An Assessment of Crown-to-Root Ratios with Short Sintered Porous-Surfaced Implants Supporting Prostheses in Partially Edentulous Patients

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Purpose: *Implant length, implant surface area, and crown-to-root (c/r) ratio and their relationship to crestal bone levels were analyzed in 2 groups of partially edentulous patients treated with sintered porous-surfaced dental implants.* ***Materials and Methods:*** *One hundred ninety-nine implants were used to restore 74 partially edentulous patients with fixed prostheses. Implants were categorized according to their length ("short" versus "long") and estimated surface area ("small" versus "large"). "Short" implants had lengths of 5 or 7 mm, while "long" implants were either 9 or 12 mm in length. "Small" implants had estimated surface areas of ≤ 600 mm*^{2}*, while "large" implants had estimated surface areas > 600 mm*^{2}*. Other data collected included c/r ratio (measured on articulated diagnostic casts), whether or not the implants were splinted, and standardized sequential radiographs.* ***Results:*** *The mean c/r ratio was 1.5 (SD = 0.4; range 0.8 to 3.0), with 78.9% of the implants having a c/r ratio between 1.1 and 2.0. Neither c/r ratio nor estimated implant surface area (small or large) affected steady-state crestal bone levels. However, implant length and whether the implants were splinted did appear to affect bone levels. Long implants had greater crestal bone loss (0.2 mm more) than short implants; splinted implants showed greater crestal bone loss (0.2 mm more) than nonsplinted ones. These differences were statistically significant.* ***Discussion and Conclusions:*** *Sintered porous-surfaced implants performed well in short lengths (7 mm or less) in this series of partially edentulous patients. The data suggested that long implants and/or splinting can result in greater crestal bone loss; longer implants and splinted implants appeared to favor greater crestal bone loss in this investigation. These conclusions are, of course, specific to the implants used and would not be relevant to other implant types.* INT J ORAL MAXILLOFAC IMPLANTS 2005;20:69–76

Key words: *crown-to-root ratios, dental implants, implant surfaces, peri-implant bone loss*

The use of root-form endosseous dental implants as tooth replacements in both completely and partially edentulous patients has become mainstream treatment in the past 2 decades, following the pioneering work of Brånemark and his colleagues.[1] These investigators established that where adequate bone quality and quantity exist, it is possible to integrate a machined threaded titanium root-form dental implant into human jawbone and subsequently to use such implants as support for fixed or removable dental prostheses. However, long implants may be a prerequisite for success with this implant device.[2] For example, Naert and colleagues[3] recently reported that the failure rate of Brånemark System (Nobel Biocare, Göteborg, Sweden) machined threaded implants in lengths of less than 10 mm was 18.5%. Similarly, Weng and associates[4] reported that machined threaded implants failed at rates of 19% in 8.5-mm lengths and 26% in 7-mm lengths, confirming an earlier finding (ie, a 25% failure rate with 7-mm-long Brånemark System implants) by Wyatt and Zarb.[5] If machined threaded implants are placed in

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sites consisting primarily of cancellous bone, such as the posterior maxilla, they are more likely to fail than if placed in primarily cortical bone.[4,6–9] Bahat[6] reported that most of his failed Brånemark System implants were in the posterior maxilla and were 7 mm in length. His failure rate was 9.5% for 7-mm-long implants compared to 3.8% for all other lengths used.

Numerous other threaded dental implant systems have since been introduced with slight modifications in design and/or surface features, such as thread pitch, implant diameter, and surface texture, but the manufacturers of the majority of these designs also recommend the use of long implants when bone quality is sufficient.[10–16] The same can be said of bullet-shaped, press-fit cylindric implants with plasma-sprayed titanium or hydroxyapatite surface coatings, especially when the implants are placed in softer bone.[17] The need for long implants is related to the nature of the bone-to-implant interfaces (ie, the mechanism of osseointegration) existing with all of these implants, which is primarily direct bone contact with the surface.[18] Relative movements are resisted by friction effects as well as limited bone interlock with surface features (ie, machining lines or intentionally textured surfaces). Longer implants provide greater surface area for direct bone contact, thereby reducing localized stresses in bone that can develop in crestal regions because of transverse force components.[19]

