual MBL (0.50), which was associated with a low interrater agreement in a single patient presenting double contours on the PA. After exclusion of this patient, a high intraclass correlation coefficient (0.80) was also found for the annual MBL. Subsequently, the average values between both examiners were used for further analysis.

The mean annual MBL was 0.029 ± 0.071 mm in total with 0.057 ± 0.086 mm in the maxilla and 0.016 ± 0.059 mm in the mandible (

Table 3).

Patient-Reported Outcome Measurements

Regarding quality of life, the OHIP presented a mean value of 2.2. The six additional questions regarding the incorporation, esthetics and hygiene revealed a high mean satisfaction of 85 - 91 % (

Figure 1).

Success Rate

Two implants had a history of periimplantitis and therefore did not fulfill the success criteria (Albrektsson, Zarb, Worthington, & Eriksson, 1986; Buser et al., 1990). A third implant was clinically unsuspicious but presented an annual MBL of 0.29 mm and therefore did not fulfill the success criteria (Albrektsson et al., 1986). The resulting success rates were 90.5 % for the criteria by Buser et al. (1990) and 89.2 % by Albrektsson et al. (1986).

Analysis of modulating factors

Smoking was the only significant factor jeopardizing the survival rate of 6 mm implants as 4 out of 10 implants in smokers were lost (hazard ratio of 36.35 compared to non-smokers, *p=0.001*) (Figure 4). Higher risks for implant failures were observed for implants in free-end situations of the mandible and implants being restored with splinted FDPs, as all losses clustered in these groups. Restrictively, no regression analysis could be performed for indication, jaw, and restoration due to a lack in variance of the losses. A summary of hazard ratios is shown in *Table 4*.

The preliminary multiple linear regression analysis found five risk factors influencing annual MBL: jaw (maxilla, mandible), localization (incisors, premolars, molars), implant diameter (4.1 mm, 4.8 mm), grinding habits (yes, no) and patients’ age. The subsequent linear mixed model then revealed that the following three factors had a significant influence:

Three factors modulated annual MBL compromising implant success rate:

1) Jaw (*p=0.02*) – an annual MBL of 0.057 mm was found for implants in the maxilla versus 0.016 mm in the mandible,
2) Diameter of the implant (*p=0.05*) – an annual MBL of 0.043 mm was found for 4.1 mm implants versus 0.019 mm for 4.8 mm implants, and
3) Patients age (*p=0.02*) – each additional year of age at surgery increased annual MBL by 0.002 mm.

No concluding significant effects were found for factors localization (p = 0.22) and grinding habits (0.17).

Discussion

Principal findings

This investigation evaluated the long-term effectiveness of 6 mm implants and revealed survival and success rates of 93.2 % and 89.2 % after a mean follow-up of 9.1 years (range 4.6 - 18.2 y). Smoking was the only factor impairing survival rates significantly. The annual MBL contributing to the failure rate was significantly increased for implants placed in the maxilla, for implants with a diameter of 4.1 mm compared to 4.8 mm, and for patients with a higher age at surgery. Soft tissue thickness and the width of the KM did not significantly influence the annual MBL.

Agreements and disagreements with previous findings

Long-term outcomes of dental implant procedures are a relevant factor in the decision-making process for implant treatments. Although short-term data is promising, long-term survival rates of 6 mm implants are scarce, considerably inferior to those of standard length implants and therefore appear less predictable (Buser et al., 2012; Chappuis et al., 2018; Papaspyridakos et al., 2018; Vazouras et al., 2020). In the present study, the only risk factor significantly impairing the survival rate of 6 mm implants was smoking. However, as the sample of smokers was very small and two smoking patients had two implant losses each, bias cannot be ruled out and the impact of smoking on 6 mm implant survival must be interpreted with great caution. Abduljabbar et al. (2018) investigated the influence of smoking on 6 mm implants after 6 years and found no effect on the clinical and radiographic status but did not report any survival or failure rates (Abduljabbar et al., 2018). However, smoking is a well-known and confirmed risk factor for dental implant failure (Moraschini & Barboza, 2016). In addition, all implant losses were located in free-end situations of the mandible and restored with splinted FDPs. Due to a lack of variance in losses, no regression analysis could be performed for splinting, indication and jaw. Two of the five losses were related to biologic complications whilst three implants suddenly became mobile after 4.8 – 11.6 years in function without previous signs of progressive peri-implant bone resorption. The latter was also described in two recent long-term studies for all lost 6 mm implants (Rossi et al., 2016; Naenni et al., 2018). Both authors hypothesized different reasons for the implant loss, which might be related to each other. Implant crowns do not wear off as much as natural tooth structures, leading to stronger occlusal contacts on the implant restoration over time (Naenni et al., 2018). This overload might cause microfractures at the bone-implant interface of short implants (Rossi et al., 2016) and inhibit bone healing processes. Accordingly, splinting of 6 mm implants (Ravidà et al., 2019) and thorough adjustment of the occlusion during the follow-ups may prevent overloading.

