The Effect of Fatigue Damage on the Force Required to Remove a Restoration in a Cement-Retained Implant System

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Purpose: **To evaluate the luting agents and retentive forces before and after mechanical stressing.**

Materials and Methods: **Sample size N was 12 for each group, and 12 Cera-One closed-end gold cylinders were cemented with three types of luting cements (ImProv, UltraTemp, and TempBond). The force required to remove the gold cylinders from the abutments was determined with an MTS testing machine. After cleaning and recementing the cylinders, the samples were placed in the housings of an Alabama-type three-body wear machine and load of 110 N was applied to the gold cylinders at a frequency of 80 cycles/min for 50,000 cycles. Then each cylinder was pulled from its abutment and the force at which the failure occurred was recorded. The procedure was repeated with 300,000 cycles.**

Results: **Statistical analysis arising from two-way ANOVA found that the forces required to remove the abutments were significantly different. The most retentive cement was ImProv. Before cyclic loading, on average, ImProv produced a retentive value 85% higher than that yielded by TempBond, and 25% higher than that of UltraTemp. The three cements were significantly different at each of the three cycle levels.**

Conclusions: **These results might suggest TempBond luting agent as the material of choice for provisional cementation because it allows easier removal of the prosthesis and maintains enough retention to prevent loosening of the restoration. The clinical implication is that the effect of cyclic load on the strength of the cements is different, an important factor in selection of a cement. ImProv had the highest retentive value before and after the two cycles, and TempBond had the lowest. UltraTemp had the highest percentage of retentive value lost. TempBond had no significant loss under loading even though initially it was the weakest.**

J Prosthodont 2006;15:289-294.

INDEX WORDS: ImProv, UltraTemp, TempBond

ONE OF THE goals of restorative dentistry is preservation of the teeth and surrounding oral structures.[1] The use of dental implants to achieve this objective has helped to overcome many of the limitations encountered with conventional fixed and removable prostheses.

Screw loosening has been shown to occur with single tooth implant-supported restorations.[2-5] Clinical studies have reported that 26% to 45% of the occlusal screws of abutments required retightening.[6,7]

Some dentists prefer cementation of implant-supported fixed prostheses[8] because of the following advantages:

1. Conventional prosthodontic procedures may be used during the clinical and laboratory phases of treatment;
2. Cementation allows for correction of improperly angled fixtures by the use of custom-cast abutments;

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Accepted May 9, 2005.

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1059-941X/06

doi: 10.1111/j.1532-849X.2006.00126.x

3. Easier control of occlusion, because screw holes use up a large percentage of the occlusal table and interfere with the contacts;[8]
4. A luting agent interface between metal surfaces will allow small discrepancies not acceptable in a screw-retained restoration and may even act as a shock absorber;[8]
5. Passivity of fit[9]—passive fit of the castings is not an achievable goal that is predictably met in the clinical setting.[8] Non-passive castings are a major cause of loose restorations, crestal bone loss, implant component fracture, and implant mobility;[9]
6. The laboratory costs for a cemented restoration are less. Screw-retained restorations require components and laboratory time;[9] and
7. Elimination of complications such as fracture of porcelain.[10] If the metal is cut back to hide the non-esthetic metal, porcelain fracture around the screw access channel may occur.[11]

Several disadvantages have been mentioned in the literature for the use of a cemented abutment:

1. Increased chair time for cementation of the abutment and removal of the excess luting agent;
2. Reduced ability to change superstructure designs;
3. Reduced treatment options if peri-implant inflammation or vertical bone loss occurs;[8]
4. The use of such a cemented superstructure does not permit removal for future maintenance;[12]
5. Removal of excess cement is difficult, if not impossible, in the peri-implant sulcus;[13] and
6. In areas of limited inter-ridge space, a screw is more effective than cement, because the abutment lacks the important factors of height and surface area.[8]

There is strong evidence that most mechanical failures of prosthodontic structures occur after several years of service.[14] It might thus be inferred that prosthodontic structures do not break as a consequence of a single, intense course of stress application but rather as the end effect of a large number of comparatively small loadings. The former situation is best duplicated using a monotonic test, whereas, the latter requires procedures appropriate for fatigue analysis.[15]

There are no reports on the effect of cyclic loading on the failure of cements in implant-supported restorations. Consequently, no comparison can be made with the estimated chewing cycles for screw-loosening of a gold screw.

