Multiple Single-Tooth Implant Restorations in the Posterior Jaws: Maintenance of Marginal Bone Levels with Reference to the Implant-Abutment Microgap

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Purpose: *The purpose of this study was to measure marginal bone loss from the implant-abutment microgap to the bone crest between multiple freestanding implants functionally loaded for up to 7.5 years in the posterior jaws.* ***Materials and Methods:*** *Patients consecutively treated for the replacement of missing posterior teeth were included in the study. Using the implant-abutment interface, which was placed level with the crestal bone as a reference point, standardized follow-up radiographs were obtained to evaluate marginal bone loss. Results were subject to statistical analysis using the Wilcoxon rank sum test and the Wilcoxon signed rank test at the 95% confidence level. Additionally, soft tissue and prosthetic complications were recorded.* ***Results:*** *One hundred seventy-three implants in 54 patients were evaluated. Implants were in function for a mean of 37 months (range, 21 to 91 months). One implant failed, for a survival rate of 99.4%. Overall mean marginal bone loss was 0.65 mm (range, 0.0 to 4.8 mm). For the 80 maxillary and 93 mandibular implants, mean marginal bone loss was 0.56 mm and 0.70 mm, respectively. The frequency of bone loss ≥ 1.0 mm was 25.0% in the maxilla and 36.0% in the mandible; 23.1% of maxillary implants and 16.7% of mandibular implants demonstrated no bone loss. No significant differences were observed between men and women or between smokers and nonsmokers. The difference between mesial and distal bone levels was statistically significant (*$P < .001$*), with respective means of 0.53 mm and 0.76 mm. Recorded prosthetic complications included cementation failure (17.7%), porcelain fracture (7.2%), and abutment screw loosening (2.2%).* ***Conclusions:*** *Multiple single-tooth implants placed in the posterior jaws perform extremely well. Furthermore, it is possible to retain bone close to the implant-abutment microgap with certain implant designs.* (Case Series) Int J Oral Maxillofac Implants 2006;21:777–784

Key words: *biologic width, bone loss, implant design, microgap*

The original criteria established for assessing implant success and survival[1] identified marginal bone levels as an important indicator for measuring the response of the peri-implant tissues to functional loading. Adaptation of the marginal crestal bone has been categorized into early bone loss of 1 to 2 mm. Ongoing bone loss should be recorded annually thereafter. Numerous reports have confirmed the response of marginal tissues to a variety of implant systems both in fully and partially edentulous patients.[2–7]

Recently a number of studies have considered the effect of stresses established in bone by the direct influence of nonpassive framework fit.[8–11] In these studies it was clear that while splinting did appear to reduce peri-implant bone stress,[8,9] there was a direct relation between the stress distribution in the framework and stresses created in the supporting structures of the surrounding bone.[10,11] In a recent study by Karl and associates[12] it was concluded that an absolute passive fit of superstructures is not possible using conventional clinical and laboratory procedures. It was therefore implied that while nonpassive prostheses do not lead to large-scale implant failures, they do cause a stress distribution in the surrounding cortical bone that may be a causative factor in marginal bone loss.

Another more recent explanation of marginal bone loss is the theory of the establishment of a biologic width intrinsically related to the position of the implant-abutment microgap and its associated microflora and micromovement.[13–16] In addition, some studies have shown that certain implant designs may contribute to bone loss (the geometry of the coronal collar has been implicated),[17–20] while

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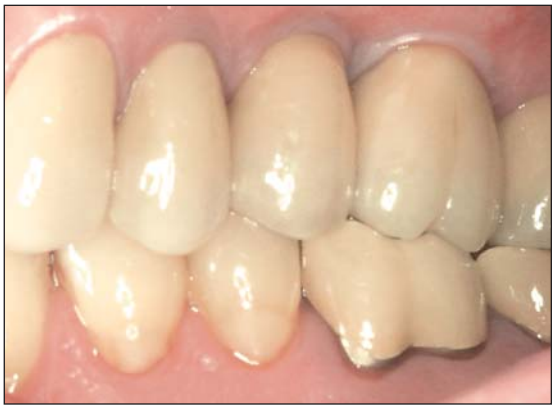

Fig 1 Four maxillary single-tooth implants in a patient after 3 years in function.

other studies have indicated that such bone loss can be prevented by incorporating a biomechanically stable joint and retention elements within the collar of the implant.[21,22]

