

Effect of Implant Diameter on Reliability and Failure Modes of Molar Crowns

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The reliability and failure modes of molar crowns supported by three different implant-supported designs were tested according to the following groups: group 1, one standard-diameter implant (3.75 mm); group 2, one narrow-diameter implant (3 mm); and group 3, two narrow-diameter implants (3 mm). Loads were applied as mouth-motion cycles using a step-stress accelerated life-testing method. β values for groups 1 and 3 (1.57 and 2.48, respectively) indicated that fatigue accelerated the failure of both groups, but not for group 2 (0.39). Abutment screw failure was the chief failure mode. Strength and reliability were significantly higher for groups 1 and 3 compared to group 2. *Int J Prosthodont* 2011;24:557–561.

Replacing a lost molar with one implant represents a biomechanical challenge. Functional forces are greater in this area, and lateral forces may lead to increased stress on components.¹ Moreover, the presence of limited bone width may hinder the placement of a wider-diameter implant. In this case, rehabilitation may involve the placement of one or two narrow-diameter implants or one standard-diameter implant after augmentation techniques to provide adequate bone dimensions.¹ This study tested anatomically designed molar crowns supported by one or two narrow-diameter implants or one standard-diameter implant under sliding contact fatigue in water, which

has been shown to reproduce clinical failures.² The postulated hypothesis was that one narrow-diameter implant supporting a molar crown would result in lower reliability compared to either two narrow-diameter implants or one standard-diameter implant.

Materials and Methods

Eighty-four Ti-6Al-4V implants (Touareg, Adin Dental Implants) were divided into three groups (Table 1) according to their width and restoration design to support a molar crown (Fig 1). Implants were embedded in orthodontic acrylic resin poured in a 25-mm-diameter plastic tube. Following connection of the corresponding proprietary cement-retained abutment (RS-3801, Adin Dental Implants) to the bearing housing, the abutment screw (RS-3400, Adin Dental Implants) was tightened according to the manufacturer's instructions. A first molar crown was waxed to the desired anatomy and cast in cobalt-chromium metal alloy (cobalt-chrome partial denture alloy, BEGO) with the cementation surface designed to fit either one standard-diameter implant (group 1), one narrow-diameter implant (group 2), or two narrow-diameter implants (group 3) (Figs 1g, 1h, and 1i, respectively). Crowns were then cemented (Rely-X Unicem, 3M ESPE) on the abutments.

First, mean single load-to-failure (SLF) values were obtained using a universal testing machine (INSTRON 5666). Load was applied using a 6.25-mm-diameter tungsten carbide (WC) ball on the mesiobuccal cusp (Fig 1f) at a rate of 1 mm/min in a 30-degree off-axis loading orientation. Then, based on the mean SLF values, three different profiles (mild, moderate, and aggressive) were designed for mouth-motion step-stress accelerated life testing (MMSSALT) (n = 18).

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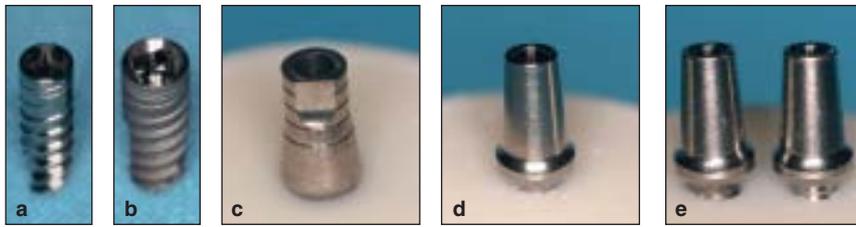
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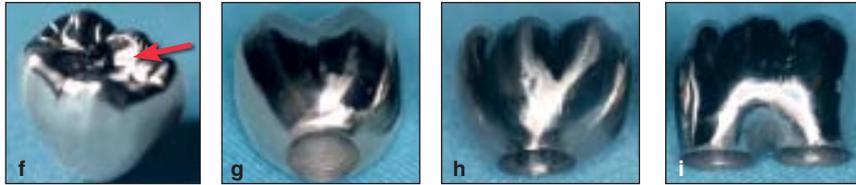
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Figs 1a and 1b (a) Narrow- and (b) standard-diameter implants used in the study.

Figs 1c to 1e Abutments used in groups (c) 1, (d) 2, and (e) 3.

Fig 1f Occlusal view of the molar crown showing the slight concave facet (red arrow) on the occlusal surface as a means to standardize the location of load application.



Figs 1g to 1i View of the abutment connection location for molar crowns in groups (g) 1, (h) 2, and (i) 3.

Fig 1j Setup for mechanical tests.

