Georg Watzak
Werner Zechner
Dieter Busenlechner
Christof Arnhart
Reinhard Gruber
Georg Watzek

Radiological and clinical follow-up of machined- and anodized-surface implants after mean functional loading for 33 months

Authors' affiliations:
Georg Watzak, Werner Zechner, Dieter Busenlechner, Reinhard Gruber, Department of Oral Surgery, Bernhard Gottlieb Dental School, Medical University of Vienna, Vienna, Austria
Christof Arnhart, Bernhard Gottlieb Dental School, Medical University of Vienna, Vienna, Austria
Georg Watzek, Department of Oral Surgery, Dental School, Medical University of Vienna, Vienna, Austria
Georg Watzak, Werner Zechner, Dieter Busenlechner, Christof Arnhart, Reinhard Gruber, Georg Watzek, Ludwig Boltzmann Institute of Oral Implantology, Vienna, Austria

Correspondence to:
Georg Watzak
Department of Oral Surgery
Dental School
Medical University of Vienna
Waehringerstrasse 25A
A-1090 Vienna
Austria
Tel.: +43 1 4277 67012
Fax: +43 1 4277 67019
e-mail: georg.watzak@meduniwien.ac.at

Date:
Accepted 30 January 2006

To cite this article:
Watzak G, Zechner W, Busenlechner D, Arnhart C, Gruber R, Watzek G. Radiological and clinical follow-up of machined- and anodized-surface implants after mean functional loading for 33 months.
Clin. Oral Impl. Res. **17**, 2006; 651–657
doi: 10.1111/j.1600-0501.2006.01275.x

Key words: bleeding, functionally loaded implants, implant surface, peri-implant bone loss, plaque index, probing depth, screw-type implants

Abstract: The purpose of this retrospective study was to compare peri-implant bone loss and mucosal conditions around machined-surface (MS) and anodized-surface (AS) interforaminal implants in the mandible at least 30 months after placement. Fifty patients, each treated with four interforaminal screw-type implants consecutively, were included. Thirty-one patients (62%) with a total number of 124 implants (64 MS and 60 AS implants, both Brånemark type MKIII) were available for follow-up. Rotational panoramic radiographs were used for evaluating marginal bone loss. Clinically, marginal plaque index (mPI), bleeding on probing (BOP) and pocket probing depth (PPD) were evaluated. AS implants showed significantly less marginal bone loss than MS implants (-1.17 ± 0.13 vs. -1.42 ± 0.13 mm; $P=0.03$). Marginal bone loss around distal implants was less pronounced at AS implants (-1.05 ± 0.14 mm) when compared with MS implants (-1.46 ± 0.14 mm; $P=0.05$). Within the smoking group, there was less peri-implant bone loss around AS implants than around MS implants (-1.08 ± 0.27 vs. -1.83 ± 0.2; $P=0.04$). No differences between MS and AS implants were found with respect to mPI (57% vs. 67%), BOP (21% vs. 17%) and mean PPD (2.59 ± 0.29 vs. 2.56 ± 0.28 mm). Overall, both types of implants, in combination with bar-supported overdentures, can produce excellent long-term results in the interforaminal edentulous mandible with less peri-implant bone loss around rough implant surfaces, which had beneficial effects at distal implants and in smokers.

For many years, screw-type machined-surface (MS) implants were thought to be ideally suited for long-term osseointegration (Albrektsson et al. 1986, 1988). The gross and microscopic nature of the MS implant surface texture (S_a value of 0.5–1 μm) was reported to be key for the osseointegration of dental implants (Skalak 1983; Albrektsson 1986). Because of the stronger bone response, i.e. more interfacial bone apposition around implants with a surface roughness of about 1.5 μm (S_a), surface modification has been the main focus in oral implants research (Albrektsson & Wennerberg 2004). Rough implant surfaces were found to show more bone-to-implant contact in the initial healing period (Zechner et al. 2003b). However, a surface roughness of more than 2 μm may increase the risk of peri-implantitis (Becker et al. 2000). Therefore, the majority of commercially available oral implants are currently moderately roughened (S_a between 1 and 2 μm), e.g. sandblasted/acid-etched, dual acid-etched and anodized-surface implants (AS). Beneficial effects of surface roughening on the apposition of bone during healing were observed in several experimental studies (Cochran et al. 1996; Davies 1998; Zechner et al. 2003a).

