CLINICAL ORAL IMPLANTS RESEARCH

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Damping behavior of implant-supported restorations

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Abstract

Objectives: The aim of the present study was to assess the shock absorbing capacity of implant-supported restorations (CAD/CAM composite resin or zirconia abutment with composite resin or porcelain crown/onlay) and a simulated natural tooth complex using the Periometer®.

Material and methods: One hundred and twenty Morse taper implants (Titamax CM 11 mm) were mounted on bone-simulating acrylic resin base and restored with CAD/CAM zirconia (60) and metal composite resin Paradigm MZ100 (60) abutments. Using CEREC3, standardized onlays (60) and crowns (60) were designed and milled in ceramic (Paradigm C) or composite resin (Paradigm MZ100) to simulate a maxillary premolar. All restorations were luted with a preheated light curing composite resin (Filtek Z100). Fifteen extracted human upper premolars were mounted with a simulated PDL and used as control group. The Periometer®, a new handheld percussion probe that measures the energy loss coefficient (LC) for both natural teeth and implant-supported structures, was positioned perpendicularly to the buccal surface of each restoration. Three measurements of the LC were collected for each specimen. The effect of each variable (abutment material, restoration material, and restoration design) on the LC was explored using multiple regression analysis.

Results: Differences in LC between the abutment material (zirconia/Paradigm MZ100), the restoration material (Paradigm C/Paradigm MZ100) and the restoration design (onlay/crown) were recorded. The average LC of zirconia and metal composite resin abutments ranged from 0.040 to 0.053 and 0.059 to 0.068, respectively. Zirconia abutments restored with composite resin restorations (LC 0.051–0.053) had the closest LC value when compared with teeth with simulated PDL (0.049).

Conclusion: Composite resin onlays/crowns bonded to zirconia implant abutments presented similar dynamic response to load (damping behavior) when compared to teeth with a simulated PDL.

For normal healthy teeth the impact energy generated by mastication is attenuated by the periodontal ligament at the healthy bone-natural tooth interface. However, when the natural tooth must be replaced by an implant due to damage or disease the ligament is lost and the implant will transmit the masticatory forces directly into the bone (Forwood & Turner 1995; Robling et al. 2001; VanSchoiack et al. 2006). Energy transfer to the bone will be influenced by the design and material of the implant restoration, which is traditionally directly connected with a screw or can be cemented to the abutment, itself attached to the implant with a screw. New research has suggested a differing restorative design with promising esthetic and biomechanical qualities. In this innovative approach the traditional principles of retention and resistance form of the abutment and its counterpart, the restoration, are replaced by the strong and reliable resin-to-ceramic adhesion (hydrofluoric acid etching and silanization) (Magne & Cascione 2006). This technique consists of a non-retentive screw-retained custom metal ceramic abutment and a separate non-retentive porcelain veneer (Magne et al. 2008, 2011a,b). This novel design can be also applied by combining either a composite resin or zirconia abutment with a porcelain or composite resin veneer, resulting in a highly esthetic solution. It corresponds to the translational application of novel design ("type III") porcelain veneers and adhesive

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restorative principles (Andreasen et al. 1992; Walls 1995; Magne et al. 2000) in the implant realm. It is particularly indicated to correct mismatching implant-crown axes and appears to facilitate the restoration of any other clinical situation featuring severely reduced spatial architecture (Magne et al. 2008).

Both ceramic and composite resin abutments have been shown to have a similar failure rate during *in vitro* accelerated fatigue testing (Magne et al. 2011a). Yet some major differences exist from a clinical standpoint. Composite resin materials used as an abutment or restoration may resolve the previous dilemma of abutment rigidity under mechanical stress. It has been shown that modern composite resins present low elastic modulus but high fracture resistance and tensile strength (Magne & Knezevic 2009a,b,c; Magne et al. 2011b) with better optical properties (Behr et al. 2001) and color stability than earlier formulations. They are easier to bond to, they show less wear rates (Kunzelmann et al. 2001), and present improved repairability (Rosentritt et al. 2000; Andriani et al. 2010). Like composite resin, zirconia possesses highly desirable characteristics. Zirconia ceramic abutments have twice the strength of alumina ones and present the unique phenomenon of transformation strengthening (Garvie et al. 1975). However, there are some concerns when using zirconia abutments, such as the difficulty to bond to this substrate (Wolfart et al. 2007; Phark et al. 2009; Magne et al. 2010) and the risk of propagating micro fractures while trimming and adjusting prefabricated abutments (Kosmac et al. 1999; Curtis et al. 2006; Wang et al. 2008).

