Reliability and Fatigue Damage Modes of Zirconia and Titanium Abutments

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The fracture strength and accelerated fatigue reliability of metal and zirconia abutment systems were tested. Implants with either titanium (Ti, n = 9) or zirconia abutments (Zr, n = 18) were restored with metal crowns. Loads were applied as either a monotonic load to failure or mouth-motion cycles using a step-stress accelerated life testing method. At failure, monotonic loads were 1,475 ± 625 N for Ti and 690 ± 430 N for Zr. In step-stress testing, the Ti group was truncated at 70,000 cycles and a 900-N load with no fractures. In the Zr group, eight specimens survived and seven failed, with a maximum load of 400 N. Strength and reliability were significantly higher for the Ti abutments compared to the Zr. *Int J Prosthodont 2010;23:56–59.*

Restoring implants in the esthetically demanding anterior region can be a challenge for the clinician.[1,2] Ceramic abutments were developed to allow esthetically optimal clinical results. However, their main concerns relate to strength and fatigue resistance when compared to metal abutments.[3] This study sought to compare the fracture strength and accelerated fatigue reliability of a metal and a zirconia abutment system.

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Materials and Methods

Nine titanium (Ti) abutments (Profile BiAbutment 4.5/5.0, Astra Tech) and implants with a 4.5-mm diameter and 15-mm length, and 18 yttria tetragonal zirconia polycrystal (Zr) abutments (Ceramic Abutment 4.5/5.0, Astra Tech) and implants with the same dimensions were donated by the manufacturer and prepared. The two systems were mounted in a 1-inch outside diameter cylindrical acrylic tube using orthodontic acrylic resin. Metal central incisor crowns (Rexillium III, Pinnacle One Laboratory Services) of standard external dimensions (11-mm height and 8.5-mm width) were fabricated and luted to the abutments using temporary cement.

A pilot study was conducted to determine specimen single load-to-failure values (N). 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) at a constant strain rate (0.5 mm/min). The crown-abutment-implant systems (n = 3) were loaded under an axial load at a 30-degree angle until failure.[4] The fatigue step-stress test used the same geometric configuration and an initial load of approximately 25% of the maximum values obtained from the load-at-failure results.

Fig 1 Specimen positioning and orientation at a 30-degree angle to the loading axis during accelerated fatigue testing.

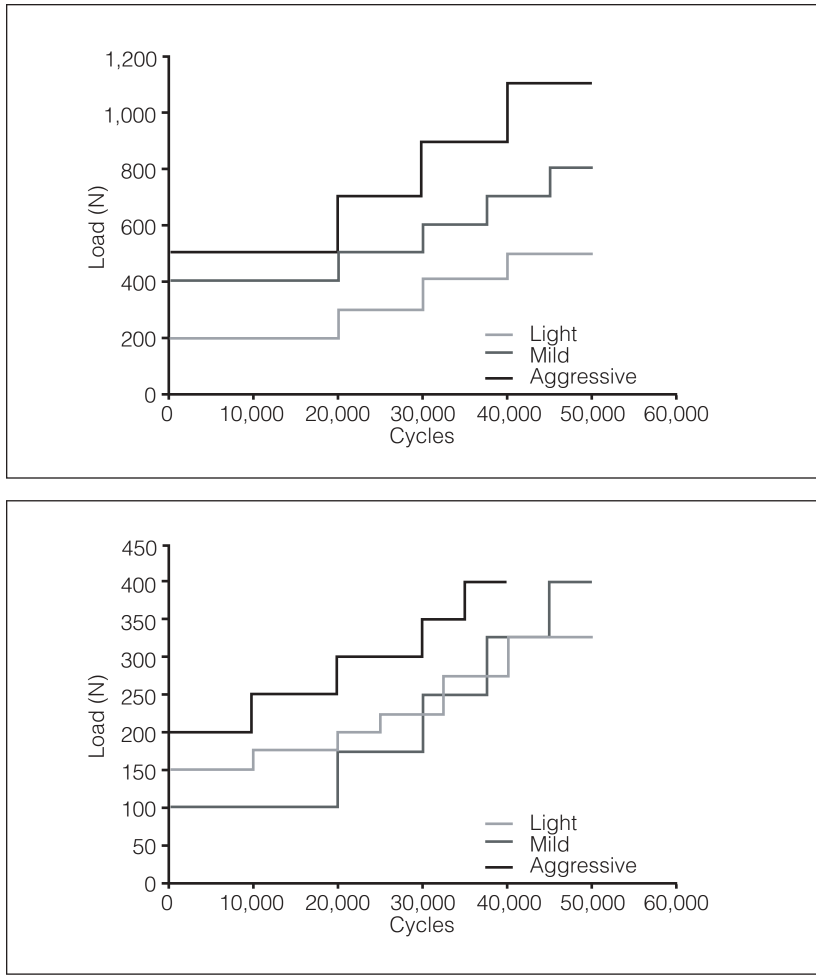

Fig 2 *(right)* Step-stress profiles developed from the mean single load to failure for **(top)** Ti and **(bottom)** Zr groups.