Long-term success, however, depends on minimizing the amount of marginal bone loss after several years of functional loading (Albrektsson et al. 1988; Sullivan et al. 2001; Ferrigno et al. 2002). Only one study compared marginal bone loss around MS and AS implants. Rocci et al. (2003) published a randomized study of immediately loaded MS and AS implants in the posterior mandible with marginal bone resorption of 0.9 mm after 1 year of loading around AS implants and 1 mm around MS implants. The data showed no significant difference. The present study focused on a comparison of MS and AS implants placed with a submerged procedure and a functional loading time of more than 1 year.

Radiologic imaging techniques to evaluate changes in marginal peri-implant bone height during implant recall programs are widely accepted. Conventional imaging techniques using intraoral periapical radiographs and extraoral panoramic radiographs have been recommended (Jeffcoat 1992; Bragger et al. 1996; Batenburg et al. 1998). Rotational panoramic radiographs are a useful alternative to intraoral periapical radiographs for evaluating peri-implant bone loss in cases with poor imaging conditions, particularly in the highly atrophic interforaminal mandible (Batenburg et al. 1998). Zechner et al. (2003b) stated in their clinical study that rotational panoramic radiographs were comparable to intraoral periapical radiographs for evaluating peri-implant bone loss in the atrophic mandible. To assess marginal mucosal conditions around dental implants clinical variables like marginal plaque index (mPI), bleeding on probing (BOP) and pocket probing depth (PPD) are currently used (Salvi & Lang 2004). Significant relationships between oral hygiene and peri-implant bone resorption were suggested (Lindquist et al. 1988). Therefore, monitoring oral hygiene habits by quantifying plaque accumulation using variables like mPI (Mombelli et al. 1987) appeared to be meaningful. The absence of BOP was reported to have a high negative predictive value, thus serving as a variable for monitoring peri-implant conditions (Jepsen et al. 1996). Moreover, PPD should not exceed 3 mm in patients with healthy soft-tissue conditions (Mombelli 1999).

In the present retrospective study, MS and AS implants were compared radiologically and clinically to evaluate marginal peri-implant bone loss and to assess marginal mucosal conditions at least 30 months after placement. To ensure comparability, only patients with four interforaminal implants supporting bar overdentures were enrolled in the study. Effects of patient age and gender, nicotine abuse, implant position, implant life and site of measurements to determine marginal bone loss and mucosal conditions were evaluated.

Material and methods

Subjects

Patients enrolled in this study presented with edentulous mandibles and received four submerged interforaminal implants between January 2000 and 2002. They were rehabilitated with bar-supported removable overdentures after a healing time of 3 months. The inclusion criteria were adequate oral hygiene, absence of local inflammation or mucosal disease, and residual bone height in the interforaminal area sufficient for accommodating four screw-type titanium implants 3.75 mm in diameter and at least 10 mm long. The exclusion criteria included severe clenching or bruxing, drug or alcohol abuse, history of radiation therapy, uncontrolled diabetes, immunocompromised status, and general contraindications for surgical procedures. Of the 50 patients, 31 (18 women and 13 men) were available for follow-up (recall rate, 62%). Nineteen patients were unavailable: seven were diseased at the time of recall, three ignored appointments, four moved away without leaving a forwarding address and five refused to show up for follow-up studies for personal reasons (e.g. long travel time, poor health). The MS implant group comprised 15 patients ranging in age from 56 to 83 years (mean 66.2 years). Nicotine abuse (more than 10 cigarettes a day) was established in five of them. The AS implant group consisted of 16 patients ranging in age from 52 to 86 years (mean 69.9 years), with four nicotine abusers.