The goal of this study was to provide data on the effect of pre-fatigue damage on the force required to remove Cera-One cylinders cemented with three types of cements—ImProv, TempBond, and UltraTemp—after cyclic loading. It has been stated that for tooth preparation, a 6-degree taper is ideal.[16] This is why, in the implant industry, most manufacturers machine their abutment to a 6-degree taper.[17] Cera-One abutments have parallel walls, therefore, it is evident that they offer more retention, thus the reason for the use of this type of abutment in this study.

Materials and Methods

Twelve regular Platform Brånemark (Nobel Biocare, Yorba Linda, CA) fixtures 11.5-mm long were embedded in a block of 66-mm diameter Sampl-Kwick epoxy resin (Buehler, Lakebluff, IL). The fixtures were randomly divided into three groups of four samples each. The fixtures were placed in the center of the block. Resin was selected as a mounting media to replicate the resiliency and elasticity of bone.[18]

Cera-One abutments were placed on the fixtures, and abutment screws were tightened to 32 Ncm of torque with a torque driver and a counter torque device. Sharifi et al believe that the gold cylinder reduces possible casting error by its precision-machined fit to the abutment, which is machined-fit so that no casting error exists to affect the results.[19] Two loops of inlay wax were cast in nickel chromium alloy (Ticonium, Albany, NY) to each of the Cera-One closed-end gold cylinders (Nobel Biocare).

Three types of cements were used to cement the gold cylinders on Cera-One abutments. They were: (1) ImProv, a recently introduced cement (Nobel Biocare), which is a eugenol-free, acrylic/urethane polymer-based provisional cement, (2) TempBond (Kerr Manufacturing Corp., Romulus, MI), which is a zinc oxide-based temporary cement, and (3) UltraTemp (Ultradent, South Jordan, UT), which is a non-eugenol polycarboxylate-based temporary luting material. All cements were mixed according to manufacturers' specifications.

The access opening to the gold screw was filled with Exaflex (GC America Inc., Alsip, IL), a poly (vinyl siloxane) impression material, because this results in higher retentive values.[20] To permit controlled loading during cementation, a dead weight of 1 kg was applied for 10 minutes immediately after luting. After setting, the excess cement was removed with an explorer. After the cementation procedure the gold cylinder/abutment complex was stored inside the 37°C incubator with 100% relative humidity (RH) for 84 hours.

Each sample was placed on an MTS Sintech ReNew 1123 testing machine (MTS, St. Paul, MN) and the force required to remove the gold cylinders from the abutments was determined (*BC*: force before cyclic loading) at a crosshead speed of 5 mm/min by means of a hook and chain mounted on a 562-lb load cell.

After this testing cycle, each abutment and gold cylinder was placed in Williams U3 (Ivoclar North America Inc., Amherst, NY) cement-removal solution in an ultrasonic unit for 20 minutes. To remove ImProv cement from the gold cylinder, it was air-abraded with 50 μm aluminum oxide particles at 50 psi from a distance of 3 cm and cleaned with distilled water in an ultrasonic unit. A spoon excavator was sometimes used to remove adherent luting agent residue.

Twelve abutment/implants were randomly divided into three groups (one for each cement) of four samples each. Each group was reused for the same cement. Limited number of implant parts available was the reason for the reuse.

The abutments were torqued in and cylinders cemented again following the same procedures mentioned. After cementation, the gold cylinder/abutment complex was stored inside the 37°C incubator with 100% RH environment for 72 hours.