The exception to this general trend is the more recently developed sintered porous-surfaced implant design, for which the mechanism of implant fixation is bone ingrowth and 3-dimensional mechanical interlocking.[18,20–24] This unique bone-to-implant interface, unlike other currently available dental implant designs, offers resistance to tensile force vectors in addition to vertical shear forces and compressive force vectors and therefore can be routinely used in lengths of 7 mm or less.[25–27]

Treatment planning for conventional fixed prosthodontic restorations using natural teeth as abutments requires consideration of the crown-to-root (c/r) ratio of these abutments.[28] Ante's law[29] dictates that "the combined peri-cemental area of all of the abutment teeth should be equal to or greater than the peri-cemental area of the teeth to be replaced." Both the c/r ratio and peri-cemental area influence the degree of stress within the attachment mechanism. In the case of teeth, the mechanism of attachment is the periodontal ligament. Because this suspensory ligament is highly reactive to occlusal overload, it is generally recommended that a ratio of 2 lengths root structure embedded in healthy bone be used for 1 length of crown (ie, c/r ratio = 1:2 or 0.5). If this is not possible, an increased number of abutment teeth should be used. When the original Brånemark System implant was introduced, because long implant roots were needed to avoid excessively high stresses to crestal bone, similarly small c/r ratios (ie, about 0.5) quickly became the norm.[2–5,11,30] Again, this was related to the fact that the mechanism of attachment (osseointegration) with these implants was direct bone-to-implant contact only and little resistance to tensile forces was provided by short implants.[31] However, as already stated, short sintered porous-surfaced implants may be routinely used and as such may be restored with what could be considered unfavorable c/r ratios, ie, c/r > 0.5. Nevertheless, in ongoing human clinical trials with this type of implant, outcomes have been favorable in all locations tested, including the more challenging posterior regions of both jaws.[25–27,32] However, to determine whether there is any relationship between c/r ratio and crestal bone loss with this type of dental implant, assessments of these ratios were done for 2 groups of partially edentulous patients participating in ongoing prospective clinical trials. The results of these assessments are reported here.

MATERIALS AND METHODS

The implant treatment provided for these patients has been reported elsewhere in 2 separate prospective studies.[26,27] One study included 50 partially edentulous patients who sought implants to replace 2 or more teeth in the maxilla; the other included 24 partially edentulous patients requiring 1 or more implants in the posterior mandible. All 74 patients, mean age 53 years (range 20 to 76 years), reported that they were currently nonsmokers. A total of 199 implants were placed; 151 implants (mean implant length, 8.7 mm) were placed in the maxillary group, and 48 implants (mean length, 7.8 mm) were placed in the posterior mandible group. The implant used was the Endopore dental implant system (Innova LifeSciences, Toronto, Ontario, Canada), an endosseous tapered root-form press-fit design. The implants used were of 4 lengths (5, 7, 9, and 12 mm) and 3 diameters (3.5, 4.1, and 5.0 mm). All of the implant models had a 1-mm machined smooth collar region, while the remainder of the implant length had a sintered porous-surface structure.[18] The implants were placed using a traditional 2-stage surgical protocol and later restored with fixed, screw-retained, implant-supported prostheses.

Data Collection

Posttreatment records, including standardized periapical radiographs of all implants in this group of patients, were collected at baseline (1 month after seating of the definitive prosthesis), after 6 months, and yearly thereafter. Radiographs were collected using customized occlusal templates and standard long-cone paralleling techniques. All films were exposed with the same calibrated x-ray machine and developed manually in batches using freshly prepared chemicals. All radiographs were masked and viewed in a darkened room by 1 radiologist (MP). The position of the alveolar crest relative to the machined-surface/porous-surface junction on both the mesial and distal aspects of each implant was measured with a reticle at 6× magnification.

The prosthetic crown length for each implant was determined by measuring the distance from the top of the implant analog to the contact position with the opposing tooth on articulated working casts used to fabricate the implant crowns for each patient (Fig 1). These crown lengths were then matched with the corresponding implant root lengths to determine a c/r ratio for each implant. For descriptive analysis, 3 categories of c/r ratio were selected: c/r ratio ≤ 1, c/r ratio = 1.1 to 2.0, and c/r ratio > 2.