Surgical and prosthodontic procedures

Screw-type Brånemark MK III implants (diameter 3.75 mm; Nobel Biocare™, Gothenburg, Sweden; Fig. 1) were placed according to the manufacturers' instructions by experienced oral and maxillofacial surgeons (Fig. 2). The implant surface was either machined (surface roughness value (S_a) = 0.53 μm) or anodized (S_a = 0.5–2 μm – increasing from coronal towards apical). Implant lengths varied between 10 and 13 mm depending on the amount of bone available. All patients received four implants interforaminally in the same manner, two of them in a mesial position (teeth 32 and 42; American tooth numbering system: 23 and 26) and two of them in a distal position (teeth 34 and 44; American tooth numbering system: 21 and 28) relative to the mental foramen. For all patients, splinting suprastructures consisted of a milled gold alloy bar (Fig. 3) cantilevered posteriorly with no more than 1.6 times the anteroposterior distance between the mesial and distal implants and an implant-supported overdenture with 12 resin teeth (McAlarney & Stavropoulos 1996).

Fig. 1. Screw-type Brånemark MK III implants. Left: machined-surface (MS) implant; right: anodized-surface (AS) implant.

Clinical and radiological examination

Patients were followed up between June 2004 and February 2005 at the Department of Oral Surgery, Bernhard Gottlieb Dental School, Vienna, Austria. The following variables were evaluated: marginal bone loss by radiographic evidence, mPI, BOP and PPD. For radiographic assessment, orthopantomograms (Scanora; Soredex, Orion, France; Fig. 4) were obtained. Peri-implant marginal bone loss mesial and

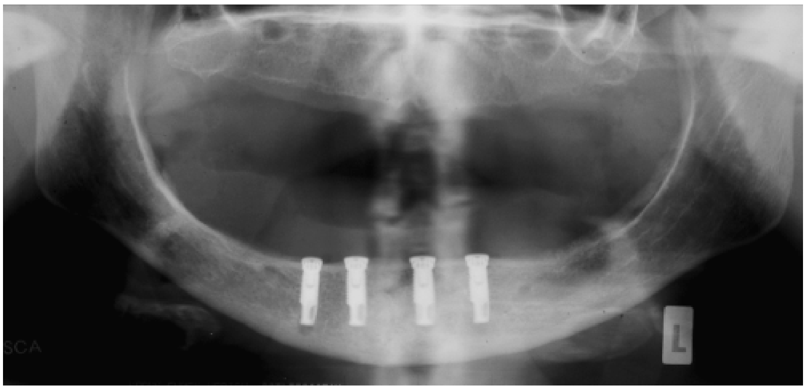

Fig. 2. Orthopantomogram after placement of four implants in the interforaminal region of the edentulous mandible.

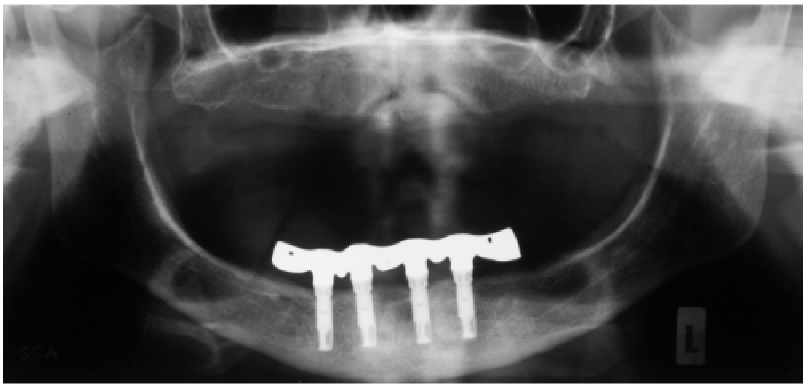

Fig. 3. Follow-up orthopantomogram after insertion of the suprastructure into the interforaminal mandible for evaluating fit.

Fig. 4. Four implants in the interforaminal mandible after mounting the suprastructure consisting of a milled gold alloy bar.

