Reliability and Failure Modes of Two Y-TZP Abutment Designs

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Fracture strength and accelerated fatigue reliability of two zirconia abutment systems were tested. Thirty-six implants with a Morse taper (MT; n = 18) or cone (C; n = 18) design were restored with metallic crowns. Loads were applied as single load to failure (SLF) or mouth-motion cycles using a step-stress accelerated life testing (SALT) method. SLF mean values were 690 ± 430 N and 209 ± 25 for MT and C groups, respectively. In terms of the SALT results, 8 specimens survived (50,000 cycles) and 7 failed (maximum load 400 N) in the MT group; whereas for the C group all abutments failed before the maximum number of cycles. Failure mode was fracture of the Y-TZP abutments for both groups. Higher reliability for a mission of 50,000 cycles at 175 N for MT versus C designs was determined, and significant differences in fracture modes were observed. *Int J Prosthodont 2015;28:75–78. doi: 10.11607/ijp.3879*

Limited data exist to allow for reliability comparisons of different Y-TZP abutment configurations under fatigue.[1–3] The study research hypothesis was that different Y-TZP abutment/implant configurations would lead to different fatigue reliability outcomes and failure modes.

Materials and Methods

Two different Y-TZP abutments and their respective implant fixtures (Ankylos [Dentsply] with a cone fit [C] and Astra Tech, with a Morse taper design [MT]) were obtained from the manufacturers. Eighteen implants of each system were obtained as this provided 3 for single load to failure (SLF) testing and 15 for step-stress accelerated life (SALT) testing distributed across three different load-cycle profiles per accepted standards. The implant restoration systems were mounted in a cylindrical acrylic tube[2] with a 1-inch outer diameter [OD] and 2-inch height by embedding in clear acrylic resin (Orthodontic resin; Caulk, Dentsply) equal to the implant platform. Metallic central incisor crowns (Rexillium III) of standard external dimensions were prepared (Marotta Dental Studio) and luted to each abutment with temporary cement.

Specimens were mounted at 30 degrees (ISO 6872) from the vertical long axis.[2,4] A 2-mm-radius stainless steel chisel loading tip was applied to the lingual aspect of the crown 2 mm gingival to the lingual incisal edge with a universal testing machine (Instron, Norwood; Fig 1). Initially, six crown/abutment/implants (three each of the MT and C groups) that were SLF tested at a t strain rate (0.5 mm per minute). Fatigue loading profiles, used as an initial load approximately 20% to 30% of the maximum values obtained from SLF results.

Specimens were mounted in the same configuration (30-degree angle) in an electrodynamic fatigue test machine (EnduraTec ELF 3300, EnduraTec Systems; Fig 1). A rubber tube was placed around the specimen mounting ring to act as a water reservoir. Three different mouth-motion (approach specimen, contact specimen, load, unload, lift-off specimen at 1.5 Hz) uniaxial step/stress profiles were utilized. The profiles (Fig 2) were characterized as "light," "medium," and "aggressive." The 15 implants per group were assigned to the profiles at a ratio of 3:2:1, respectively.[4] Maximum load was 400 N and maximum cycles were 100,000. Failed specimens were inspected and randomly both failing and surviving specimens were embedded and sectioned.

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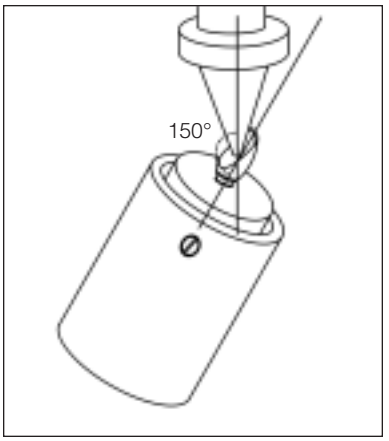

Fig 1 This schematic representation shows the specimen positioning and orientation at a 30-degree angle to the loading axis. Note that the indenter is located at the midlingual aspect of the central incisor alloy crown.