To optimize treatment concepts, we need a better understanding of the factors that influence the performance of short implants. Therefore, not only implant survival rates were investigated, but also success rates and the annual MBL. Various definitions for implant success are described in the literature without consensus regarding the ideal criteria. We selected two well established definitions to categorize the results leading to slightly different success rates (A: Albrektsson et al., 1986; B: Buser et al., 1990). Both 6 mm implant success rates (A: 89.2 %, B: 90.5 %) were inferior to the results of standard implants (Buser et al., 2012). Success criteria were not fulfilled in 7 (B) and 8 (A) cases respectively: five implants were lost (A, B), two implants developed a peri-implant infection, which was successfully treated (A, B) and one implant presented an annual MBL of 0.29 mm (A). However, all other 6 mm implants had ≤ 0.2 mm annual MBL. A mean MBL of 0.63 - 0.8 mm was reported for 6 mm implants after 10 years of function (Lai et al., 2013; Rossi et al., 2018), which would result in an annual MBL of 0.063-0.08 mm. The recent findings are in line with the latter and support the hypothesis, that short implants undergo the same MBL as standard implants (Monje et al., 2014). The influencing factors on implant success were assessed using a further analysis of the annual MBL. First, the annual MBL was significantly higher (*p=0.02*) in the maxilla (0.057 mm) compared to the mandible (0.016 mm) which might be associated with the reduced bone density of the maxilla, a tendency also reported by Rossi et al. (2018). Nevertheless, those results might be affected by shorter follow-up intervals for implants in the maxilla (7.8 years) than in the mandible (9.8 years), as increased bone remodeling takes place specifically in the first postoperative year (Albrektsson et al., 1986). Second, the annual MBL was significantly modulated by the implant diameter. Implants with 4.1 mm in diameter had a twofold higher annual MBL compared to implants with 4.8 mm in diameter (*p=0.05*). Therefore, larger implant diameter might protect the marginal bone from stress-induced resorption as an increasing implant diameter reduces stress to the crestal bone, especially in short implants (Petrie & Williams, 2005). Third, the patient's age at surgery influenced the annual MBL, as each additional year of age increases annual MBL by 0.002 mm (*p=0.02*). A recent consensus report (Schimmel et al., 2018) stated that age is not a risk factor for implant failure, but may affect peri-implant MBL. Peri-implant MBL in this age-group may be also influenced by medication intake (Chappuis et al., 2018). However, as only minor changes were found and the patient's age is an inalterable factor, the clinical relevance of this finding remains questionable. Interestingly, width and thickness of the keratinized mucosa did not affect the annual MBL. However, these findings are contradictory to the results of a recent meta-analysis (Thoma et al., 2018), showing better peri-implant health and less MBL for grafted soft tissues. As splinted restorations were used in the majority of 6 mm implants, the measurement of the height of the restoration was not applicable. Splinting transfers the occlusal forces to several implants and the effect of CIR does not come into play, as this is the case in single-tooth restorations. Therefore, the clinical or anatomical CIR was not assessed in this investigation.

To the best of the authors' knowledge, this is the first long-term investigation including PROMs for 6 mm implants. Generally, patients were highly satisfied with the procedure and outcome of the treatment and showed mean values of 2.2 in the OHIP-G14 questionnaire which is in line with the mean score of 1.6 mentioned for screw-retained partial dentures in the literature (Preciado, Del Río, Lynch, & Castillo-Oyagüe, 2013). Regarding the VAS, slightly lower values were found for the hygiene of the implants and the overall procedure. The first might be due to the mostly posterior implant position, that may challenge older patients with limited manual abilities. The second could be related to the treatment modalities of a university clinic working on a referral base, resulting in additional appointments for examination or follow-up visits for the patient.

Limitations and recommendations for future research

The present investigation has several limitations. The study cohort had a rather small sample size of 55 patients (74 implants) and various follow-up periods. In some instances, the radiographs were dated earlier than 12 months postoperatively for the assessment of the MBL. Additionally, the investigated implants included two diameters (4.1 mm or 4.8 mm) and surfaces (SLA or SLActive) and were installed in various locations. The restoration was delivered at different timepoints by dentists of unknown expertise using multiple types of dental prostheses, which might have distorted the results. Nevertheless, this investigation reveals additional long-term results of 6 mm implants and might be the first one assessing PROMs. Further long-term investigations may clarify the tendencies found for the influence of indication, jaw and type of restoration on the survival and success rates of 6 mm implants.