It has been thought that splinting implants helps to distribute functional loads and therefore reduces marginal bone loss. This has been studied using finite element analysis[9,11] and photoelastic modeling.[8] However, the advent of single-tooth replacement has indicated that marginal bone levels can be optimally maintained even though the implant is subjected to higher forces of differing vectors.[7,23–26] This has also resulted in an increased use of multiple single-tooth implants to replace consecutive teeth in an effort to optimize esthetics and circumvent the problem of nonpassively fitting frameworks.[27,28]

Excellent results have been demonstrated with the Astra Tech single tooth (ST) implant.[23,25] This implant has been biomechanically designed based on studies that demonstrated that the conical implant-abutment interface[21], so-called microthreading,[22] and a rough surface[29] all contribute to reducing the stresses in the marginal cortical bone when the implant is placed under functional load. Furthermore, it has been postulated that the internal conical interface improves marginal tissue response through a reduced risk of so-called microleakage[30] and an improved resistance to micromovement under bending moments through a more rigid connection.[31–33] These design features make this system suitable for use as multiple freestanding implants posterior to the canines in both jaws.

This study considered the long-term marginal bone changes around multiple freestanding implants in the posterior jaws in relation to the implant-abutment junction, which was used as the reference position, and which, according to the theory of biologic width, cannot have bone approximate it.

MATERIALS AND METHODS

A retrospective review was undertaken of the records of a consecutive cohort of patients treated for the restoration of missing teeth in the posterior quadrants by means of multiple freestanding implant-supported crowns from July 1997 to March 2003.

Patients had to have been treated with 2 or more unsplinted implants (Astra Tech, Mölndal, Sweden) located distal to the canines (Fig 1). Smokers were included in the review. Ideally, implants were placed in a transmucosal manner and according to a previously established protocol.[25] They could vary in length but were to be 4.5 mm in diameter as a standard, except where circumstances within surgery dictated a smaller or larger implant diameter, such as a narrower-than-anticipated ridge or where a 4.5-mm-diameter implant failed to achieve primary stability.

At implant placement, particular attention was paid to the crestal positioning of the implant head. The implant-abutment junction was placed at the crestal bone level, since in the system employed, the rough surface and retention elements are taken to the top of the implant. For the purpose of this analysis the implant-abutment junction or "microgap" was considered the reference point from which all future bone levels were measured in order to provide a more exact evaluation of this system's ability to maintain marginal bone.

All radiographs were taken in a standardized manner using a paralleling device (Dentsply Rinn, York, PA), and every effort was made to ensure the x-ray beam was at a right angle to the long axis of the implants.

The geometry of the implant was used to aid assessment of distortion and measurement of bone loss. For the 4.5-mm-diameter implant, the reference point at the top of the implant-abutment microgap is 0.3 mm above the base of the coronal bevel. There is a distance of 0.7 mm from the reference point to the first MicroThread (Astra Tech). The pitch distance between microthreads measures 0.185 mm, and the total length of the collar down to the first macrothread is 5.5 mm. These dimensions and geometric markers are identified in Fig 2.

The most recent radiographs for each patient were evaluated by the author, and any radiographs on which it was difficult to discern the microthreads clearly were excluded from the analysis to ensure reproducibly quantifiable measures of bone loss at × 8 magnification (Fig 3).

The accuracy was measured to the nearest microthread (not present on the 4.0-mm-diameter implants, n = 8) and measurements were always rounded up rather than down. When bone was seen

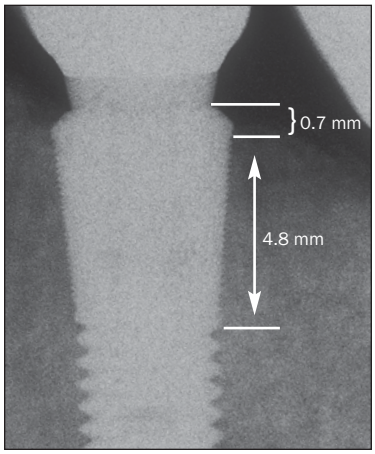

Fig 2 Dimensions in relation to the geometry of an Astra Tech 4.5-mm-diameter implant. The pitch distance between microthreads was 0.185 mm.