The four samples cemented with the same type of luting cement were placed in the housings of an Alabama-type three-body wear machine (Dentsply Caulk), adjusted so that a load of 110 N was applied to the gold cylinders at a frequency of 80 cycles/min. This compressive load was applied along the axis of the abutment. The container around the sample housings and samples was filled with de-ionized water to create a wet environment and to reduce any heat that might be generated during the experiment. A standardized test for determining the retention strength of crowns to abutments is currently not available. In this study, a cyclic rate of 80 cycles/min was used.[21] Chewing rate differs from one person to another and there is variation in the chewing rate of the same person. The rate is also dependent on the type of food. It was shown that fatigue characteristics of zinc phosphate depend on frequency, that is, a time to fracture was shorter at the loading frequency of 20 Hz than that of 1 Hz.[22]

During testing a counter registered the number of cycles applied by the loading device. The load application was continued for 50,000 cycles. After 50,000 cycles, the samples were placed on the MTS testing machine, and the force required to remove the gold cylinders from the abutments was measured using the same crosshead speed (*A1C*: force after first cyclic loading). This was to determine the degree of fatigue damage. If it was observed that some samples failed before the completion of the test, the force to remove them would have been considered zero.

Eight samples were used for each of the cements. Because of the number of implants and abutments available, the test was run for four samples first, and after cleaning the abutments and cylinders, the test was run again using recycled implants and abutments. The retrievability issue and the possible need for recementation of loosened crowns demonstrate the differences between new, clean surfaces versus recementation of previously cemented abutments. Previous studies[8,23,24] included the reuse of paired abutments and castings for tensile testing. Repeated cementation of the dental castings and the surface oxidation were not a concern, because it has been shown that these factors do not significantly affect the tensile bond strengths of luting agents.[25,26]

After this testing cycle, each abutment and gold cylinder were cleaned. The specimens were air-dried and inspected under magnification to ensure complete removal of luting agent residue.

The abutments were torqued in and cylinders were cemented again following the same procedures as mentioned. After cementation, the gold cylinder/abutment complex was stored inside the 37°C incubator with 100% RH environment for 24 hours.

After 300,000 cycles, samples were placed on the MTS testing machine, and the force required to remove the gold cylinders from the abutments was recorded using the same crosshead speed (*A2C*: force after second cyclic loading).

At the end of each cycle the abutments were checked manually for screw loosening.

To measure the amount of fatigue due to cyclic loading, each sample had the force required to remove the gold cylinder from the abutment recorded at *BC* (before cyclic loading), *A1C* (after cyclic loading of 50,000 cycles), and *A2C* (after cyclic loading of 300,000 cycles). The difference between these measurements indicated the fatigue due to cyclic loading.

There was no relevant data in the literature to assist in the determination of sample sizes. It was decided to make sample size calculations based on detecting shifts in force either from one cyclic load to another for any particular cement or between cements at a particular load. By estimating mean force to be at least 120 N and a standard deviation no larger than 15 N, it was determined by calculation that a sample size of eight would have a power of at least 0.9 to detect a 20% shift in the mean force for any pair-wise comparison. A two-way (cements and cycles) ANOVA was performed, and it was found that both the cements and the cycles were significantly different. A one-way ANOVA for the three cements at each cycle level *BC*, *A1C*, and *A2C* found the cements were significantly different before cyclic loading and after each of the cycles. Pair-wise comparisons between the cements at each of the three cycle levels were then performed as well as pair-wise comparisons between *BC*, *A1C*, and *A2C* for each cement.

Table 1. Mean Forces (N) Required to Remove the Gold Cylinders (Standard Deviation)

Cycle	*UltraTemp*	*ImProv*	*TempBond*
BC	140.2 (9.1)	175.7 (21.4)*	95.2 (14.2)
A1C	132.1 (13.6)	155.8 (20.2)	88.9 (11.3)
A2C	102.2 (31.6)*	139.1 (20.5)*	86.7 (12.0)

BC: before pre-fatigue cycle.
A1C: First pre-fatigue cycle (50,000 cycles).
A2C: Second pre-fatigue cycle (300,000 cycles).
*Indicates significant differences at the 0.005 level when compared with the different cycle levels.