Table 1 Description of the Study Groups

| | Crowns (n) | Implants | Implant dimensions |
|----------|------------|-----------------------|--------------------|
| Group 1 | 21 | Touareg ISP - 1038 | 3.75 × 10.0 mm |
| Group 2 | 21 | Touareg ISP - NP 1030 | 3.00 × 10.0 mm |
| Group 3* | 21 | Touareg ISP - NP 1030 | 3.00 × 10.0 mm |

*Group 3 had two implants per restoration whereas groups 1 and 2 had only one.

A Servo-All-Electric system (TestResources 800L) was used to simulate mouth-motion (contact, load, slide, lift-off) cyclic loading under water (load orientation and indenter as in SLF testing). Weibull cumulative damage analysis (Alta Pro 7, Reliasoft) calculated the probability of failure at a load of 200 N (two-sided 95% confidence bounds). Representative failed specimens were inspected using a polarized-light stereomicroscope (MZ-APO, Carl Zeiss MicroImaging) and scanning electron microscope (Model S-3500N, Hitachi).

Results

Mean SLF values were 765.70 ± 80.24 N for group 1, 673.44 ± 105.93 N for group 2, and 811.18 ± 101.83 N for

group 3. β^* values derived from the use-level probability Weibull calculation were 1.57 (1.02 to 2.24) and 2.48 (1.61 to 3.83) for groups 1 and 3, respectively, indicating that fatigue accelerated the failure of both groups. The β value of 0.39 (0.24 to 0.62) for group 2 indicated that load dictated the failure mechanism (Table 2, Fig 2a). The Weibull parameter contour plot (Weibull modulus [m] versus characteristic strength [$\eta = \text{Eta}$]) showed $m = 12.7$ for group 1, $m = 9.4$ for group 2, and $m = 14.4$ for group 3 (Fig 2b). The characteristic strength was significantly higher ($P < .05$) for groups 1 ($\eta = 469$ N) and 3 ($\eta = 466.9$ N) compared to group 2 ($\eta = 342.5$ N). Groups 1 and 3 exhibited significantly higher reliability than group 2 (Table 2).

All specimens failed after MMSSALT testing (Table 3, Fig 3). Failure analysis is presented in Figs 4a to 4c.

*This parameter describes failure rate changes over time ($\beta < 1$ = failure rate is decreasing over time, commonly associated with "early failures" or failures that occur due to egregious flaws; $\beta \sim 1$ = failure rate does not vary over time, associated with failures of a random nature; $\beta > 1$ = failure rate is increasing over time, associated with failures related to damage accumulation).

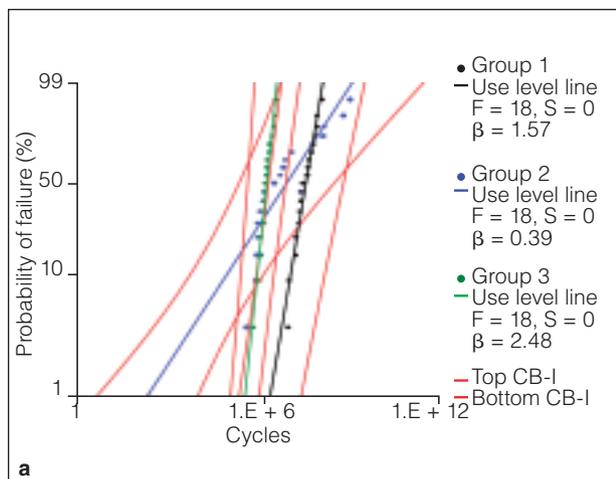


Fig 2a Use-level probability Weibull calculation for the different groups showing the probability of failure as a function of cycles. F = failure; S = survival; CB = confidence boundary.

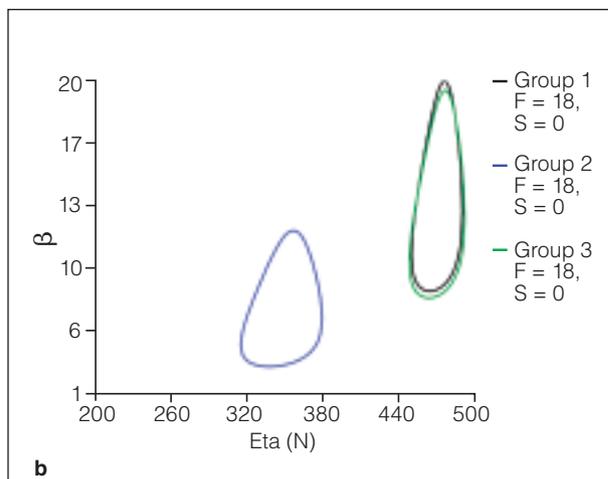


Fig 2b Contour plot (Weibull modulus vs characteristic strength) for group comparisons. Note the overlap between groups 1 and 3, showing no significantly different characteristics for strength, although both were significantly higher than that for group 2. F = failure; S = survival.