Statistical Analysis

Each implant was allocated an identification code that depended on the number of implants placed in each subject's mouth; the maximum number of implants placed in a subject's mouth was 12. Analysis of variance (ANOVA) revealed that the steady-state bone level was not influenced by the implant's designated number (*P* = .17). As well, both the mean value and range of values for the steady state bone level were within 0.5 and –1.5 mm for most subjects who had at least 1 implant (Fig 2). Therefore, the unit of analysis for this study was the individual implant.

Univariate and bivariate data analyses were conducted with SAS software (SAS Institute, Cary, NC) using the Proc Freq, Proc Univariate, Proc Means, Proc Corr, and Proc GLM procedures. The chi-square test was used to conduct cross-tabular analyses; where the number of implants did not permit, the Fisher exact test was used. ANOVA was used to assess the effect of splinting on the crestal bone level relative to the machined-surface/porous-surface junction. The Tukey test was used to conduct post hoc examination of the differences between group means. Although categories of *(a)* c/r ratio, *(b)* length of implant, and *(c)* estimated surface area of implant were identified for descriptive purposes, these variables were treated as continuous variables. Therefore, the linear regression analysis was used to examine the effect of these variables on steady-state bone levels.

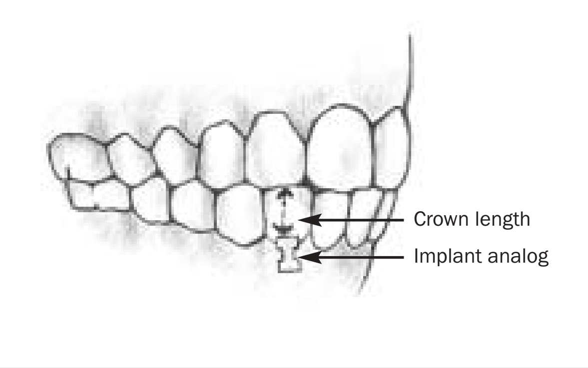

Fig 1 The c/r ratio was determined by measuring the "crown length" as the distance on articulated models from the top of the implant analog to the point of occlusal contact with the opposing tooth. This measurement for each crown was then divided by the known length of the implant supporting it, resulting in the c/r ratio for a given implant/crown combination.

RESULTS

Table 1 lists the dimensions of the implants used arranged according to their estimated surface areas and locations in different regions of the mouth. Of the 199 implants placed, 48 (24.1%) were placed in the mandible and the remaining 151 (75.9%) were placed in the maxilla. Thirty-five (17.6%) were placed in the anterior maxilla, 116 (58.3%) were placed in the posterior maxilla, and 48 (24.1%) were placed in the posterior mandible. Eighty-seven implants had an estimated surface area of 600 mm^2 or less; these were the 5-mm-long implants (n = 2; 1%), the 9-mm-long mini-implants (3.5 mm wide; n = 44; 21.6%), and the 7-mm-long regular-diameter implants (n = 41; 20.6%). The remaining 112 implants had estimated surface areas > 600 mm^2. Figure 3 shows the specific tooth sites in which the implants were placed. The great majority replaced premolars (n = 89; 44.7%) and molars (n = 75; 34.6%).

Figure 4 presents the distribution of the 199 implants by their c/r ratios. Table 2 shows the distribution of the implants according to their c/r ratios; the average c/r ratio for all 199 implants was 1.5 (SD = 0.4; range 0.8 to 3.0). The vast majority (157 implants or 78.9%) of implants had a c/r ratio between 1.1 and 2.0. Also shown are the c/r ratios for implants with various lengths. Both splinted and nonsplinted implants had a mean c/r ratio of 1.5 (SD = 0.4).