While *in vitro* studies have compared the survivability of implant restorations utilizing composite resin or zirconia abutments there has been no such research done to relate the dynamic response to load of said abutment materials. As demonstrated by numerous long-term clinical trials on implant survival and success, the stiffness of the traditional implant-abutment-restoration complex and the corresponding load transfer to the surrounding bone does not appear to have adverse effects. It can be hypothesized, however, that micro movements between the abutment and the implant platform, a possible source of bone resorption (Hermann et al. 2001, King et al. 2002), may be minimized by the inclusion of a resilient element in the form of a high-quality composite resin abutment or restoration. Other potential improvements from the use of resilient abutments or restorations include reduction of incidence of ceramic fractures/chipping or screw loosening of implant-supported restorations/suprastructures.

If compensation for the lost periodontal ligament is deemed appropriate, it is paramount that the implant or restoration be designed to transmit near to natural level stresses to the surrounding tissues. As per today's clinical techniques, this compensation must primarily be borne by the abutment or restoration, rather than the implant. One way of assessing the dynamic response to load is the use of percussion testing with a probe (Sheets & Earthman 1997). The Periometer® (Perimetrics, Newport Beach, CA, USA) is an FDA approved instrument that provides the clinician with two basic pieces of diagnostic data, a numeric reading for the loss coefficient (damping behavior) and an energy return vs. time analysis for the sample being tested (Brenner & Earthman 1994; VanSchoiack et al. 2006; Lincoln et al. 2006, Meyer et al. 2009). The percussion data of the device were validated using load cell measurements of force transmitted through the entire implant and supporting structure (Sheets & Earthman 1997). Therefore, the effect of changing a single component on the overall damping behavior of an implant-supported structure can be assessed experimentally using the Periometer®.

The aim of the present study was to assess the shock absorbing capacity of implant-supported restorations (CAD/CAM metal composite resin or zirconia abutment with composite resin or porcelain crown/onlay) and a simulated natural tooth complex using the Periometer®. The working hypothesis considered was that the inclusion of composite resin components (abutment or restoration) would allow dental implants to demonstrate a damping behavior similar to that of natural teeth with an artificial periodontal ligament (PDL).

Material and methods

The study was approved by the University of Southern California Institutional Review Board. One hundred and twenty Morse taper implants (Titamax CM 11 mm; Neodent, Curitiba, Brazil) were mounted on bone-simulating acrylic resin base (Palapress; Heraeus Kulzer, Armonk, NY, USA). Sixty CAD/CAM zirconia (NeoShape CAD/CAM system; Neodent) and 60 composite resin abutments were fabricated. For each material, the abutment design followed the natural emergence profile of a maxillary second premolar including clearance for either a crown or an onlay restoration.

While the zirconia abutments (Neodent) were monobloc structures (Fig. 1a), composite resin abutment resulted from the assembly of a solid metal abutment connecting into the implant (CM Universal Post, 4.5 mm – diameter, 4.5 mm – height, 2.5 mm – neck; Neodent) with a composite resin mesostructure (Paradigm MZ100; 3M-ESPE, St. Paul, MN, USA). This component was generated using the correlation mode with the CEREC 3 CAD/CAM system (Sirona, Bensheim, Germany), using the two designs (onlay or crown) of the zirconia abutment as a reference (Fig. 1b). The fitting surfaces of the metal solid abutment and composite resin mesostructure were subjected to airborne-particle abrasion with 27 μm silica-modified aluminum oxide (Cojet; 3M-ESPE) at 0.2 MPa for 10 s at a distance of 10 mm and silanization (Silane; Ultradent, South Jordan, UT, USA) for 20 s and drying at 212 F for 1 min. The two parts were luted together using adhesive resin (Optibond FL – Bottle 2; Kerr, Orange, CA, USA) and preheated restor-

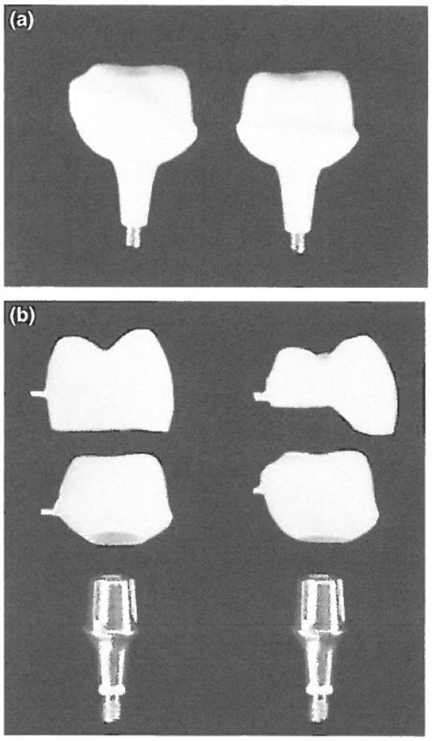

Fig. 1. Original zirconia abutments provided by the manufacturer (a, onlay design on left, crown design on right). Composite resin abutments resulting from the assembly of a solid abutment (b, bottom), the composite mesostructure (b, middle) and the corresponding restorations (b, top).