Table 2 Calculated Reliability for a Mission of 50,000 Cycles at a 200-N Load

| Output | Group 1 | Group 2 | Group 3 |
|-------------|---------|---------|---------|
| Upper | 0.99 | 0.96 | 0.99 |
| Reliability | 0.99 | 0.89* | 0.99 |
| Lower | 0.99 | 0.71 | 0.99 |

*Statistically significant difference.

Table 3 Failure Modes After Mechanical Testing According to Failure Criteria Used

| | Group 1 | Group 2 | Group 3 |
|---|---|---|--|
| No. of implant/abutment/screws (each specimen) | 1 | 1 | 2 |
| SLF | Screw: 3 fractures Abutment: 3 bendings | Screw: 3 fractures Abutment: 3 bendings | Screw: 2 bendings, 4 fractures Abutment: 4 bendings, 2 total fractures |
| MMSSALT | | | |
| Mild (n = 9) | Screw: 9 fractures Abutment: 9 total fractures | Screw: 9 fractures Abutment: 9 total fractures | Screw: 18 fractures Abutment: 12 partial and 6 total fractures |
| Moderate (n = 6) | Screw: 6 fractures Abutment: 6 total fractures | Screw: 6 fractures Abutment: 6 total fractures | Screw: 1 bending, 11 fractures Abutment: 1 bending, 4 partial and 7 total fractures |
| Severe (n = 3) | Screw: 3 fractures Abutment: 3 total fractures | Screw: 3 fractures Abutment: 3 total fractures | Screw: 1 bending, 5 fractures Abutment: 1 bending, 5 total fractures |

SLF = single load-to-fracture; MMSSALT = mouth-motion step-stress accelerated life testing.

Discussion

MMSSALT accelerated the failures of molar crowns supported by one standard-diameter implant and two narrow-diameter implants but not those supported by one narrow-diameter implant, as per β values.³ Fatigue

played little or no role in the failure of group 2 ($\beta < 1$), and hence, data were replotted according to fatigue load at failure. Weibull modulus (m) and characteristic strength were significantly higher for groups 1 and 3 compared to group 2. m is an indicator of strength reliability and the asymmetric strength distribution as



Fig 3 Failure modes of group 3 specimens after mechanical testing: (a) intact screw, (b) screw bending, (c and d) screw fracture localized in the transition area from the smooth to the threaded surface, (e) intact abutment, (f) abutment bending, and (g and h) abutment partial and total fracture, respectively.

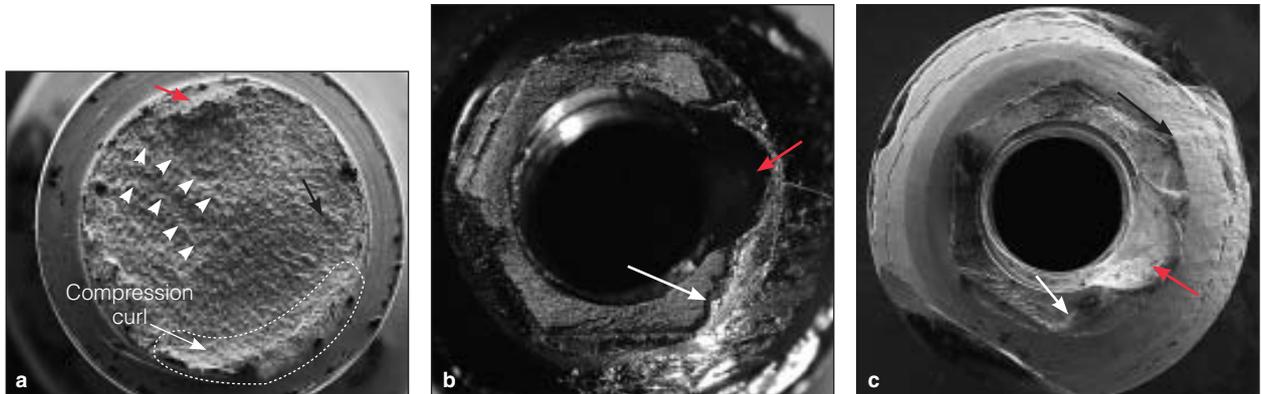


Fig 4a Representative scanning electron microscopic image of a screw fracture. The white arrows (*beach marks*) and the oval dotted white line (*compression curl*) show typical marks indicating the direction (*black arrow*) of crack propagation from lingual to buccal. The red arrow shows the site of fracture origin.

Figs 4b and 4c Magnifications of abutments in (b) light-polarized and (c) scanning electron microscopes. The red arrows indicate the screw mark held in the internal surface of the abutment. The white arrows show compression curls, also indicating the direction (*black arrow*) of crack propagation from lingual to buccal.

a result of flaws within the material.⁴ A higher *m* indicates smaller or fewer defects (greater structural reliability), and a lower *m* is evidence of greater variability of the strength, reflecting more flaws in the system and a decrease in reliability.⁴ The reliability calculated

in this study indicated this relationship with a significantly lower percentage of crowns supported by one narrow-diameter implant (group 2) surviving, compared to both one standard-diameter implant (group 1) and two narrow-diameter implants (group 3).