Cross-tabular analyses of the data were used to assess associations between c/r ratio and implant length, estimated implant surface area, and splinting

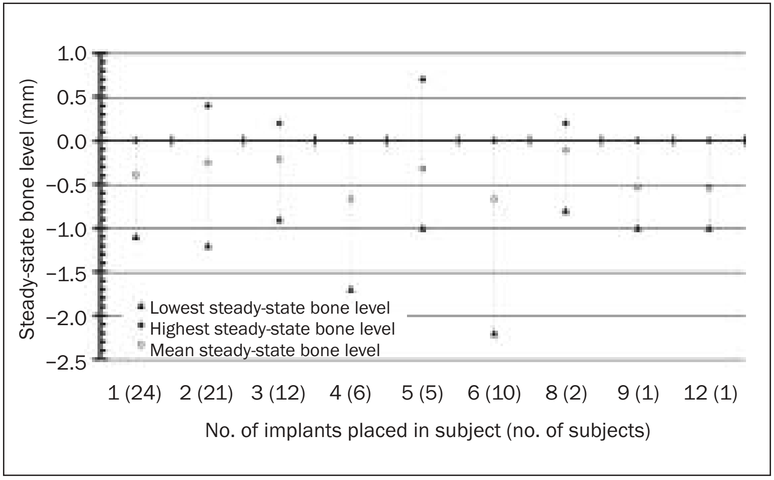

Fig 2 Mean, highest, and lowest steady-state bone levels according to the number of implants placed in each subject.

Table 1 Distribution of Implants According to Their Estimated Surface Area

Implant length (mm)	Estimated surface area (mm^2)	Location Anterior maxilla n (%)	 Posterior maxilla n (%)	 Posterior mandible n (%)	Total n (%)
9 (mini)*	512	19 (54.3)	20 (17.2)	4 (8.3)	43 (21.6)
7 (regular)†	527	0 (0.0)	24 (20.7)	17 (35.4)	41 (20.6)
5 ‡	530	0 (0.0)	2 (1.7)	0 (0.0)	2 (1.0)
7 (wide body)‡	638	0 (0.0)	16 (13.8)	13 (27.1)	29 (14.6)
9 (regular)†	640	13 (37.1)	40 (34.5)	14 (29.2)	67 (33.7)
12†	781	3 (8.6)	14 (12.1)	0 (0.0)	17 (8.5)
Total		35 (100.0)	116 (100.0)	48 (100.0)	199 (100.0)

*Diameter = 3.5 mm.
†Diameter = 4.1 mm.
‡Diameter = 5.0 mm.

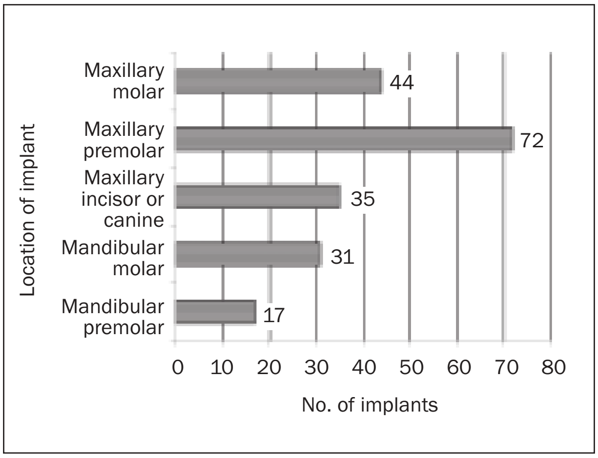

Fig 3 Implants by the location in which they were placed.

(Table 3). Because of the limited numbers of each type of implant, the implants were placed into categories based on their lengths and estimated surface areas. Implant at least 9 mm in length were categorized as "long," while those less than 9 mm long were categorized as "short." Implants with estimated surface areas 600 mm^2 or smaller were categorized as "small"; those with estimated surface areas greater than 600 mm^2 were categorized as "large." The results of the cross-tabular analyses presented in Table 3 show that only splinting was not associated with c/r ratio ($P < .05$). The ANOVA was used to examine the association between c/r ratio and time in function.

The mean period of follow-up ± SD was significantly reduced from nearly 5 years (53.2 ± 7.0 months) for implants with a c/r ratio ≤ 1.0 to nearly 3 years (34.0 ± 12.2 months) for implants with a c/r ratio > 2.0; the average implant had functioned for nearly 4 years (46 months). Implants with larger surface areas were used more frequently in lower c/r ratios.