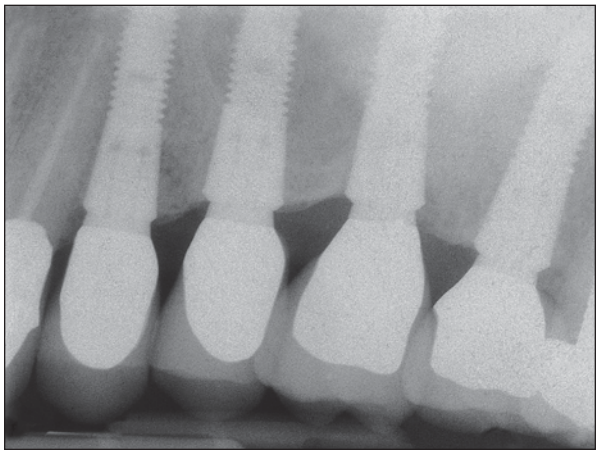

Fig 3 A 3-year follow-up radiograph of the case shown in Fig 1. Sinus augmentation was performed in this case. Note the close relationship between the bone and the implant-abutment junction.

above the reference point, it was still scored as zero so as to avoid introducing any bias in the results.

To fully appreciate the marginal bone response, the range, mean, and frequency data were determined. In particular the frequency of cases where no bone loss was observed and the frequency of cases where bone loss greater than or equal to 1.0 mm were observed were considered by jaw. Marginal bone response was also considered according to gender, jaw, and smoking status (smoker or nonsmoker). Finally the difference between mesial and distal bone levels was analyzed using the pooled data.

A statistical analysis was performed using SAS software (SAS Institute, Cary, NC) for gender, jaw, and smoking using the nonparametric Wilcoxon rank sum test. For mesial and distal surfaces it was possible to use the Wilcoxon signed rank test assuming normal approximations. Statistical significance was established at $P < .05$.

In addition to these statistical analyses, a note was made of any other adverse events, such as soft tissue complications, prosthetic complications, or component failure. With respect to occlusion, all implants in the study were distal to the canines and as such were placed into a protected occlusion during lateral excursions. Where canine guidance was not applicable, implants were placed into group function. All centric and lateral contacts were assessed by means of 8-μm Shim stock and 40-μm articulating paper (Coltene/Whaledent, Langenau, Germany).

RESULTS

The patient pool consisted of 20 men and 34 women. The ages ranged from 40 to 79 years, with a mean age of 57 years. Radiographic marginal bone loss was measured from the microgap for implants that had been in function for a mean of 3 years (range, 21 to 91 months).

In total 181 implants were placed, with an average of 3 implants per quadrant. One hundred sixty implants were 4.5 mm in diameter (88.4%), 13 were 5.0 mm, and 8 were 4.0 mm. Forty-eight implants were placed using a 2-stage surgical technique, while the remaining 133 (73.5%) were placed transmucosally with the connection of a healing abutment. The distribution of the implants by position is shown in Table 1. Only 7 patients were smokers. Fifteen patients received their implants placed with either staged or simultaneous sinus grafts, and 5 patients received simultaneous onlay grafts.

One implant was removed 11 days postoperatively because of the presence of intractable pain but was successfully replaced. The overall survival rate from baseline to 12 months was therefore 99.4%. No further failures occurred after up to 7.5 years in function.

The radiographic images of 173 implants were suitable for analysis. Eighty implants were maxillary, and 93 were mandibular. The mean marginal bone loss from the microgap for the total group was calculated as 0.65 mm (range, 0.00 mm to 4.80 mm). For maxillary implants the mean marginal bone loss measured 0.56

Table 1 Distribution of Implant-Supported Single-Tooth Restorations

Location	n
Maxilla	
First premolar	19
Second premolar	28
First molar	28
Second molar	8
Mandible	
First premolar	9
Second premolar	31
First molar	37
Second molar	21