Conclusion

In the scope of comprehensive treatment planning, 6 mm micro-rough implants offer less-invasive treatment options involving mostly splinted restorations. The present study demonstrated survival and success rates of 93.2 % and 89.2 % for 6 mm micro-rough implants in various indications after a mean follow-up period of 9.1 years. A detrimental risk factor for implant failure was smoking. Factors that negatively affected annual MBL and thus implant success were anatomical location (maxilla compared to mandible) and implant diameter (4.1 mm compared to 4.8 mm). The soft tissue thickness and the width of KM had no effect on annual MBL.

References

Abduljabbar, T., Al-Hamoudi, N., Al-Sowygh, Z. H., Alajmi, M., Javed, F., & Vohra, F. (2018). Comparison of peri-implant clinical and radiographic status around short (6 mm in length) dental implants placed in cigarette-smokers and never-smokers: Six-year follow-up results. *Clinical Implant Dentistry and Related Research*, *20*(1), 21–25. https://doi.org/10.1111/cid.12564

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 & Maxillofacial Implants*, *1*, 11–25.

Buser, D., Janner, S. F. M., Wittneben, J.-G., Brägger, U., Ramseier, C. A., & Salvi, G. E. (2012). 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: A retrospective study in 303 partially edentulous patients. *Clinical Implant Dentistry and Related Research*, *14*(6), 839–

851. https://doi.org/10.1111/j.1708-8208.2012.00456.x

Buser, D., & von Arx, T. (2000). Surgical procedures in partially edentulous patients with ITI implants. *Clinical Oral Implants Research*, *11*, 83–100. https://doi.org/10.1034/j.1600-0501.2000.011S1083.x

Buser, D., Weber, H.-P., & Lang, N. P. (1990). Tissue integration of non-submerged implants. 1-year results of a prospective study with 100 ITI hollow-cylinder and hollow-screw implants. *Clinical Oral Implants Research*, *1*(1), 33–40. https://doi.org/10.1034/j.1600-0501.1990.010105.x

Chappuis, V., Avila-Ortiz, G., Araújo, M. G., & Monje, A. (2018). Medication-related dental implant failure: Systematic review and meta-analysis. *Clinical Oral Implants Research*, *29*(S16), 55–68. https://doi.org/10.1111/clr.13137

Chappuis, V., Rahman, L., Buser, R., Janner, S., Belser, U., & Buser, D. (2018). Effectiveness of contour augmentation with guided bone regeneration: 10-year results. *Journal of Dental Research*, *97*, 266–274. https://doi.org/10.1177/0022034517737755

Di Fiore, A., Vigolo, P., Sivolella, S., Cavallin, F., Katsoulis, J., Monaco, C., & Stellini, E. (2019). Influence of crown-to-implant ratio on long-term marginal bone loss around short implants. *The International Journal of Oral & Maxillofacial Implants*, *34*(4), 992–998. https://doi.org/10.11607/jomi.7161

Heitz-Mayfield, L. J., Schmid, B., Weigel, C., Gerber, S., Bosshardt, D. D., Lang, N. P., & Jonsson, J. (2004). Does excessive occlusal load affect osseointegration? An experimental study in the dog. *Clinical Oral Implants Research*, *15*(3), 259–268. https://doi.org/10.1111/j.1600-0501.2004.01019.x

Isidor, F. (2006). Influence of forces on peri-implant bone. *Clinical Oral Implants Research*, *17*(S2), 8–18. https://doi.org/10.1111/j.1600-0501.2006.01360.x

Jung, R., Al-Nawas, B., Araújo, M., Avila-Ortiz, G., Barter, S., Brodala, N., … Windisch, P. (2018). Group 1 ITI Consensus Report: The influence of implant length and design and medications on clinical and patient-reported outcomes. *Clinical Oral Implants Research*, *29*, 69–77. https://doi.org/10.1111/clr.13342

Jung, R., Zembic, A., Pjetursson, B., Zwahlen, M., & Thoma, D. (2012). Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clinical Oral Implants Research*, *23 Suppl 6*, 2–21. https://doi.org/10.1111/j.1600-0501.2012.02547.x