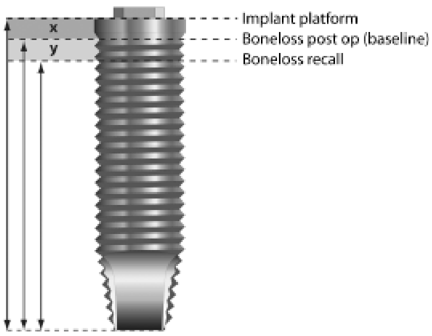

Fig. 5. Morphometric landmarks. Measured implant lengths on the orthopantomogram were divided by the actual lengths of the implants to determine the magnification factor and compute the actual bone loss at surgery (baseline: *x*) and at recall (*y*) mesial and distal to the implants.

distal to each implant was assessed with a precision slide jaw caliper with a maximum resolution of 0.01 mm (Züricher Modell; Planer, Vienna, Austria). Data were compared on baseline and follow-up radiographs by measuring the vertical distance between the implant–abutment interface and the implant apex as well as the bone level at the crest and implant apex (Fig. 5). The difference in these two distances was defined as peri-implant bone loss. To correct for dimensional distortion, the apparent dimensions of the implants were measured on the radiographs and divided by the actual implant size. Bone loss in millimeters detected radiologically was divided by the magnification factor to obtain the actual bone loss.

As the radiographic evaluation was confined to the mesial and distal sites, the clinical variables from only these implant aspects were included in the analysis. mPI (0, no plaque; 1, plaque on the probe; 2, visually detected plaque; 3, abundance of plaque) and BOP (presence of bleeding: BOP +; absence of bleeding: BOP −) scores were recorded. Probing depth measurements were made to the nearest millimeter using a calibrated probe.

Statistical analysis

Differences between the two implant types (MS vs. AS) were evaluated by a linear mixed model with repeated measurements correcting for the prognostic factors gender and age, nicotine use, implant life (at follow-up), site of measurements (mesial vs. distal to the implants), implant position (mesial vs. distal to the foramen) and bone loss at the time of surgery (baseline). Potential interactions between the implant type and prognostic factors were analyzed and, where there was no significant effect, removed from the model. The variance–covariance matrix for repeated measurements was assumed to achieve a compound symmetry structure. Model assumptions about heterogeneity, skew distributions and outliers were analyzed by residual plots. For categorical prognostic factors, the effects of predictive covariates on bone loss were described by least-square means and corresponding standard errors of the means (Table 1). Continuous variables (patient age, implant life and bone loss at the time of surgery) were described by parameter estimates and corresponding standard errors. Associations between prognostic factors were assessed by linear mixed models with repeated measurements. Statistical calculations were run on the statistical package SAS (SAS Version 9, SAS Institute Inc., Cary, NC, USA). All *P*-values given were two-sided, and $P \leq 0.05$ was considered statistically significant.

Results

Patient age ranged from 52 to 86 years (mean 67.55 years) at follow-up. Implants had been in place for 29.8 to 47.4 months (mean implant life 35.94 months for all implants; 39.47 months for MS implants; and 33.19 months for AS implants; Table 2).

***Table 1*. Peri-implant bone loss as related to prognostic factors**

	LSM	SEM	*P*
Gender			
Male	− 1.09	0.12	
Female	− 1.5	0.09	0.01
Nicotine use			
No MS implants	− 1.02	0.13	
No AS implants	− 1.27	0.15	0.25
Yes MS implants	− 1.83	0.2	
Yes AS implants	− 1.08	0.27	0.04
Implant position			
Mesial MS implants	− 1.39	0.13	
Mesial AS implants	− 1.29	0.14	0.65
Distal MS implants	− 1.46	0.14	
Distal AS implants	− 1.05	0.14	0.05
Implant site			
Mesial side of implant	− 1.32	0.09	
Distal side of implant	− 1.28	0.09	0.55

$P \leq 0.05$ was considered statistically significant. Potential interactions between the implant type and prognostic factors were analyzed and, where there was no significant effect, removed from the model.
LSM, least-square means; SEM, standard error of mean; MS, machined surface; AS, anodized surface.