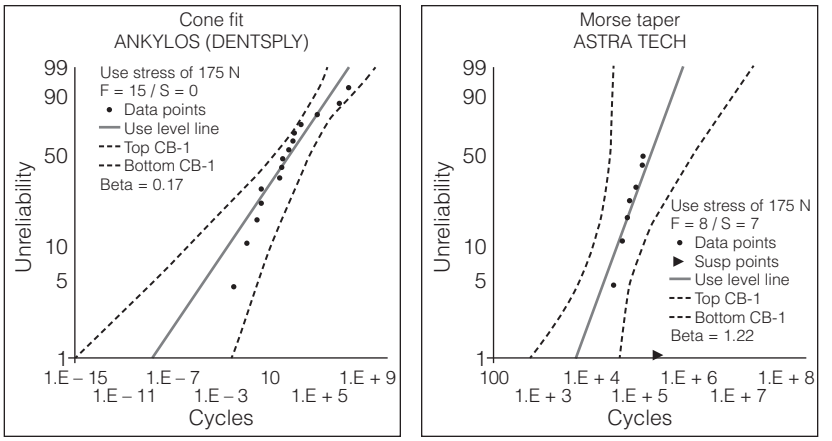

Fig 2 Use level probability plots for both groups. Note that the Morse taper (MT) group showed Weibull β = 1.2 and the cone fit (C) group presented β = 0.17.

Table 1 Calculated Reliability at 90% Confidence Intervals (CI) Using Standard Probability Calculation for Cone Fit (C) and Morse Taper (MT) Groups*

Reliability 90% CI	C 100 N	C 175 N	MT 100 N	MT 175 N
Upper	0.95	0.25	0.99	0.96
Reliability	0.89‡	0.10†	0.98‡	0.83‡
Lower	0.74	0.03	0.75	0.43

*Mission of 50,000 cycles at 100 and 175 N was considered for group comparisons. Note that C showed a significant drop in reliability when the load jumped from 100 to 175 N.
†and ‡ = statistically significant differences considering 90% CI.

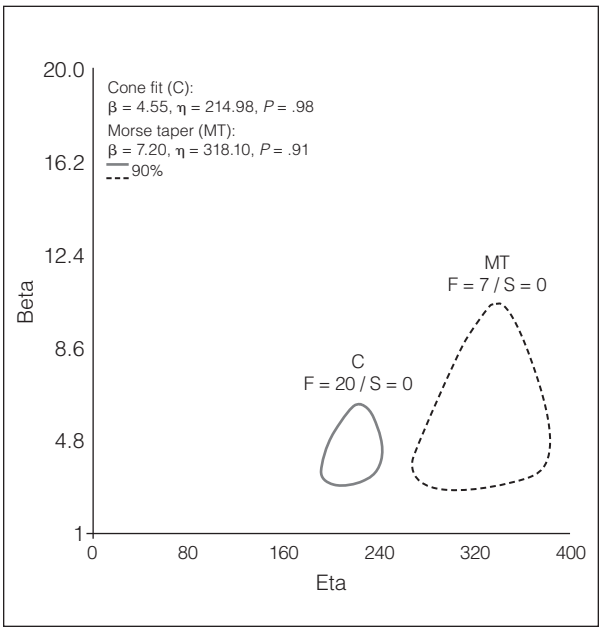

Fig 3 Weibull probability calculation represented as contour plot showed Weibull modulus β = 4.55 and characteristic strength η = 214.98 for cone fit (C), and β = 7.20 and η = 318.10 for Morse taper (MT) abutments.