ative composite resin (Filtek Z100; 3M-ESPE, preheated for 5 min in Calset; Addent, Danbury, CT, USA). After removal of the composite resin excesses, all surfaces were light polymerized for 60 s at 1000 mw/cm^2 (Valo; Ultradent).

Using the Cerec 3 machine (Sirona) 60 restorations (30 crowns and 30 onlays) were milled in composite resin (Paradigm MZ100; 3M/ESPE) and the other sixty (fifteen of each restoration design) in glass ceramic (Paradigm C; 3M/ESPE). The porcelain restorations were initially polished using the intra-oral Dialite porcelain adjustment polishing kit (Brasseler, Savannah, GA, USA) and the composite resin ones, were polished using the Q-Polishing System (Kit ref. 4477; Komet, Rock Hills, SC, USA) and silicon carbide-impregnated polishing brushes (Occlubrush; Kerr-Hawe, Bioggio, Switzerland).

Each abutment was inserted into a Morse taper implant and 15 N/cm of torque was applied to the abutment screw. Teflon tape was used to cover the abutment screw and fill part of the access-channel. Ceramic and composite resin restorations were adhesively placed on the abutments using preheated restorative composite resin (Filtek Z100; 3M-ESPE) according to pre-established protocols for zirconia (Magne et al. 2011a) and composite resin abutment (Magne et al. 2011b).

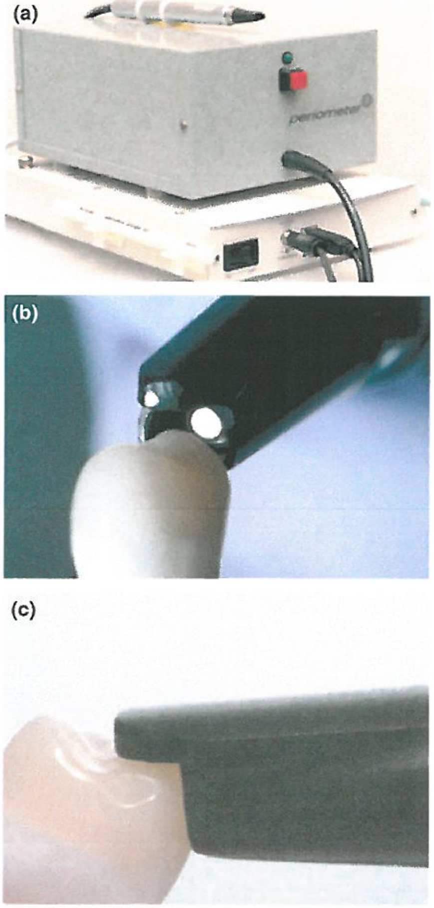

Fig. 2. Prototype version of the Periometer® (a) and its probe with percussion rod (b, probe pulled back to show percussion rod). Positioning on the specimen (c).

The above-described procedures generated eight experimental groups (120 specimens) and a control group (15 natural premolars): two groups of metal composite resin abutments restored with crowns (one group with composite resin crowns and one group with ceramic crowns), two groups of metal composite resin abutments restored with onlays (one group with composite resin onlays and one group with ceramic onlays), two groups of zirconia abutments restored with crowns (one group with composite resin crowns and one group with ceramic crowns) and two groups of zirconia abutments restored with onlays (one group with composite resin onlays and one group with ceramic onlays).

An additional control group was obtained by mounting fifteen extracted human maxillary premolars in the same bone-simulating acrylic base material. However, unlike the implant groups, a simulated PDL was obtained by coating the root of the teeth with two layers of a silicon film (RubberSep; Kerr) before resin mounting.

The Periometer® device (Fig. 2a) was used to assess the percussion loss coefficient (LC) and an energy return of each restoration and tooth. The probe tip (Fig. 2b) was positioned perpendicularly to the coronal third of the buccal surface of each restoration/tooth. The specimen was held at an angle to keep the Periometer® probe horizontal (Fig. 2c) and avoid any gravitational effects during the percussion test. The Periometer® operates by actuating a rod to impact the sample 16 times over a 4-s time span. The system software records data from 10 of these percussions and registers it as a truncated graph of energy vs. the time of each impact (Fig. 3). This datum represents the raw energy return and is used to determine the LC. The device delivers a maximum force of approximately 10 N to the abutment. This loading amplitude is considerably less than that typically measured for normal occlusion (Bates et al. 1975) and is therefore unlikely to create any damage to the specimens.