Abutment screw fracture was observed in all crowns supported by one implant, which is in agreement with the prosthetic failure modes reported clinically.⁵ Although the use of one narrow-diameter implant to support crowns provides an alternative to clinicians in areas where bone volume is limited, caution in the occlusal design of prosthetics, such as reduction of the occlusal table and cusp inclines, can be suggested to minimize off-axis forces. However, if two narrow-diameter implants are indicated, a 12-mm space between implants is required.¹ Implants also should be placed as parallel as possible to allow passive fit for the cemented crown. Otherwise, angulated abutments may be used as an alternative to correct the misalignment.

Conclusion

The hypothesis that the reliability of molar crowns supported by one narrow-diameter implant was lower than that of one standard-diameter implant or two narrow-diameter implants was confirmed.

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References

1. Balshi TJ, Hernandez RE, Pyszczak MC, Rangert B. A comparative study of one implant versus two replacing a single molar. *Int J Oral Maxillofac Implants* 1996;11:372–378.
2. Coelho PG, Bonfante EA, Silva NR, Rekow ED, Thompson VP. Laboratory simulation of Y-TZP all-ceramic crown clinical failures. *J Dent Res* 2009;88:382–386.
3. Abernethy RB. Reliability and statistical analysis for predicting life, safety, survivability, risk, cost and warranty claims. In: Abernethy RB. *The New Weibull Handbook*. North Palm Beach, Florida: Dr Robert Abernethy, 2004:11–26.
4. Ritter JE. Predicting lifetimes of materials and material structures. *Dent Mater* 1995;11:142–146.
5. Cho SC, Small PN, Elian N, Tarnow D. Screw loosening for standard and wide diameter implants in partially edentulous cases: 3- to 7-year longitudinal data. *Implant Dent* 2004;13:245–250.

Literature Abstract

Esthetic outcomes with porcelain-fused-to-ceramic and all-ceramic single-implant crowns: A randomized clinical trial

The aim of this randomized controlled trial was to compare the objective and subjective esthetic outcomes of two types of screw-retained single-implant crowns. Twenty patients were randomly assigned to two groups: For the control group, a screw-retained porcelain-fused-to-metal crown was fabricated; patients in the test group received a screw-retained all-ceramic crown. Patients were followed-up with at baseline (B; 2 months after implant placement but before prosthodontic treatment), 2 weeks after crown insertion (CI), 1 year after CI (1Y), and 2 years after CI (2Y). At each follow-up appointment, the following objective measurements were recorded: mesial and distal papilla height (PH), clinical crown height at the implant site (CLi), clinical crown length at the adjacent teeth (CLt), width of keratinized mucosa at the implant site (KMi) and adjacent teeth (KMt), first bone-to-implant contact (FBIC), full-mouth plaque score (FMPS), and full-mouth bleeding score (FMBS). A pink esthetic score (PES) and white esthetic score (WES) were calculated for both study groups. In addition, nine expert clinicians not involved in the treatment and investigation were asked to visually inspect standardized intraoral photographs and to subjectively determine whether the crowns were all-ceramic or porcelain-fused-to-metal. The objective and subjective parameters between the groups at B, CI, 1Y, and 2Y and differences between each study time point were analyzed using the Mann-Whitney *U* test. The significance level was set at a $P \leq .05$. A paired *t* test was used to compare the PES and WES, with the significance level set at $P = .05$. No implant or abutment failures were recorded during the entire length of the study. There were no statistically significant differences for PH, CLt, CLi, KMi, KMt, FMPS, FMBS, and FBIC at all time points, except FMPS at 2Y. Out of a maximum score of 20 for PES and WES, the porcelain-fused-to-metal and all-ceramic groups scored a mean value of 13.89 and 13.12, respectively, with no statistically significant differences between scores. The expert clinicians' ability to correctly determine the crown type for both groups was not significantly different from the value that would be expected from random guessing. The authors correctly concluded that without specific esthetic parameters such as tooth morphology, interproximal papilla, and level of cervical margins, the implant crown material alone would not be sufficient to ensure an optimal esthetic outcome.

Gallucci GO, Grütter L, Nedir R, Bischof M, Belser UC. *Clin Oral Implants Res* 2010;22:62–69. **References:** 20. **Reprints:** Dr German O. Gallucci, Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Harvard University, 188 Longwood Avenue, 02115 Boston, MA, USA. Email: german_gallucci@hds.harvard.edu—*Elvin W.J. Leong, Singapore*