Step-stress accelerated life testing was employed. An electrodynamic fatigue test machine (EnduraTec ELF-3300, EnduraTec Systems) (Fig 1) was used to provide mouth-motion (contact, slide, lift off) cyclic loading in a moist environment. Three different step-stress profiles were designed for the Ti (n = 9) and Zr groups (n = 18) (Fig 2).[5] The profiles were characterized as light, mild, and aggressive according to the increase in load application after a specific number of cycles. The Zr profiles were designed to end at a maximum of 400 N (Fig 2). Failed specimens were inspected and selectively embedded and sectioned (Figs 3 and 4). Weibull cumulative damage analysis (ALTA PRO, Reliasoft) was used to calculate step-stress unreliability at 200- and 300-N loads with two-sided 90% confidence bounds.

Results

Monotonic loads for failure were 1,475 ± 625 N for Ti and 690 ± 430 N for Zr. Step-stress testing for Ti was truncated at 70,000 cycles and a 900-N load with no complete fractures, but with deformation in some specimens; these were considered to be failures (Figs 3a to 3d). For the Zr step-stress testing, eight specimens survived and seven failed by abutment fracture (Figs 3e and 3f). Fracture origin and crack propagation was investigated using scanning electron microscopy (Fig 4). Calculated reliability for the Zr group at 50,000 cycles and a 175-N load was 0.83 (two-sided 90% confidence bound: 0.96–0.42) and 0.18 (two-sided 90% confidence bound: 0.53–0.10) for a 300-N load, while for the Ti group at loads of 400 N and below, reliability was 1.00 (two-sided 90% confidence bound: 1.00–0.93), indicating a significant difference (Table 1).