Lai, H.-C., Si, M.-S., Zhuang, L.-F., Shen, H., Liu, Y., & Wismeijer, D. (2013). Long-term outcomes of short dental implants supporting single crowns in posterior region: A clinical retrospective study of 5-10 years. *Clinical Oral Implants Research*, *24*(2), 230–237. https://doi.org/10.1111/j.1600-0501.2012.02452.x

Mombelli, A., 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*(4), 145–151. https://doi.org/10.1111/j.1399-302X.1987.tb00298.x

Monje, A., Fu, J.-H., Chan, H.-L., Suarez, F., Galindo-Moreno, P., Catena, A., & Wang, H.-L. (2013). Do implant length and width matter for short dental implants (<10 mm)? A meta-analysis of prospective studies. *Journal of Periodontology*, *84*(12), 1783–1791. https://doi.org/10.1902/jop.2013.120745

Monje, A., Suarez, F., Galindo-Moreno, P., García-Nogales, A., Fu, J.-H., & Wang, H.-L. (2014). A systematic review on marginal bone loss around short dental implants (<10 mm) for implant-supported fixed prostheses. *Clinical Oral Implants Research*, *25*(10), 1119–1124. https://doi.org/10.1111/clr.12236

Morand, M., & Irinakis, T. (2007). The challenge of implant therapy in the posterior maxilla: Providing a rationale for the use of short implants. *Journal of Oral Implantology*, *33*(5), 257–266. https://doi.org/10.1563/1548-1336(2007)33[257:TCOITI]2.0.CO;2

Moraschini, V., & Barboza, E. (2016). Success of dental implants in smokers and non-smokers: A systematic review and meta-analysis. *International Journal of Oral and Maxillofacial Surgery*, *45*(2), 205–215. https://doi.org/10.1016/j.ijom.2015.08.996

Naenni, N., Sahrmann, P., Schmidlin, P. R., Attin, T., Wiedemeier, D. B., Sapata, V., … Jung, R. E. (2018). Five-year survival of short single-tooth implants (6 mm): A randomized controlled clinical trial. *Journal of Dental Research*, *97*(8), 887–892. https://doi.org/10.1177/0022034518758036

Naert, I., Duyck, J., & Vandamme, K. (2012). Occlusal overload and bone/implant loss. *Clinical Oral Implants Research*, *23*, 95–107. https://doi.org/10.1111/j.1600-0501.2012.02550.x

Nunes, M., Almeida, R., Felino, A., Maló, P., & De Araújo Nobre, M. (2016). The influence of crown-to-implant ratio on short implant marginal bone loss. *The International Journal of Oral & Maxillofacial Implants*, *31*, 1156–1163. https://doi.org/10.11607/jomi.4336

Papaspyridakos, P., De Souza, A., Vazouras, K., Gholami, H., Pagni, S., & Weber, H.-P. (2018). Survival rates of short dental implants (≤6 mm) compared with implants longer than 6 mm in posterior jaw areas: A meta-analysis. *Clinical Oral Implants Research*, *29*, 8–20. https://doi.org/10.1111/clr.13289

Petrie, C. S., & Williams, J. L. (2005). Comparative evaluation of implant designs: Influence of diameter, length, and taper on strains in the alveolar crest: A three-dimensional finite-element analysis. *Clinical Oral Implants Research*, *16*(4), 486–494. https://doi.org/10.1111/j.1600-0501.2005.01132.x

Preciado, A., Del Río, J., Lynch, C. D., & Castillo-Oyagüe, R. (2013). Impact of various screwed implant prostheses on oral health-related quality of life as measured with the QoLIP–10 and OHIP–14 scales: A cross-sectional study. *Journal of Dentistry*, *41*(12), 1196–1207. https://doi.org/10.1016/j.jdent.2013.08.026

Ravidà, A., Barootchi, S., Askar, H., Suárez López del Amo, F., Tavelli, L., & Wang, H.-L. (2019). Long-Term Effectiveness of Extra-Short (≤ 6 mm) Dental Implants: A Systematic Review. *The International Journal of Oral & Maxillofacial Implants*, *34*, 68–84. https://doi.org/10.11607/jomi.6893

Romeo, E., Storelli, S., Casano, G., Scanferla, M., & Botticelli, D. (2014). Six-mm versus 10-mm long implants in the rehabilitation of posterior edentulous jaws: A 5-year follow-up of a randomised controlled trial. *European Journal of Oral Implantology*, *7*, 371–381.