Table 2 Marginal Bone Loss

		Bone loss (mm)					
	n	Min	Median	Max	Mean	SD	*P*
Jaw							
Mandible	34	0.1	0.54	2.7	0.70	0.63	.812
Maxilla	24	0.0	0.46	1.4	0.56	0.38	
Gender							
Female	34	0.1	0.52	2.7	0.72	0.59	.370
Male	20	0.0	0.48	1.4	0.53	0.35	
All	54	0.0	0.51	2.7	0.65	0.52	
Smoking status							
No	47	0.0	0.50	2.7	0.63	0.52	.425
Yes	7	0.1	0.84	1.6	0.77	0.52	
All	54	0.0	0.51	2.7	0.65	0.52	
Surface							
Mesial	54	0.0	0.35	2.6	0.53	0.49	< .001
Distal	54	0.0	0.64	2.8	0.76	0.59	
Difference M-D	54	−1.2	-0.21	0.3	-0.23	0.31	

mm compared to 0.70 mm for mandibular implants (P = .8189) (Table 2). The frequency of no bone loss was calculated to be 23.1% for maxillary implants and 16.7% for mandibular implants. In contrast, the frequency of implants losing greater than or equal to 1.0 mm of bone from the microgap was 25.0% in the maxilla and 36.0% in the mandible.

The mean marginal bone loss measured 0.72 mm for women and 0.53 mm for men (P = .3704). Mean marginal bone loss for nonsmokers was 0.63 mm, compared to 0.77 mm for smokers (P = .4247). There were no statistically significant differences (Table 2). However, when considering mesial versus distal bone loss, the results revealed a highly significant difference (P < .001), with distal bone levels showing a greater propensity to bone loss (Table 2).

With regard to other adverse events, there were 18 patients with recorded episodes of inflammation related to 1 or more implants. The majority of patients were given simple oral hygiene instructions, but in 4 patients the degree of inflammation warranted intervention by means of submucosal irrigation with chlorhexidine and topical application of 2% w/w minocycline gel (Dentomycin, Blackwell Supplies, Gillingham, England). One patient presented with a purulent exudate associated with 1 implant; however, after 3 treatments with topical chlorhexidine and minocycline gel, the infection resolved and has not recurred since. Two implants in 1 patient presented with a persistent apical infection after surgery. After attempts at both systemic and topical antimicrobial therapy failed to resolve the infection, surgical debridement was undertaken, with decontamination of the implants using strip gauze soaked in chlorhexidine for 5 minutes, followed by irrigation of the bony defect with 1 g tetracycline in 20 mL of saline. Defect sites were grafted with anorganic bone mineral (Bio-Oss; Geistlich Pharma, Wolhusen, Switzerland). The infection remitted successfully, and the implants have been in function successfully without recurrent symptoms for 2 years.

Of interest is the fact that the worst implant for bone loss (4.8 mm) was not associated with any clinical signs or symptoms of infection, inflammation, or pain. The bone loss occurred within the first 6 months of loading and has remained stable from that point up to the 5-year recall.

With respect to prosthetic complications, there were 32 recorded episodes of crown cementation failure. Such failure occurred as early as the day following cementation and as late as 5 years postcementation. This equates to a 17.7% decementation rate over 7.5 years, with crowns in first molar positions affected in 61% of cases. All crowns were initially cemented with Temp Bond (Kerr UK, Peterborough, UK). Twenty-three became decemented only once, but 3 crowns became decemented a second time after polycarboxylate cement had been used (Poly F; De Trey Dentsply, Konstanz, Germany). One crown in 1 patient decemented 3 times; on the third occasion, it was recemented with glass ionomer (Fuji +; GC Corporation, Tokyo, Japan). For the 4 crowns that became decemented more than once, the occlusion was checked and refined where indicated.

In addition to crown decementation, porcelain fracture was recorded for 13 crowns (7.2% of the

Table 3 Distribution of Prosthetic Complications by Tooth Position

	Tooth number																
	2 17	3 16	4 15	5 14	12 24	13 25	14 26	15 27	18 37	19 36	20 35	21 34	28 44	29 45	30 46	31 47	Total
No. of crowns decemented once	0	1	2	1	1	2	3	1	1	4	0	0	0	0	7	0	23
No. of crowns decemented twice	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	3
No. of crowns decemented three times	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
No. of crowns with porcelain fracture	1	0	0	1	1	1	1	0	2	1	1	0	0	1	3	0	13
No. of loose abutment screws	0	1	0	0	0	0	0	0	2	1	0	0	0	0	0	0	4

Top row uses Universal system of tooth numbering; bottom row uses FDI system.

study sample), primarily in the mandibular molar positions (46%), from as early as 2 months postplacement to up to 1 year and 7 months postplacement. In general, these were superficial fractures, necessitating only polishing, and to date none of these crowns have required replacement. Finally, 4 abutment screws in 4 patients came loose at 6, 8, 12, and 48 months, which equates to a screw loosening rate of 2.2%.