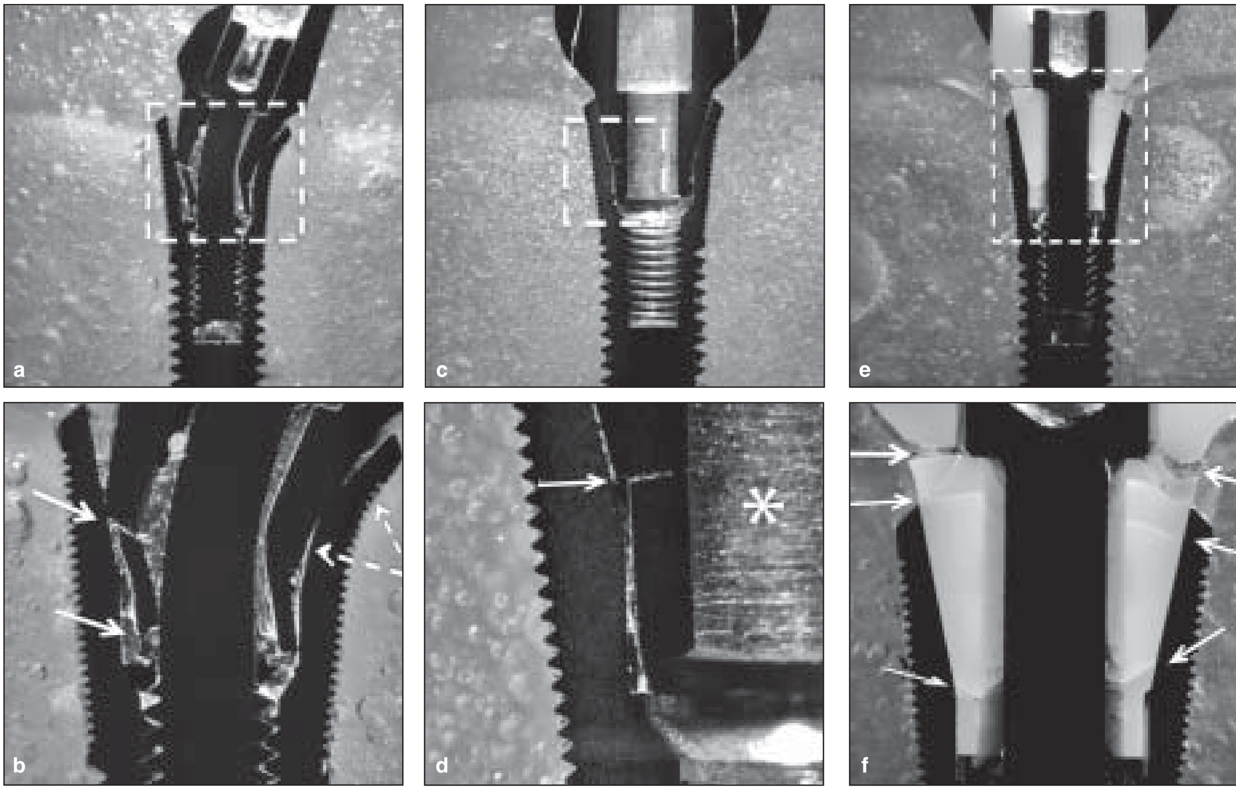

Fig 3 Sectioned images of failed specimens. **(a)** Mesial-distal section of a Ti abutment and implant after catastrophic failure. **(b)** Higher magnification of Fig 3a showing the fracture sites *(solid arrows)*. Bending implant and abutment sites can also be seen *(segmented arrows)*. **(c and d)** Fracture of a Ti abutment at the morse taper part *(solid arrow)*. Note the placement of the internal screw *(asterisk)*. **(e and f)** Multiple fractures of a Zr abutment *(solid arrows)*.

Table 1 Zr and Ti Abutment Reliability for 50,000 Cycles at a Given Load

Material	Load (N)	Reliability	Two-sided 90% confidence interval
Zr	175	0.83	0.96–0.42
	200	0.73	0.91–0.32
	300	0.18	0.53–0.10
	400	0.00	0.22–0.00
Ti	400	1.00	1.00–0.93
	500	0.99	1.00–0.60

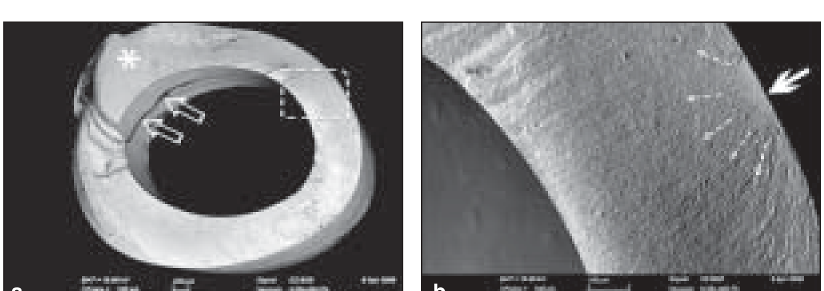

Fig 4 Representative scanning electron microscopy of a fractured Zr abutment after 50,000 cycles and a 400-N load. **(a)** A compressive curl at the compressive zone can be seen *(asterisk)*. Note that two fracture lines have combined into one larger fracture at the compressive area *(open arrow)*. **(b)** Higher magnification. The fracture origin *(solid arrow)* determined by the hackle line direction *(segmented arrows)* can be seen.

Discussion

The methodology followed was designed to simulate mastication by cyclic loading with lift off of the stylus from the crown. The decision to use 50,000 to 70,000 cycles was based on previous studies of Hertzian contact fatigue, where damage accumulation was apparent in the range between 10^4 and 10^6 cycles.[6] Performing the test to 1,000,000 cycles would greatly extend the testing time.

The Zr abutment fatigue failure was in the range of 200 to 400 N. None of the specimens tested with the aggressive profile (n = 4) survived. On the other hand, all of the specimens tested with the mild profile (n = 5) survived. For the light profile, there were four failures and two survivors (n = 6). Cumulatively, the distribution and analysis suggests that with 70,000 cycles and the loads applied, fatigue causes a reduction in strength. Given a mission of 50,000 cycles, the reliability for the Zr group decreased with increasing load, while for the Ti group no failures occurred in the range of 200 to 400 N (reliability = 1.00). The Zr abutments accumulate damage from occasional loads in the range of 175 N or above, while for Ti abutments this does not occur until loads higher than 400 N are experienced, indicating the comparative robustness of the metal system.

Conclusions

- The Ti abutments did not exhibit any failures below 900 N.
- The Zr abutment failure zone is in the range of 250 to 400 N when fatigue tested and depends on the aggressiveness of the step-stress test.
- The reliability of the Zr abutment for 50,000 cycles dropped considerably from 0.93, or 93%, at 175 N to 0.18, or 18%, at 300 N.

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