Rossi, F., Botticelli, D., Cesaretti, G., De Santis, E., Storelli, S., & Lang, N. P. (2016). Use of short implants (6 mm) in a single-tooth replacement: A 5-year follow-up prospective randomized controlled multicenter clinical study. *Clinical Oral Implants Research*, *27*(4), 458–464. https://doi.org/10.1111/clr.12564

Rossi, F., Lang, N. P., Ricci, E., Ferraioli, L., Baldi, N., & Botticelli, D. (2018). Long-term follow-up of single crowns supported by short, moderately rough implants-A prospective 10-year cohort study. *Clinical Oral Implants Research*, *29*(12), 1212–1219. https://doi.org/10.1111/clr.13386

Salvi, G., & Brägger, U. (2009). Mechanical and technical risks in implant therapy. *The International Journal of Oral & Maxillofacial Implants*, *24 Suppl*, 69–85.

Schimmel, M., Srinivasan, M., McKenna, G., & Müller, F. (2018). Effect of advanced age and/or systemic medical conditions on dental implant survival: A systematic review and meta-analysis. *Clinical Oral Implants Research*, *29*, 311–330. https://doi.org/10.1111/clr.13288

Schwarz, F., Derks, J., Monje, A., & Wang, H.-L. (2018). Peri-implantitis. *Journal of Clinical Periodontology*, *45*, S246–S266. https://doi.org/10.1111/jcpe.12954

Srinivasan, M., Vazquez, L., Rieder, P., Moraguez, O., Bernard, J.-P., & Belser, U. C.

(2014). Survival rates of short (6 mm) micro-rough surface implants: A review of literature and meta-analysis. *Clinical Oral Implants Research*, *25*(5), 539–545. https://doi.org/10.1111/clr.12125

Thoma, D. S., Naenni, N., Figuero, E., Hämmerle, C. H. F., Schwarz, F., Jung, R. E., & Sanz-Sánchez, I. (2018). Effects of soft tissue augmentation procedures on peri-implant health or disease: A systematic review and meta-analysis. *Clinical Oral Implants Research*, *29*, 32–49. https://doi.org/10.1111/clr.13114

Vazouras, K., Souza, A. B., Gholami, H., Papaspyridakos, P., Pagni, S., & Weber, H. (2020). Effect of time in function on the predictability of short dental implants (≤6 mm): A meta-analysis. *Journal of Oral Rehabilitation*, *47*(3), 403–415. https://doi.org/10.1111/joor.12925

Villarinho, E. A., Triches, D. F., Alonso, F. R., Mezzomo, L. A. M., Teixeira, E. R., & Shinkai, R. S. A. (2017). Risk factors for single crowns supported by short (6-mm) implants in the posterior region: A prospective clinical and radiographic study. *Clinical Implant Dentistry and Related Research*, *19*(4), 671–680. https://doi.org/10.1111/cid.12494

Tables & Figures Legends

Table 1:

Criteria for implant success.

Table 2:

Implant characteristics, surgical and restorative procedures of the 6 mm implants (number of implants and rates). All information is given for both jaws as well as maxilla and mandible separately. The information regarding lost implants were included to the columns "maxilla", "mandible" and "total". Additionally, to better understand potential risk factors, information about lost implants are shown separately in the column "total losses". N=74. (FDP fixed dental prosthesis, RDP removable dental prothesis, GBR guided bone regeneration, CR cement retained, SR screw retained)

Table 3:

Complications, survival and success (number of implants and rates) as well as clinical and radiographic parameters (mean values and standard deviation, SD) of the 6 mm implants. All information is given for both jaws as well as maxilla and mandible separately. N=74.

Table 4

*Survival Hazard Ratios from Cox Proportional Hazard Regression. *Is significantly higher than 1.*

1) HR not computable as only females had implant losses (5)
2) HR not computable as only non-grinders had implant losses (5)
3) HR not computable as only one experimental group had implant losses (5)
4) HR not computable as only one experimental group had implant losses (5)

Figure 1

Patient-reported outcome measures were evaluated using the shown phrases. The patients had to visualize their agreement to the statements on a visual analog scale, using 0 % as full disagreement and 100 % as complete agreement. The boxplot of each statement is presented with x indicating mean values.

Figure 2

Overall survival rate of 6 mm implants over time (dotted lines: 95 % confidence intervals).

Figure 3

Representative clinical images of 6 mm implants from a buccal and occlusal view with corresponding PAs. The FDI-classification indicates the implants position, with 6 mm implants written underlined. Follow-up periods are given in years.

Figure 4

Survival rates of 6 mm implants in non-smokers (grey) and smokers (black) over time.

Table 1

Criteria for implant success.