The mean ± SD crestal bone levels relative to the smooth collar-to-porous surface junction of the implants were −0.3 ± 0.5 mm for the mesial aspect and −0.4 ± 0.5 mm for the distal aspect. The mean ± SD of the differences between these 2 means was −0.1 ± 0.5 mm, an amount too small to measure on a radiograph; this difference was clinically irrelevant. In

Fig 4 Distribution of the 199 implants according to their c/r ratios.

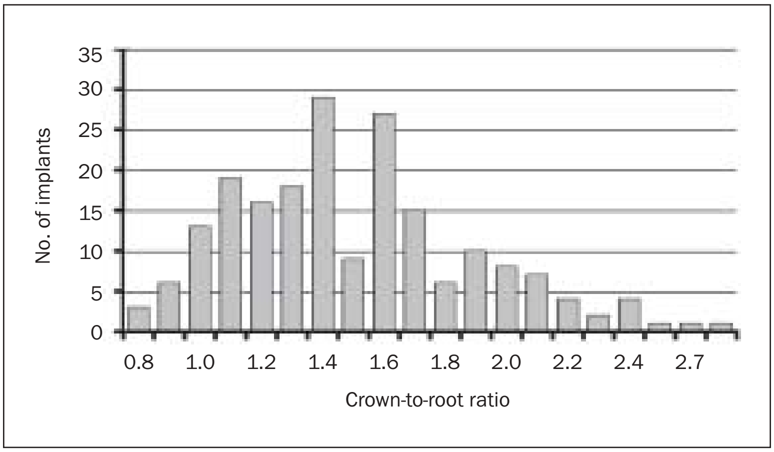

Table 2 Crown-to-Root Ratios of Implants by Selected Characteristics

		Crown-to-root ratio		
Characteristic	n (%)	Mean (SD)	Minimum	Maximum
Crown-to-root ratio				
≤ 1.0	22 (11.1)	0.9 (0.1)	0.8	1.0
1.1 to 2.0	157 (78.9)	1.5 (0.2)	1.1	2.0
> 2.0	20 (10.0)	2.3 (0.2)	2.1	3.0
Length of implant (mm)				
12	17 (8.5)	1.0 (0.1)	0.8	1.2
9	110 (55.3)	1.4 (0.2)	0.9	2.0
7	70 (35.2)	1.8 (0.4)	1.0	2.7
5	2 (1.0)	2.6 (0.6)	2.1	3.0
Splinting				
No	123 (61.8)	1.5 (0.4)	0.8	3.0
Yes	76 (38.2)	1.5 (0.4)	0.8	2.7
All implants	199 (100.0)	1.5 (0.4)	0.8	3.0

Table 3 Mean Crown-to-Root Ratios of Implants in Relation to Characteristics

	Crown-to-root ratio				
Characteristic	≤ 1.0 n (%)	1.1 to 2.0 n (%)	> 2.0 n (%)	Total n (%)	*P*
Length (mm)*					
< 9 (short)	2 (2.8)	50 (69.4)	20 (27.8)	72 (36.2)	< .001
≥ 9 (long)	20 (15.8)	107 (84.2)	0 (0.0)	127 (63.8)	
Estimated surface area (mm^2)					
< 600 (small)	5 (5.8)	69 (80.2)	12 (14.0)	86 (43.2)	.05
≥ 600 (large)	17 (15.0)	88 (77.9)	8 (7.1)	113 (56.8)	
Splinting					
No	11 (8.8)	101 (82.4)	11 (8.8)	123 (61.8)	.25
Yes	12 (15.7)	55 (72.9)	9 (11.4)	76 (38.2)	
All implants	23 (11.6)	156 (78.3)	20 (10.1)	199 (100.0)	

*Fisher exact test.