***Table 2*. Life of MS implants vs. AS implants in months**

	Minimum	Maximum	Mean
MS implants	33.2	47.4	39.47
AS implants	29.8	38.6	33.19

MS, machined surface; AS, anodized surface.

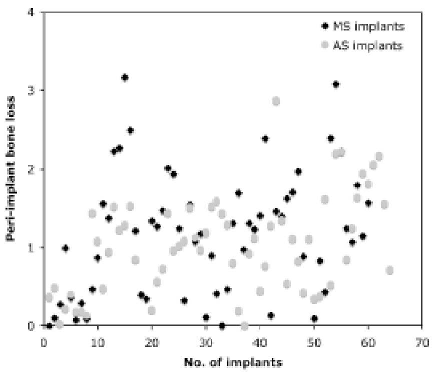

Fig. 6. Plot graph of peri-implant bone loss around all implants followed up in numerical order. MS implants, machined-surface implants; AS implants, anodized-surface implants.

The mean functional loading time was 32.98 months. None of the implants in the MS group failed. The survival rate of AS implants was 98.44% owing to an implant failure after 3 months of functional loading.

All implants showed significantly less bone loss in males than in females (-1.09 ± 0.12 vs. -1.50 ± 0.09 mm; $P = 0.01$), without significant interaction between gender and the two groups of implant types ($P > 0.05$).

There was a significant interaction between 'nicotine use' and 'implant type' ($P = 0.03$): non-smokers showed -1.02 mm bone loss around MS implants vs. -1.27 mm around AS implants ($P > 0.05$). Smokers showed -1.83 mm bone loss around MS implants vs. -1.08 mm around AS implants ($P = 0.04$). However, looking at the 'implant type' alone, the mean marginal bone loss around AS implants (-1.17 ± 0.13 mm) was significantly less than around MS implants (-1.42 ± 0.13 mm; $P = 0.03$; Fig. 6). Without breaking down the smoking as well as the non-smoking group by MS and AS implants, there was, however, significantly less bone loss in non-smokers than in smokers (-1.14 ± 0.09 vs. -1.46 ± 0.16 mm; $P = 0.01$).

A significant interaction was detected between the implant position and the two groups of implant types ($P = 0.02$): bone loss -1.39 mm for MS implants vs. -1.29 mm for AS implants mesially ($P > 0.05$) and -1.46 mm for MS implants vs. -1.05 mm for AS implants distally ($P = 0.05$). However, without distinguishing between MS and AS implants, the mean bone loss around all mesial and distal implants was not significantly different ($P > 0.05$).

No statistically significant relationship was detected between measurements on the mesial (1.32 mm) and distal sides (1.28 mm) of the same implant and the bone loss measured at follow-up ($P > 0.05$). Mesial and distal in this context refer to the mid-sagittal plane inspecting each single implant.

There was a significant relationship between baseline measurements (bone loss at the time of surgery) and measurements at follow-up ($P < 0.0001$), but no significant relationship between bone loss and patient age or implant life ($P > 0.05$).

The clinical data for MS and AS implants are listed in Table 3. Plaque was found on 57% (mPI score 1: 45%; score 2: 12%; score 3: 0%) of the evaluated surfaces around MS implants and 67% (mPI score 1: 53%; score 2: 14%; score 3: 0%) of these around AS implants. The difference between the two implant types was not significant ($P > 0.05$). Twenty-one percent of the MS implant sites showed bleeding on sulcus probing vs. 17% of the AS implants. The difference between the two implant types was again not significant ($P > 0.05$). A significant relationship was found to exist between plaque and bleeding for all implants ($P = 0.03$), i.e. the higher the mPI score, the more likely BOP was. MS implants showed a mean PPD of 2.59 ± 0.29 vs. 2.56 ± 0.28 mm for AS implants. There were no significant differences in mean PPD around MS and AS implants ($P > 0.05$). A PPD of ≤ 3 mm was observed at 87% of all implant sites, while PPDs of 3.5–5 and 5.5–7 mm were recorded at 10% and 3% of the sites, respectively. The