Results

Mean SLF values were C = 209 ± 25 N and MT = 690 ± 430 N. Mouth-motion SALT results (Fig 2) for MT group showed Weibull β = 1.2. The C group presented β = 0.17, indicating "early" failures with fatigue having little influence. Although at 100 N both types presented high reliability (Table 1), for a mission of 50,000 cycles at 100 and 175-N loads, reliability presented statistically significant differences (nonoverlap of 90% confidence interval) between MT and C, with C being less likely (10%) to survive at 175 N load. C group had a Weibull modulus β = 4.6 and characteristic strength η = 215, while for MT β = 7.2 and η = 318 (Fig 3).

All modes of failure occurred within the inner portion of the abutment. For MT group, two failure modes were observed: *(1)* catastrophic (Fig 4) and *(2)* crack on the MT part (Fig 5). All C group abutments had one failure mode on the compression side with the crack originating at the implant-abutment junction (Fig 4). Of the 15 MT Y-TZP abutments, 8 failed (crack or catastrophic failure) and 7 survived (Fig 2).

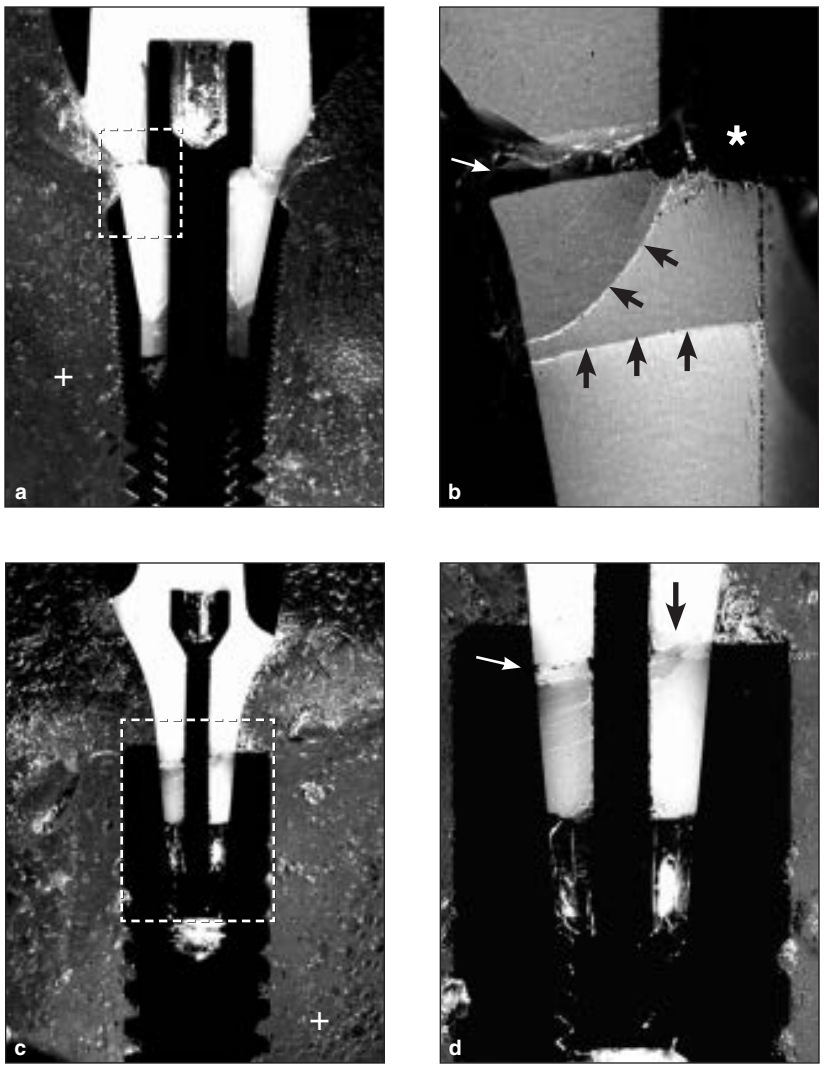

Fig 4 Sectioned images of failed specimens. **(a)** A mesiodistal section of Morse taper zirconia abutment-fixture after catastrophic failure; the white dotted lines indicate a tension zone of the fractured site. **(b)** Compression zone in higher magnification of Fig 4a, indicating fracture sites *(black arrows)* and complete fracture *(white arrow).* The symbols **+** and ***** indicate the sites of embedded resin. **(c and d)** Fracture of the cone fit zirconia abutment. Fig 4d is a higher magnification of the white dotted lines in Fig 4c,in which the white arrow indicates the fracture in the tension zone and the black arrow indicates the fracture in the compression zone.