Results

The specimens were all tested before cyclic loading, then tested after 50,000 cycles and 300,000 cycles, and measurements were made on a sample of eight independent specimens each before cycling (*BC*), after the first cycle (*A1C*), and after the second cycle (*A2C*).

Mean forces (in N, with standard deviations) for each of the three luting agents are summarized in Table 1, where asterisks indicate significant differences at 0.005 level when compared with the different cycle levels. The most retentive cement was ImProv. Before cyclic loading, on average, ImProv produced a retentive value 85% higher than that yielded by TempBond and 25% higher than that of UltraTemp. Also, there were significant differences between *BC*, *A1C*, and *A2C*.

For all three cements, failures were primarily adhesive; minimal cohesive failure was observed for TempBond and UltraTemp. Also, no screw loosening was observed after the loading cycles.

Discussion

Because the major disadvantage of cemented implant-supported restorations appears to be the difficulty of retrievability, factors that influence the amount of retention are of interest.[17]

Fatigue is the breaking or fracturing of the material caused by repeated cyclic or applied loads below the yield limit.[27] Intraoral occlusal forces create this dynamic repetitive loading; thus, instead of a monotonic static load to fracture, it would be more clinically relevant to test the specimen under a physiologic fatigue load. Cement behavior under fatigue loading may very well be different compared with continuous load application.[28] Except for the retentive values of TempBond and UltraTemp after 300,000 cycles, which were statistically insignificant, the choice of luting agent significantly ($p < 0.0001$) affected all other cement retentive values at *BC*, *A1C*, and *A2C*, suggesting that choice of luting agent is an important variable.

The retentive values of the luting agents used in this study can be compared only loosely with those obtained with cementation of conventional fixed restorations to natural teeth. First, the metal abutment cannot be precisely compared with dentin as a surface to which castings are cemented. In addition, while the abutment taper and height were fixed in this study, the studies that compared retentive strengths of cements on natural teeth each used natural tooth preparations of different tapers, heights, and surface areas.[9]

A standardized test for determining the retention strength of crowns to abutments is currently not available. In this study a cyclic rate of 80 cycles/min was used. Chewing rate differs from one person to another and there is also a variation in the chewing rate of the same person. The rate is also dependant on the type of food. It was shown that fatigue characteristics of zinc phosphate depend on frequency, that is, a time to fracture was shorter at the loading frequency of 20 Hz than that of 1 Hz.[22] A chewing cycle of 80 cycles/min is a reasonable estimate.[21] If chewing takes place for a total of 20 minutes a day, then 1600 cycles a day could be expected.[29] Thus 300,000 cycles simulates the number of chewing cycles in 6 months. In a study by Jorneus et al, the occlusal forces for individual patients ranged from 140 to 390 N.[30]

In one study, TempBond luting agent exhibited a mean uniaxial resistance of 40.6 to 81.6 N depending on abutment type,[10] and in another study with Cera-One abutments, the mean cement failure load, depending on chimney height and cement volume, was 57.8 to 75.6 N,[31] which are lower than the numbers obtained in the present study. Differences in specimen preparation and experimental method and implant systems used (difference in surface design of the cemented portion of the abutment and restoration, different taper of the abutment, different degree of luting agent space) preclude direct comparison with other studies.

The location at which cement failure occurs may be another important consideration in the selection of a cement when retrievability is desired.

A cement that adheres to the abutment may be difficult to remove, and attempts to do so may damage the abutment surface. Furthermore, there may be decreased retention resulting after cementing over that abutment again, if the cement remains permanently attached to the abutment.[9] In this study, failure in all three cements occurred at the interface of cement and the abutment, although there was some cohesive failure in TempBond and UltraTemp. When failure occurs, residual cements cover the internal surface of the gold alloy cylinder. But some residual TempBond and UltraTemp remained on the abutment, which could be easily removed. Thus, these three cements appear to be useful clinically for the aforementioned reasons.