***Table 3*. Clinical variables around MS and AS implants**

	MS implants	AS implants	*P*
mPI (1–3)	57%	67%	0.42
BOP	21%	17%	0.07
PPD	2.59 (± 0.29) mm	2.56 (± 0.28) mm	0.95

$P \leq 0.05$ statistically significant.
mPI, marginal plaque index (presence of plaque score 1–3); BOP, bleeding on probing; PPD, pocket probing depth; MS, machined surface; AS, anodized surface.

relationship between PPD values greater than 3 mm and other clinical variables of all implants was considered significant: PPD > 3 mm and BOP ($P = 0.03$); PPD > 3 mm and plaque ($P = 0.02$). No statistically significant relationships were detected between clinical variables and implant type, nicotine use, gender, age and implant life ($P > 0.05$).

Discussion

The present study showed that both MS and AS screw-type implants with bar-supported overdentures can produce excellent long-term results in edentulous atrophic mandibles with significantly less peri-implant bone loss around AS implants than around MS implants. These results confirm what previous studies showed, i.e. that roughened implant surfaces are beneficial for long-term peri-implant bony healing (Albrektsson & Isidor 1994; Khang et al. 2001; Zechner et al. 2004). Successful long-term osseointegration of implants has been attributed to sustained increased bone remodeling (Garetto et al. 1995). Rough surfaces provide an intimate connection with peri-implant bone during early osseointegration that, in the long run, supports the distribution of functional loads and consequent adaptive remodeling (Stanford and Schneider 2004). Despite the multitude of clinical and/or radiological studies of machined and rough-surface implants (Albrektsson et al. 1988; Jemt et al. 1996; van Steenberghe et al. 2001), only Rocci et al. (2003) compared AS implants with MS implants in relation to the bone support during a follow-up period of 12 months. The difference in peri-implant bone loss reported was not statistically significant, and the survival rate was 95.45% for AS-implants vs. 85.45% for MS implants. In the present study, the survival rates were 98.44% vs. 100%. However, data of these two studies defy comparison, because they were derived in different clinical setups. In the present study, a submerged procedure was chosen for undisturbed bony healing after implant placement. Thus, early osseointegration was not hampered by immediate loading.

The statistical analysis of the effects of gender on peri-implant bone loss showed more bone resorption around implants placed in females than in males, without any difference between AS and MS implants. These findings are at odds with earlier clinical reports, which did not show any statistical interaction between mean marginal bone loss and patient age or gender (Carlsson et al. 2000; Eliasson et al. 2000; Zechner et al. 2004). In the female group of the present study, there were no individuals younger than 52 years. The authors, therefore, conclude in concordance with Zioupos et al. (2000) that postmenopausal female bone tends to undergo accelerated resorption, which increases porosity levels and consequently produces a weaker bone matrix material (internal porosity) with rarefaction of the bone structure, i.e. a breakdown of the bone matrix. This progressive loss of bone mass may exceed the normal age-related loss of bone mass (Rizzoli et al. 2001). The findings of von Wowern and Gotfredsen (2001) suggested that peri-implant bone loss may be accentuated when mandibular osteoporosis is present at the beginning of implant treatment, particularly in postmenopausal women. To the best of the authors' knowledge, none of the patients in the present study had diagnosed osteoporosis.

Nicotine use significantly correlated with marginal peri-implant bone loss in the mandible. The interaction between the implant type and nicotine use was found to be significant. If nicotine abuse was detected, less peri-implant bone loss was found around AS implants than around MS implants. Rocci et al. (2003) reported a significantly higher number of failed MS implants than AS implants in smokers. In their meta-analysis, Bain et al. (2002) found a 3-year cumulative success rate of 93.5% for smoking MS implants and 98.7% for smoking dual acid-etched implants. This suggests that modified rough-surface implants like AS or dual acid-etched implants seem to be beneficial in smokers.