Discussion

There was a statistically significant difference in reliability between the two abutment systems, with MT > C only at 175 N. MT failures were primarily from the tensile side (lingual), as expected. All failed from compression (facial) in C group. A hypothesis that can be made is that the cone type of connection and the very precise fit creates a high local stress region on the compression side. Low Weibull modulus ($\beta = 0.2$) indicates that fatigue is not influencing the failure, but when a certain threshold of stress is obtained, the compressive failure occurs.

The MT abutment failure zone is in the range of 250 to 400 N. Failures occurred over a wide range,[6] while none of the specimens tested (n = 4) with the aggressive profile survived. All of the specimens tested (n = 5) with the mild profile survived. For the light profile, there were four failures and two survivors, suggesting that fatigue at up to 70,000 cycles with the loads applied has a limited effect on strength.

MT zirconia abutments present stress concentration zones that might lead to early failure of the abutment connection, with Astra being more reliable than Ankylos with the test configuration here employed. The MT system developed compressive ceramic failure, while the C system failed at the tension side.

Fig 5 Sectioned image of a failed Morse taper (MT) specimen with a fracture at the MT part of the abutment. White arrows point to several cracks formed as a result of the fatigue employed.

Redesigning zirconia MT implant/abutment systems is advisable to enhance reliability calculations.

This study was limited to mouth-motion lingual loading of the abutment; off-axis loading may lead to different results.

Conclusions

The research hypothesis was accepted for a mission of 50,000 cycles at 175 N of load. The two abutment configurations showed different behaviors regarding location of initial fracture.

Acknowledgments

Figure 1 was provided courtesy of Dr Carlos AO Fernandes, Associate Professor, Federal University of Ceara, Ceara, Brazil. Microscopic imaging was made possible by an agreement between the Department of Biomaterials and Biomimetics at New York University College of Dentistry and Foundation for Human Health and Evolution. The authors would like to thank Professor George Romanos for his kindness in providing some of the Ankylos components for the study. The authors reported no conflicts of interest related to this study.

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Literature Abstract

Osteonecrosis following short-term, low-dose oral corticosteroids: A population-based study of 24 million patients

The aim of this retrospective clinical chart review study was to report the incidence and risk of osteonecrosis after methylprednisolone taper pack (MTP) was prescribed, using a novel software platform to evaluate a multicenter electronic medical database. A total of 24,533,880 patient medical records from 14 United States healthcare systems were accessed. All patients were distributed among four groups. Group 1 comprised all patients (n = 128,890) who were ever prescribed an MTP; group 2 comprised all patients (n = 98,390) who received only one MTP in their clinical history; group 3 comprised all patients (n = 30,500) who received two or more MTPs; and group 4 (control) consisted of patients (n = 24,404,990) who were never prescribed MTPs. Pearson chi-square was used to compare proportions of categorical variables. Two hundred patients in group 1 (0.155%; relative risk = 1.868), 130 patients in group 2 (0.132%; relative risk = 1.597) and 70 patients in group 3 (0.230%; relative risk = 2.763) developed osteonecrosis. Women who received more than one MTP had the highest incidence (0.247%) of developing osteonecrosis with a relative risk of 3.094. The authors concluded that even a single prescription of short-term, low-dose oral corticosteroid is associated with a low but significantly increased risk of osteonecrosis and that with multiple such prescriptions, the risk becomes greater. However, the authors also cautioned that osteonecrosis has multiple etiologies, hence only an association, not causation, should be inferred from this current large database analysis.

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