Criteria for implant success according to Albrektsson et al. (1986)	Criteria for implant success according to Buser et al. (1990)
Absence of persistent pain, infection, neuropathies, paresthesia or violation of the mandibular canal	Absence of persistent subjective complaints, such as pain, recurrent peri-implant infection with suppuration, foreign body sensation or dysesthesia
Clinically immobile implant	Absence of mobility
No peri-implant radiolucency	Absence of continuous radiolucency around the implant
Vertical bone loss less than 0.2 mm annually following the implant's first year of service	Possibility for restoration

Table 1

Implant characteristics, surgical and restorative procedures of the 6 mm implants (number of implants and rates). All information is given for both jaws as well as maxilla and mandible separately. The information regarding lost implants were included to the columns "maxilla", "mandible" and "total". Additionally, to better understand potential risk factors, information about lost implants are shown separately in the column "total losses". N=74.

Procedure-related data	**n (maxilla) no losses**	**%**	**n (mandible) including 5 losses**	**%**	**n (total) including 5 losses**	**%**	**n total losses**
Surface							
SLA	**2**	8.7	**14**	27.5	**16**	21.6	1
SLActive	**21**	91.3	**37**	72.5	**58**	78.4	4
Implant diameter							
4.1 mm	**5**	21.7	**27**	52.9	**32**	43.2	3
4.8 mm	**18**	78.3	**24**	47.1	**42**	56.8	2
Site of insertion							
Incisor	**2**	8.7	**0**	0	**2**	2.7	0
Premolar	**8**	34.8	**12**	23.5	**20**	27.0	2
Molar	**13**	56.5	**39**	76.5	**52**	70.3	3
Indication							
Single-tooth gap	**1**	4.3	**1**	2.0	**2**	2.7	0
Free-end situation	**14**	60.9	**38**	74.5	**52**	70.3	5
Extended edentulous spaces	**5**	21.7	**12**	23.5	**17**	23.0	0
Edentulous jaws	**3**	13.0	**0**	0	**3**	4.1	0
Surgical Intervention							
Timepoint of implantation							
Immediate (Type 1)	**0**	0	**0**	0	**0**	0	0
Early 4 - 8 weeks (Type 2)	**0**	0	**1**	2.0	**1**	1.4	0
Early 12 - 16 weeks (Type 3)	**1**	4.3	**4**	7.8	**5**	6.8	0
Late 6 months (Type 4)	**22**	95.7	**46**	90.2	**68**	91.9	5
Augmentative Procedures							
None	**20**	87.0	**38**	74.5	**58**	78.4	4
Simultaneous GBR	**2**	8.7	**6**	11.8	**8**	10.8	0
Staged block graft	**1**	4.3	**7**	13.7	**8**	10.8	1

Restorative Procedures

FDPs							
Single crowns (CR/SR)	**0/1**	0/4	**2/4**	4/8	**2/5**	3/7	0/0
Splinted crowns (CR/SR)	**6/5**	26/22	**13/7**	25/14	**19/12**	26/16	0/2
Bridges (CR/SR)	**0/3**	0/13	**9/5**	18/10	**9/8**	12/11	2/0
Bridges + extension (CR/SR)	**1/3**	4/13	**8/2**	16/4	**9/5**	12/7	1/0
RDPs							
Implant supported bar, SR	**2**	9	**0**	0	**2**	3	0
Attachments, SR	**2**	9	**1**	2	**3**	4	0

FDP fixed dental prosthesis, RDP removable dental prothesis, GBR guided bone regeneration, CR cement retained, SR screw retained

Table 1

Complications, survival and success (number of implants and rates) as well as clinical and radiographic parameters (mean values and standard deviation, SD) of the 6 mm implants. All information is given for both jaws as well as maxilla and mandible separately. N=74.

Follow-up data						
Complications	**n (maxilla)**	**%**	**n (mandibula)**	**%**	**n (total)**	**%**
Biological	**0**	0	**4**	7.8	**4**	5.4
Mechanical	**1**	4.3	**2**	3.9	**3**	4
Technical	**1**	4.3	**5**	9.8	**6**	8.1
Survival and Success						
Survival	**23**	100	**46**	90.2	**69**	93.2
Removed or lost implants	**0**	0	**5**	9.8	**5**	6.8
Implants fulfilling success criteria of Buser et al.	**23**	100	**44**	85.3	**67**	90.5
Implants fulfilling success criteria of Albrektsson et al.	**22**	95.7	**44**	85.3	**66**	89.2
Clinical Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age at surgery, years	**63,56**	11,42	**59,50**	10,95	**60,80**	11,26
Implant follow-up, years	**7,80**	3,36	**9,81**	3,59	**9,14**	3,64
Months in function (only failed implants)					**83,40**	29,96
Modified plaque index	**0,28**	0,47	**0,24**	0,32	**0,26**	0,38
Modified sulcus bleeding index	**0,22**	0,35	**0,24**	0,13	**0,11**	0,24
Probing depth, mm	**3,45**	1,40	**2,80**	0,68	**3,01**	1,03
Distance from gingival margin to implant shoulder, mm	**-1,26**	1,42	**-0,32**	1,14	**-0,64**	1,32
Keratinized mucosa, mm	**3,39**	2,02	**1,16**	0,94	**1,91**	1,76
Thickness of keratinized mucosa, mm	**1,44**	0,83	**1,37**	0,64	**1,39**	0,70
2-Dimensional Radiographic Analysis						
Distance from implant shoulder (postop) to the first bone-to-implant contact	**1,67**	0,41	**2,43**	0,75	**2,18**	0,75