The implant position (mesial vs. distal) did not interact significantly with peri-implant bone loss. But anodized surfaces seemed to have beneficial effects especially at distal implants. There was no difference in bone loss around mesial MS and AS implants, but a pronounced difference in bone loss around distal implants, with less peri-implant bone loss around AS implants than around MS implants. A possible explanation may be the intimate connection of roughened surface implants with peri-implant bone and, consequently, a more favorable distribution of load transfer. In the literature, the influence of the implant position on peri-implant bone resorption is a controversial issue. Lindquist et al. (1996) and Zechner et al. (2004) reported significantly more bone resorption around MS and sandblasted/acid-etched implants in mesial positions than around those in distal positions. Carlsson et al. (2000) stressed that MS implants at the most distal sites were more likely candidates for overloading and peri-implant bone loss. Regarding the prosthetic load, Romeo et al. (2003) reported that the amount of bone loss around the implant closest to the cantilever correlated with the length of the cantilever segment. In the present study, care was taken not to exceed an anteroposterior spread ratio of 1 : 1.6, which is well within the biologically tolerated loading range (McAlarney & Stavropoulos 1996).

In the present study, no significant differences were found between AS and MS implants in terms of plaque, BOP and PPD. In their comparative study, van Steenberghe et al. (2001) also found no significant difference between machined and sandblasted surface implants using these clinical variables. Histomorphometric measurements revealed that the peri-implant soft-tissue level was similar for loaded MS implants and for roughened surface implants (Abrahamsson et al. 2001) even in the presence of plaque (Abrahamsson et al. 1998; Watzak et al. 2005, accepted for publication in COIR). Overall, moderately roughened implants (S_a between 1 and 2 μm) appear not to increase the risk of peri-implantitis like implants with a surface roughness of more than 2 μm (Becker et al. 2000).

Conclusions

The data from this retrospective radiological and clinical study of interforaminal mandibular implants suggest that AS implant surfaces are beneficial for long-term osseointegration without significant differences in clinical variables. There was significantly less marginal peri-implant bone loss around AS implants than around MS implants after 33 months of mean functional loading, with a beneficial effect of anodized surfaces at distal implants. Males showed significantly less bone loss than females, without any difference between AS and MS implants. Nicotine abuse had a significant negative effect on peri-implant hard tissue, but less peri-implant bone loss was found around AS implants than around MS implants in smokers.

Acknowledgements: The corresponding author wishes to thank Martina Mittlboeck for her support.

要旨

本後ろ向き研究は、インプラント周囲の骨喪失と粘膜の状態について、埋入後少なくとも３０ヶ月経過している下顎において、オトガイ孔間に埋入した機械研磨（MS）インプラントと陽極酸化表面（AS）インプラントの比較を行った。オトガイ孔間にスクリュー・インプラント４本を埋入した連続患者５０名を対象とした。うち患者３１名（６２％）のインプラント合計１２４本（MSインプラント６４本、ASインプラント６０本、いずれも Branemark タイプ MKIII）について、経過観察できた。回転式パノラマＸ線像を用いて、辺縁骨の喪失を評価した。臨床的には、辺縁プラーク指数（PI）、プロービング時の出血（BOP）とプロービング時のポケット深さ（PPD）を評価した。AS インプラントは MS インプラントに比べ、辺縁骨の喪失が有意に少なかった（－１．１７±０．１３mm対—１．４２±０．１３mm；p＝．０３)。遠心側インプラント周囲の辺縁骨の喪失は MS インプラント（－１．４６±０．１４mm；p＝．０５）に比べて AS インプラント（－１．０５±０．１４mm）の方が少なかった。喫煙者群では AS インプラント周囲の骨喪失の方が MS インプラント周囲より少なかった（－１．０８±０．２７対—１．８３±０．２０；p＝．０４)。MS インプラントと AS インプラントの間に、mPI（５７％対６７％)、BOP（２１％対１７％）及び平均 PPD（２．５９±０．２９mm対２．５６±０．２８mm）に関しては、差異はなかった。

全体として両タイプのインプラントは、無歯顎下顎オトガイ孔間においてバー支持型のオーバーデンチャーに比べ、優れた長期結果を達成し、粗いインプラント表面周囲の骨喪失も少なく、遠心側インプラント及び喫煙患者において有効であった。

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