Soluble luting agents leave a gap between the preparation finish line and the margin of the restoration and eventually cause loss of retention. In a study by Ramp et al, intraorally, the eugenol-containing luting agents were the most soluble of those tested.[24] Singer and Serfaty observed 9.8% cement washout for the restorations, which was attributed to the relatively short abutments supporting FPDs placed in the posterior region and the use of TempBond cement.[32] On the other hand, although complications associated with cement washout have been reported for cement-retained restorations[32] such restorations have high clinical success rates.[33] If the cement washout does occur, recementation is a very simple procedure.[32]

TempBond had the lowest amount of initial retentive value compared with the other two cements. The retentive values for TempBond were not significantly different before and after two cyclic loadings. This might suggest that TempBond luting agent should be the material of choice for provisional cementation, because it allows easier removal of the prosthesis and maintains enough retention to prevent loosening of the restoration. If the TempBond material failed to provide adequate retention, then either UltraTemp or ImProv luting agents can be used. Although as seen in the extrapolated graph (Fig 1), it can be inferred that even these cements might lose strength in time. The curves on the graph fit the data and are then extrapolated to further cycles. Thus after about 550,000 cycles, TempBond is expected to be more retentive than UltraTemp, and after 1,400,000, cycles TempBond is expected to be more retentive than ImProv. We emphasize that this extrapolation assumes that the cements behave in the future as they have in the past where we observed the data. The fact that the other cements lost significant retentive value during loading may be clinically important when comparing UltraTemp and ImProv with TempBond. Another clinical implication of this study is that not only are the initial retentive values of provisional cements not equal, but also the effect of cyclic load on the retentive value of the cement, which is an important factor in selection of a cement material, is different.

Conclusions

Within the limitations of this in vitro study it was concluded that:

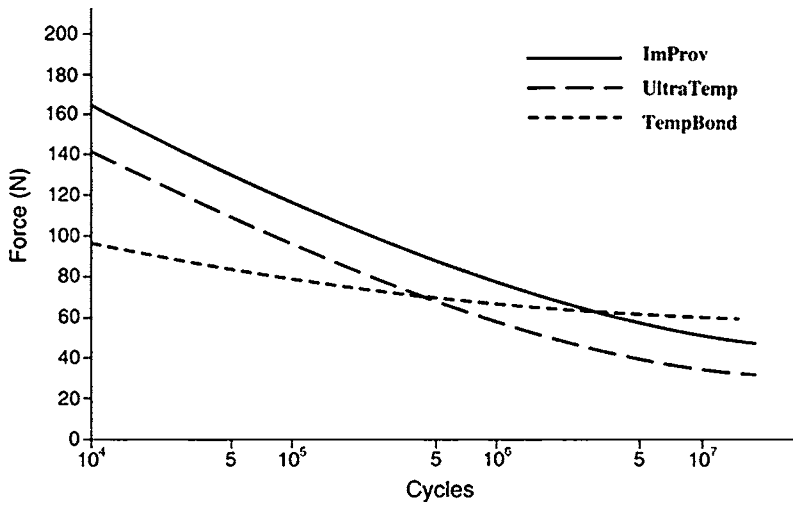

Figure 1. Extrapolation of pre-fatigue effects on remaining retention forces for three cements.

1. ImProv was most retentive before and after two cyclic loadings.
2. TempBond was least retentive before and after two cyclic loadings.
3. TempBond had the smallest percentage (8.8%) lost before and after 300,000 cycles.
4. UltraTemp had the highest percentage (27.2%) lost before and after 300,000 cycles; ImProv was second with 20.8% lost.
5. TempBond had no significant loss of retentive value under loading even though initially it was the weakest.

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