50% of the cases, no difference existed in the bone levels at the mesial and distal surfaces of the implants, and in 75% of cases the 2 bone levels were within ± 0.3 mm. A normal plot of the differences revealed that there was only 1 outlying observation with a difference of –1.9 mm. Therefore, the average bone level on both sides of an implant was taken to represent the steady-state bone level of that implant. The mean ± SD steady-state bone level relative to the smooth collar-to-porous surface junction for all

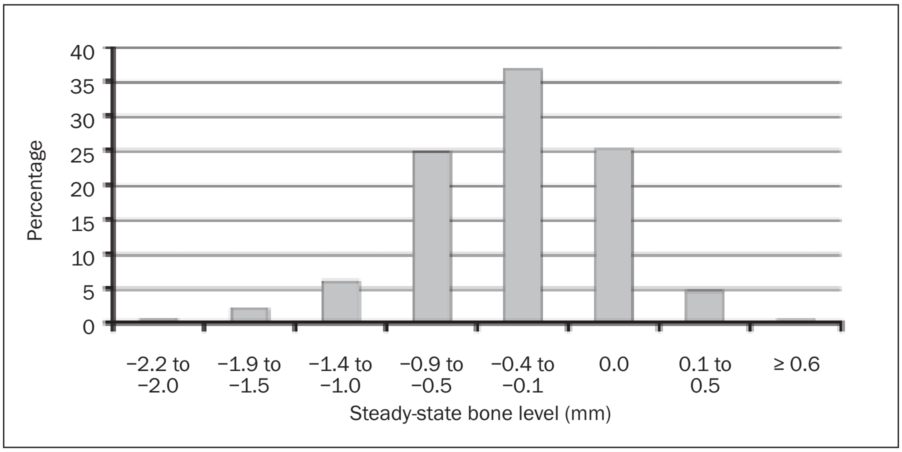

Fig 5 Distribution of the implants according to their steady-state bone levels.

Table 4 The Results of the Linear Regression and ANOVA Tests to Examine the Effect of Crown-to-Root Ratio, Implant Length, Estimated Implant Surface Area, and Splinting on Steady-State Bone Level of Implants

	Steady-state bone level (mm)		
Characteristic	**n (%)**	**Mean (SD)**	***P****
Crown-to-root ratio[†]			
≤ 1.0	22 (11.1)	−0.4 (0.3)	
1.1 to 2.0	157 (78.9)	−0.4 (0.4)	.2968
> 2.0	20 (10.0)	−0.3 (0.5)	
Implant length (mm)[‡]			
< 9 (short)	72 (36.2)	−0.2 (0.4)	< .0047
≥ 9 (long)	127 (63.8)	−0.4 (0.4)	
Implant surface area (mm^2)[‡]			
< 600 (small)	86 (43.2)	−0.3 (0.4)	.0740
≥ 600 (large)	113 (56.8)	−0.4 (0.5)	
Splinting			
No	123 (61.8)	−0.3 (0.4)	.0445
Yes	76 (38.2)	−0.5 (0.4)	

*Linear regression test used for c/r ratio, implant length, and implant surface area; ANOVA used for splinting.

[†] Actual c/r ratio used for analysis.

[‡] Ranked scores treated as continuous variables.

implants was –0.4 ± 0.4 mm. As seen in Fig 5, the most frequent bone level category was –0.1 mm to –0.4 mm; this level was observed in 73 (or 36.7%) implants. Fifty (or about 25%) implants had no change in the steady-state bone level over the study period. It must be recognized, however, that such small changes in crestal bone level are well within the range of intra-observer measurement errors known to be associated with the method used to measure these changes in the radiographs.[33]

Pearson's correlation test revealed that steady-state bone level was unrelated to the length of time an implant had functioned in the mouth (rho = –0.05, $P = .53$). The results of linear regression presented in Table 4 revealed that there was no statistically significant ($P = .2968$) association between steady-state bone level and the c/r ratio of implants; the actual c/r ratios were used for the analyses. As well, there were no statistically significant differences ($P = .0740$) in the steady-state bone levels of "large" and "small" implants. Factors that did significantly influence steady-state bone levels were implant length ($P = .0047$ with ranked values treated as continuous variable) and splinting ($P = .04$). Splinted implants had a steady-state bone level 0.2 mm lower than that of nonsplinted implants; as well, long implants had a steady-state bone level 0.2 mm lower than that of short implants.