All prosthetic complications and their distribution by tooth position can be seen in Table 3.

DISCUSSION

The implants in the present study population were all placed in a routine private practice setting by a single clinician and have been carefully monitored for a mean of 3 years and a maximum of 7.5 years. However, the current study is based upon a retrospective analysis and as such should be interpreted with caution.

Since 1997, the author has favored the use of free-standing implants in the posterior jaws where appropriate, in recognition of the perceived benefits of leaving implants unsplinted, including the elimination of detrimental stresses that might be induced in the peri-implant bone.[10,11] However, work by Guichet and associates has shown that tight contact points can lead to equally detrimental stresses in the bone.[8] When the implants are fully seated, the contact points should allow passive withdrawal of 8-µm foil.[34] Bone loss around the unsplinted implants used in the present study was equivalent to that observed in previous studies of splinted implants.[3,4]

Another advantage of the method described here is the elimination of cumbersome prostheses with large quantities of gold and porcelain, which reduces the risk of veneer and framework fracture. When free-standing single-tooth implants are used, if 1 unit is compromised, as occurred in 7% of the current sample, only 1 unit needs to be removed rather than a whole fixed partial denture with numerous units. From an esthetic perspective, crowns on multiple single implants have the potential to give the impression of being more individual than is often obtainable in a splinted situation. Patients also appreciate the ability to more easily floss between units as compared to the somewhat tedious task of threading floss under a bridge.

Tarnow and colleagues[13] have proposed that implants placed too close to natural teeth or within 3 mm of each other compound the problem of marginal bone loss.[13] Such bone loss can and often does result in loss of interdental soft tissue, leading to unsightly black triangles where papillae should be. This may of course be a good argument for splinting to allow the use of pink porcelains. However, the current study did not show such bone loss.

While it is usual to measure bone loss with respect to a baseline value recorded at prosthesis delivery, ie, after an initial period of bone adaptation, it was recently proposed by Berglundh and coworkers[35] that this method may be inappropriate when comparing data to implants with a rough surface to the top, which do not demonstrate this initial bone loss or "adaptation." According to Berglundh and colleagues,[35] such an approach would have resulted in

a marginal bone loss of approximately 2 mm for Brånemark implants (Nobel Biocare, Göteborg, Sweden) with their machined collar compared to 0.1 mm for Astra Tech implants with their rough surface to the top. In this particular study, it was concluded that this usual method of measurement might result in a negative bias of as much as 1.4 mm. Measurement of total bone loss with respect to a fixed reference point on the implant, typically the implant-abutment junction, is useful for the establishment of a level playing field.

The effect of such differences was also recently highlighted in an experimental study by Alomrani and associates[36] in which Esthetic Plus implants (Straumann, Waldenburg, Switzerland) with a machined collar measuring 1.8 mm in height were compared to test Straumann implants of identical geometry and dimension but with the rough surface taken to the top adjacent to the implant-abutment junction. In this study the distance from the marginal bone level to the microgap measured 0.74 mm when the microgap was level with the crestal bone compared to 2.43 mm for control implants placed according to currently recommended protocol.

This stark contrast in bone response to a roughened coronal collar was first discussed in an article which considered the differing response to 2 geometrically similar implants. One had a machined titanium conical collar and an external hex joint, while the other was an Astra Tech ST 4.5-mm implant with a rough surface and microthreads to the top of the implant, and an internal conical joint.[26] In this report it was noted that for studies reporting on implants of the former design, catastrophic bone loss was seen around implants, typically 3 to 4 mm, down to the first thread at the base of the conical collar.[17–19] Such loss could not be easily explained by the theory of biologic width, in which it has been proposed that bone can be maintained to within 1 to 2 mm from the microgap.[14–16] In contrast, for the Astra Tech implants, a mean marginal bone loss of only 0.33 mm was reported; this increased to 0.60 mm after 4 years of function, which is comparable to the current data. Thirty-three percent of the rough-collared implants had no bone loss.[26]