Distance from implant shoulder (follow-up) to the first bone-to-implant contact	**2,03**	0,60	**2,55**	0,51	**2,38**	0,60
Annual marginal bone loss (mm)	**0.057**	0.086	**0.016**	0.059	**0.029**	0.071

Table 1

*Survival Hazard Ratios from Cox Proportional Hazard Regression. *Is significantly higher than 1.*

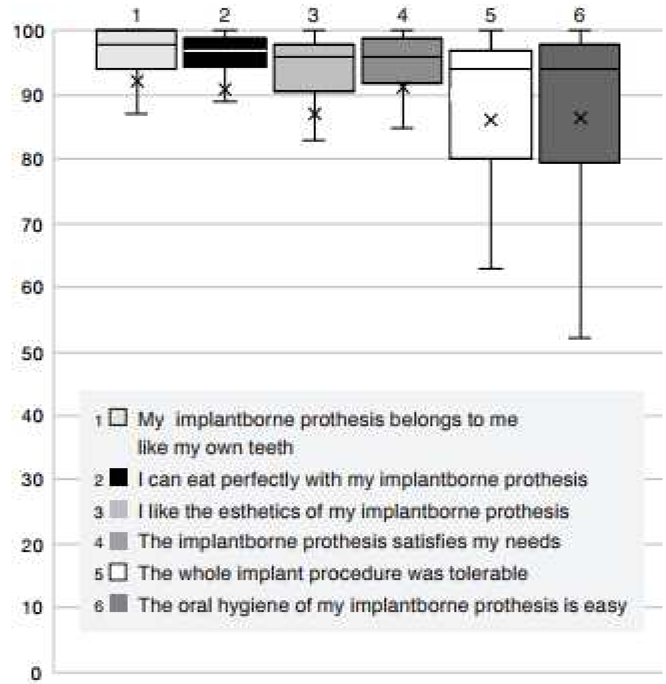
Survival Hazard Ratios	Reference Group	Comparison Group	HR (95%-CI)
Smoking	No/Ex-Smoker	Smoker	36.35* (3.99 – 331.5)
Age	Age X	Age X + 1	1.01 (0.93 – 1.11)
Gender	1)		
Grinding	2)		
Medical Risk Factors	No	Yes	1.84 (0.30 – 11.19)
Surface	SLA	SLActive	2.92 (0.26 – 32.42)
Implant Diameter	4.1mm	4.8mm	0.47 (0.08 – 2.83)
Implant Site	Premolars	Molars	0.53 (0.09 – 3.20)
Indication	3)		
Restauration	4)		
Retention	Cemented	Screw Retained	1.17 (0.19 – 7.19)

1) HR not computable as only females had implant losses (5)

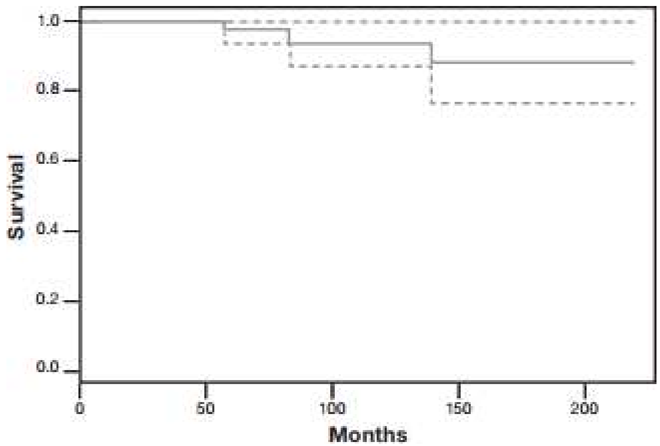
2) HR not computable as only non-grinders had implant losses (5)