Loss coefficients obtained from the eight experimental groups were analyzed with a multiple regression analysis with the abutment material, the restoration material and the restoration design as independent variables. SPSS 12.0 for Windows (IBM Corp., Somers, NY, USA) was used to run the statistical analysis. All statistical testing was performed at a preset alpha of 0.05. The Dunnett *t*-test (two-sided) was used to test for differences between each group's mean LC and the control group's mean LC (natural teeth with simulated PDL).

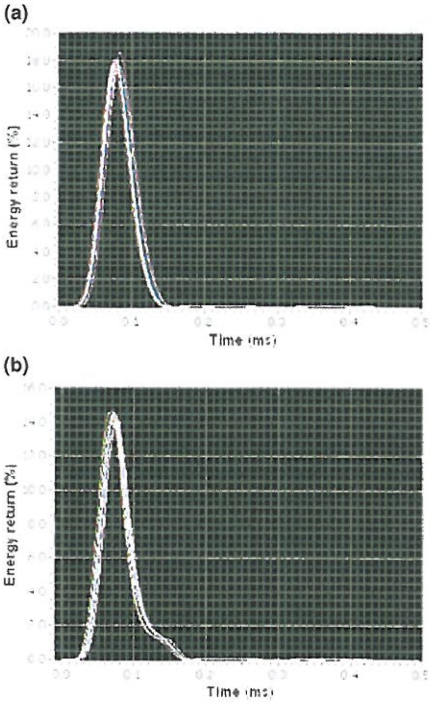

Fig. 3. Examples of energy return graphs generated by the Periometer® software. Zirconia abutment with composite resin onlay, corresponding LC of 0.0498 (a); Composite resin abutment with composite resin onlay, corresponding LC of 0.0679 (b).

Results

Examples of energy return graphs generated by the Periometer® software are presented in Fig. 3. The LC for each abutment material, restoration material, and restoration design are presented in Table 1. The average LC of zirconia and composite resin abutments ranged from 0.040 to 0.053 and 0.059 to 0.068, respectively. Multiple regression analysis revealed that all three independent variables had a significant effect, the major effect being the abutment, then the restoration with its design having the least contribution (Table 2). The Dunnett *t*-test (Table 3) revealed that only the implants restored with zirconia abutments and composite resin restorations (either crown or onlay, LC of 0.053 and 0.051, respectively, groups 5 and 6) were

Table 1. **Mean (SD) energy loss coefficient for each experimental group**

Abutment material	Composite resin				Zirconia				Natural teeth
Restoration material	Composite resin		Ceramic		Composite resin		Ceramic		–
Restoration design	Crown	Onlay	Crown	Onlay	Crown	Onlay	Crown	Onlay	–
Loss coefficient	0.068 (0.003)	0.066 (0.006)	0.061 (0.005)	0.059 (0.005)	0.053 (0.002)	0.051 (0.003)	0.042 (0.004)	0.040 (0.003)	0.049 (0.009)
Group no.	1	2	3	4	5	6	7	8	9

Table 2. **Multiple regression analysis, LC as dependent variable**

Independent variables	Coefficient	SE	*t*	*P*	*r*
(Constant)	0.09618				
Abutment	−0.01673	0.0007208	−23.205	<0.0001	−0.8133
Restoration	−0.008943	0.0007208	−12.408	<0.0001	−0.4349
Design	−0.001708	0.0007208	−2.369	0.0195	−0.08304

Table 3. **Multiple comparisons Dunnett *t* (two-sided), LC as dependent variable (group numbering according to Table 1)**

(I) Group	(J) Group	Mean difference (I–J)	SE	Sig.	95% confidence interval Lower bound	Upper bound
1	9	0.018528889(*)	0.0016496851	0.000	0.014091230	0.022966548
2	9	0.017382222(*)	0.0016496851	0.000	0.012944564	0.021819881
3	9	0.012406667(*)	0.0016496851	0.000	0.007969008	0.016844325
4	9	0.010282222(*)	0.0016496851	0.000	0.005844563	0.014719881
5	9	0.004255555	0.0016496851	0.066	−0.000182103	0.008693214
6	9	0.002868889	0.0016496851	0.379	−0.001568770	0.007306548
7	9	−0.006626667(*)	0.0016496851	0.001	−0.011064325	−0.002189008
8	9	−0.008800000(*)	0.0016496851	0.000	−0.013237659	−0.004362341

not statistically significantly different from the control group of natural teeth with simulated PDL (LC of 0.049).