The way in which bone responds around an implant may be due to multivariate factors. The arguments proposed by Hansson for a biomechanical rationale are compelling,[21,22,29] although it can sometimes be difficult to extrapolate theoretical and finite element calculations to clinical reality. It is also plausible that the tight conical joint, with its high resistance to bending moments[31–33] and a microgap of only 2 to 4 μm,[37] contribute significantly to the maintenance of marginal bone, and this is reinforced by the finding that in the current group of 181 implants, only 4 abutment screws were identified as loose after a mean of 3 years in function. This component failure rate is impressive when compared to recently reported data for implants with an external hex joint design.[38]

With an overall mean marginal bone loss of only 0.65 mm from the microgap, the data presented in the current study are in close agreement with numerous studies on the Astra Tech system.[3,4,6,7,23–26] Furthermore, the finding that 20% of all implant surfaces demonstrated no marginal bone loss is confounding with respect to the theory of biologic width.

The fact that significantly greater bone loss occurred distally is not easy to interpret, and it is difficult to ascertain what might be the cause of this statistical difference. In contrast it was interesting to note the absence of a significant difference between jaws, and between smokers and nonsmokers, although there was a trend toward higher bone loss in smokers and in the mandible, where the denser bone would have been expected to resist bone loss compared to the lower-density bone of the maxilla. It is possible that this may be related to the relatively avascular nature of this dense mandibular cortical bone. It could be postulated that the very slow turnover of such bone and the feathering of the bone as a result of the tapered implant design may contribute to a net resorptive process and therefore greater crestal bone loss.

It is also worth noting that the patient was used as the statistical unit in the current analysis. While there would have been more observations if the implants had been used as the unit, it would have been inappropriate to extract statistical results in this way. This is due to the fact that some of these implant units were biologically dependent (different implants in the same patient) and some were independent. An important assumption when calculating *P* values is that the units used are all independent.

With respect to other adverse events, there were only few reported episodes of soft tissue inflammation and only one case of possible peri-implantitis where a purulent exudate could be identified. These episodes were resolved successfully through antimicrobial and/or surgical intervention.

The relatively high rates of crown cementation failure (17.7%) and porcelain fracture (7.2%) may be related to the implant support and the application of a more rigid implant-abutment joint design. In a previously published study in which prosthetic complications were compared for tooth-supported versus implant-supported restorations, a significantly higher rate of porcelain fracture was noted with implant-supported fixed partial dentures.[39] Further-

more, in 2 studies on the reasons for crown replacement, porcelain fracture was cited as a frequent cause.[40,41] In contrast, in a study by Schwartz-Arad and associates[42] that looked at the restoration of implants in the molar region, the porcelain fracture rate was only 1.2%, but the screw loosening rate was 11.5%, compared with 7.2% and 2.2% for the current study, which suggests that a weaker joint more prone to loosening might reduced the incidence of porcelain fracture. A similar finding was published in a 10-year evaluation of complications by Priest,[43] who reported a porcelain fracture rate of 0.9%, a cementation failure rate of 5.4%, and a screw loosening/fracture rate of 8.9%.

In the current study, 61% of all crowns that demonstrated cementation failure were in the first molar position, with lower molars demonstrating the highest propensity to fracture (46%). Many of these restorations demonstrated a long crown length due to vertical tissue atrophy, and this has also been associated with an increased risk for fracture.[44] However, the use of stronger cements and additional occlusal refinements appears to have resolved the majority of these issues.

Although there were 4 abutment screws that loosened, in 2 cases the loosening occurred more than 1 year after prosthesis delivery, and in 1 case it occurred 4 years after delivery. Furthermore, none of the units associated with loose screws demonstrated any prior history of decementation or porcelain fracture.

CONCLUSIONS

It can be concluded that within the confines of the current data, the Astra Tech system can perform extremely well when used in a multiple single-tooth format for the restoration of posterior jaws, with only minimal marginal bone loss, as measured from the microgap after a mean of 3 years in function (range, 21 to 91 months). These data, along with the finding that 23.1% of maxillary implants and 16.7% of mandibular implants demonstrated bone at or above the microgap, cast doubt on the theory of biologic width with regard to the influence of the location of the implant-abutment microgap, which may need to be re-evaluated.

While prosthetic complications are always of concern, they did highlight the advantages of a multiple single-tooth protocol, where maintenance and repairs were confined to the crown in question and did not necessitate the removal of a longer-span fixed partial prosthesis.

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