3) HR not computable as only one experimental group had implant losses (5)

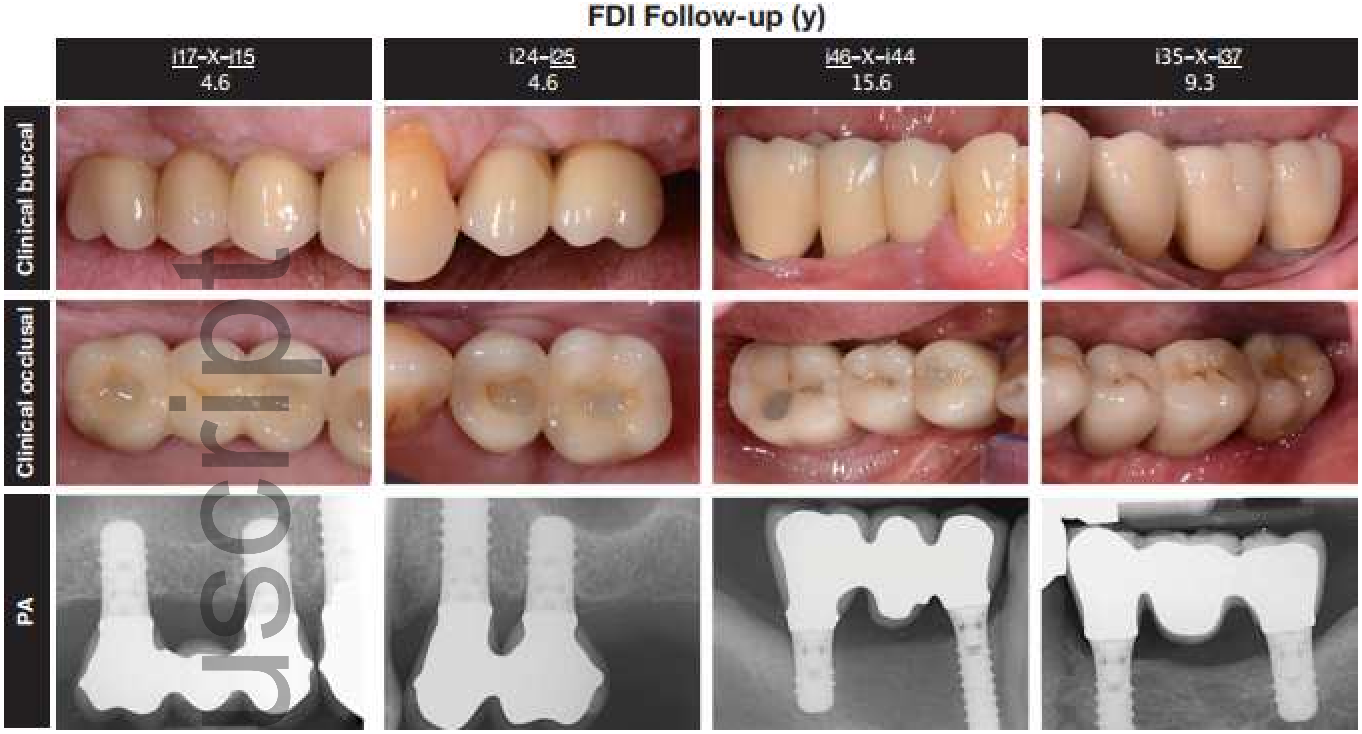
4) HR not computable as only one experimental group had implant losses (5)



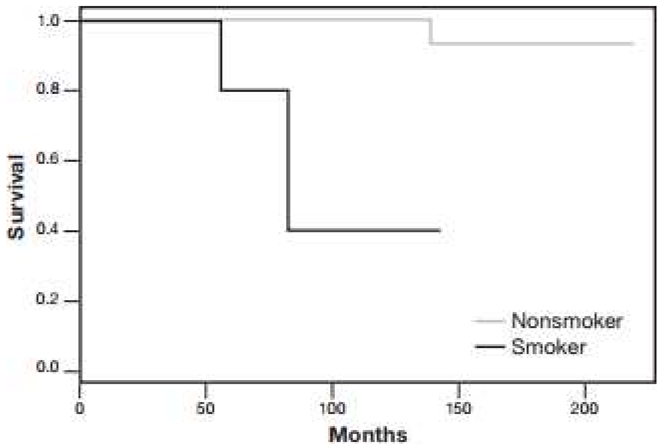
clr_13795_f1.tiff



clr_13795_f2.tiff



clr_13795_f3.tiff



clr_13795_f4.tiff