DISCUSSION

This report provides information on a group of 74 partially edentulous patients participating in 2 prospective clinical trials with a sintered porous-surfaced dental implant system and fixed implant-supported restorations.

The c/r ratios for the implants used in these 2 trials were assessed and categorized, and it was found that the majority of the implants had a c/r ratio of between 1.0 and 2.0, with an average of 1.5. This might have been considered unfavorable for long-term implant survival given the generally recommended c/r ratio of 0.5 (1 length crown: 2 lengths root) for natural teeth acting as fixed partial abutments or for restorations intended for support by other dental implant designs. It should be pointed out, however, that there are no comparable reports in the literature in which the performances of threaded or press-fit cylindric implants were evaluated in relation to the c/r ratios employed. The present data for c/r ratio indicate a growing investigator confidence in the implant device as the study proceeded, as larger c/r values were used for patients treated later in the study. While the average functional time for all implants was nearly 4 years, those implants with c/r ratios equal to or less than 1.0 had an average functional time of nearly 5 years, while those with c/r ratios > 2.0 on average had been functioning only approximately 3 years.

The data collected in the present study were further classified according to both implant length and estimated implant surface area. Implants less than 9 mm long were considered "short," and those 9 mm or 12 mm long were considered "long." Implants with estimated surface areas of 600 mm^2 or less were classified as "small" implants, while those with estimated surface areas greater than 600 mm^2 were seen as "large." This latter categorization of the data was done because others have suggested that increases in surface area created by increasing implant diameter or roughening the machined surfaces of threaded dental implants may be key factors in improving performance.[11–13,15,34–37]

Therefore, in the present report, both implant length and implant surface area were used along with c/r ratio data to investigate possible influences on peri-implant crestal bone stability. The steady-state bone level data determined from standardized sequential radiographs taken of all implants did not indicate a significant change in crestal bone levels in relation to time in function. The mean steady-state bone level was –0.4 mm, indicating that the crestal bone remained stable at a level 0.4 mm apical to the smooth surface/porous surface junction. C/r ratio appeared to have no significant effect on crestal bone levels, suggesting that a c/r ratio of 1.5 or greater is not detrimental to the continued health of a sintered porous-surfaced implant. Likewise, there was no difference in crestal bone levels between "small" and "large" estimated implant surface areas, likely because surface area with this type of implant geometry is not as important as actual bone ingrowth and the resulting 3-dimensional mechanical interlocking that occurs with sintered porous-surfaced implants.[18,32] Such implants can routinely be used in what have been traditionally considered short lengths, do not require splinting of multiple implant units, and perform very well in bone of low density, such as that found in the posterior maxilla.[26,27,32,38,39]

The factors that appeared to influence crestal bone levels in the present analyses were implant length and whether the implants had been splinted in the prosthesis design. Long implants showed greater crestal bone loss than short ones. Likewise, splinted implants showed more crestal bone loss than nonsplinted ones. Both of these effects might be related to "stress-shielding" effects on the crestal bone and resultant disuse atrophy[40] and will require further investigation. Nevertheless, the present findings may indicate that sintered porous-surfaced implants, unlike other currently used endosseous dental implant designs that rely on bone-to-implant surface contact and implant surface area rather than bone ingrowth and true 3-dimensional mechanical interlocking, are best used in short lengths and without splinting, if feasible, so as to ensure continued optimal loading of the bone-to-sintered surface interface.

CONCLUSION

The present study was a retrospective analysis of the c/r ratios used in 2 previous prospective clinical trials involving 74 partially edentulous patients treated with 199 sintered porous-surfaced dental implants. The mean ± SD c/r ratio used was 1.5 ± 0.4, and 157 of the implants had this mean value. The average functional time for the implants was nearly 4 years (46 months), and crestal bone levels remained essentially unchanged with time in function. Neither c/r ratio nor estimated implant surface area influenced the steady-state crestal bone levels. Long implants showed significantly greater (0.2 mm more) crestal bone loss than short implants. Likewise, splinted implants showed significantly greater (0.2 mm more) crestal bone loss than nonsplinted implants.

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