Discussion

The aim of the present study was to assess the shock absorbing capacity of implant restorations (metal composite resin or zirconia abutment with composite resin or porcelain crown/onlay) compared to natural teeth. The working hypothesis was confirmed as the inclusion of composite resin components (abutment or restoration) allowed dental implants to demonstrate a damping behavior similar to that of natural teeth with a simulated PDL.

The Periometer® is a new type of probe with substantial advantages over existing devices. It can be used on both teeth and implants and does not require removal of the superstructure, thus preserving the mucosal barrier and possibly the crestal bone (Abrahamsson et al. 1997). Because the Periometer® yields a common engineering damping capacity parameter (loss coefficient) as well as an energy return graph, it can be used to determine whether or not defects exist in an implant or the surrounding bone (Meyer et al. 2009). Reproducibility of the data is particularly high because of the standardization of the probe placement. It appears that the damping effect of the real periodontal ligament (LC of 0.07–0.13 measured *in vivo*) exceeds that of our simulated natural tooth group (LC of 0.049 for group 9). This can be explained by the lack of adhesion between our simulated PDL (a double layer of silicon film) and the root or bone. Application of load *in vivo* results in a combination of compressive and tensile forces in the periodontal ligament (Ren et al. 2008), could not be reproduced in our experiment due to the weak adhesion between the silicon material and the root or resin base. Our periodontal membrane was also isotropic, which is not the case of the periodontal ligament. On the other hand, the range of LC of all implant groups matched well with that tested on rigid abutments *in vivo* (LC of 0.03–0.08). A previous study has concluded that although the loss coefficient generally does decrease with increasing bone density as expected, it was evident that the structure of the bone/implant interface also strongly affected this parameter (VanSchoiack et al. 2006).

Since the periodontal ligament is lost with the placement of an implant, it is important that the implant-supported restoration be designed to transmit near natural level stress waves through the tissues and bone. There seems to be a threshold level that if not met or is greatly exceeded, will induce the bone to undergo osteoclastic activity, resulting in possible implant failure (VanSchoiack et al. 2006) or will prompt unusual behavior of neighboring teeth such as contact opening or spontaneous intrusion (Sheets & Earthman 1997). An increased damping behavior, such as the one obtained in groups 1–4 in the present study not only presents the potential of minimizing those phenomena, but also reduces the impending micro movements between the different components of the restored implant. Those micro movements between the abutment and the implant platform become a possible source of bone resorption (Hermann et al. 2001; King et al. 2002), even with the current trend in implant dentistry, which is the placement of the implant with the platform at the level of the bone (Jung et al. 2008) or even in a subcrestal position. The use of an internal Morse taper connection has been proposed as a solution to stabilize the abutment. For other systems without such a connection, it can be hypothesized that a more flexible abutment/restoration will allow stress absorption through deformation with the effect of preventing micro movements at the platform level. Finally, by the same token, the increased damping behavior of the abutment and restoration may also logically reduce the risk for ceramic fractures/chipping, and screw loosening. Further research using the finite element analysis should establish how all those elements interact with each other. Clinical research should also confirm whether those most "compliant" groups in the present study (groups 1 and 2) would in fact match the pre-established standard for natural teeth (LC of 0.07–0.13 *in vivo*).

There are also potential clinical improvements that could result from the novel-design abutments. Unlike zirconia, composite resin abutment can be easily prepared intraorally, allowing the immediate placement of the abutment in form of provisional restoration. Following healing of the tissue, the abutment can be directly prepared as needed and restored with a bonded restoration. Without the necessity of the abutment removal or replacement, the mucosal barrier and the crestal bone are more likely to be preserved (Abrahamsson et al. 1997). Because of the possibility of using a non-retentive abutment design (such as the onlay groups in the present study) and the simplified and predictable bonding (resin to resin adhesion), the restoration of cases with abnormal implant axis or location, as well as situations with limited occlusal or interdental clearances, can be resolved (Magne et al. 2008).

The present work confirmed that the inclusion of composite resin components (abutment or restoration) allowed dental implants to demonstrate a significantly increased damping behavior. Within the limitations of this study, it appeared that composite resin onlays/crowns bonded to zirconia implant abutments presented a dynamic response to load closest to that of natural teeth with a simulated PDL. Further *in vitro* and clinical trial studies should assess the fatigue behavior and long-term survival of these novel-design implant-supported restorations.

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