Original Article

In-vitro fatigue and fracture performance of three different ferrulized implant connections used in fixed prosthesis

Saverio Cosola [a,d]*, Paolo Toti [a,b], Enrico Babetto [c],
Ugo Covani [b], Miguel Peñarrocha-Diago [d],
David Peñarrocha-Oltra [d]

[a] Department of Stomatology, Tuscan Stomatological Institute, Foundation for Dental Clinic, Research and Continuing Education, Forte Dei Marmi, Italy
[b] Saint Camillus International University of Health and Medical Sciences, Rome, Italy
[c] Sweden & Martina's Research and Development Department, Padua, Italy
[d] Department of Stomatology, Faculty of Medicine and Dentistry, University of Valencia, Valencia, Spain

Background/purpose: The aim of the present *in vitro* study was to evaluate fatigue resistance of dental fixtures in three different types of fixture/abutment finishing line.
Materials and methods: Transmucosal dental implants, with or without ferrulized neck, underwent fatigue tests (static and dynamic load) using the following standard protocol: UNI EN ISO 14801:2016. Two types of loading devices (screw- or cement-retained restoration) were also tested, and fatigue cycle tests were run to failure. Data of static and dynamic load tests were analyzed by proper statistical methods.
Results: Following standard protocol for fatigue testing, the IL_C type (Implant Level with ferrulized neck and cement-retained crown) showed a non-significant but higher Ultimate Failure Load (UFL = 445.7 N) compared to AL type (Abutment Level without ferrule effect, 421.6 N) and IL_S type (Implant Level with ferrulized neck and Screw-retained crown, 362.8 N). No fracture of the titanium-base was registered in the tested specimens during the static loadings. Permanent deformations of the materials were observed.
Conclusion: The number of cycles to either fracture or deformation (higher than 4 mm) occurring during fatigue tests showed that the stress rupture curve of the materials in group IL_S appeared to be significantly different from those of the IL_C and AL groups (p-values < 0.01): much higher life of one-half order of magnitude.

* Corresponding author. Department of Stomatology, Tuscan Stomatological Institute, Foundation for Dental Clinic, Research and Continuing Education, Via Padre Ignazio da Carrara 39, 55042 Forte Dei Marmi, Italy.
E-mail address: s.cosola@hotmail.it (S. Cosola).

Introduction

To rehabilitate partial edentulous patients with an implant-supported dental crown, clinicians need more than one component to replicate a single real tooth. Physiological activities of biting and mastication stress and strain the components to withstand fatigue loadings, and this can increase the incidence of mechanical failures.[1]

In cases where components are three, there is an osseointegrated endosseous part (fixture), an abutment, that is, the transmucosal connection between the implant and the implant-supported restoration, which is the third component in the system.

The studies of Vasconcellos et al. and of Rani et al. suggest that fixed partial dentures generate the highest values of the peri-implant strain magnitude.[2,3] This is probably due to the effect of cross-arch stabilization of fixed full-arch restorations.

Moreover, the type of the prosthesis (splinted versus single crowns) and of the retention (screw- versus cement-retained implant prostheses) affect occlusal loading.[3]

The achievement of stability between the fixture and the prosthesis anchoring device, by whatever means possible, can reduce the risk of fracture of the implant components. The ferrule screw/cement connection between the dental implant and the prosthesis acts in a similar way to that of a weakened teeth rehabilitation; its prognosis and long-term treatment success are related to the ferrule effect.[4,5]

Regarding crown margin placement, few authors have attempted to evidence the differences between the implant and the crown line location, but they explored the hypothesis through an *in silico* study.[6]

Null hypothesis is the absence of difference between the prosthesis with ferrulized neck (implant-level) and the prosthesis without ferrulized neck (abutment-level) used for transmucosal dental implants.

Material and methods

Subjects

In the present *in vitro* study three different types of fixture/abutment finishing line were used for implant-supported fixed prosthesis: configuration 1 (Abutment Level, AL), configuration 2 (Implant Level with ferrulized neck and Screw-retained crown, IL_S), and configuration 3 (Implant Level with ferrulized neck and cement-retained crown, IL_C).

Instrumentation/measurement

Three specimens were tested for each type of configuration (static load test method), and the behavior of (at least) 11 specimens per group were tested during cyclic loading phase, according to the ISO 14801: 2016 guidelines.[7] Rapidly, the protocol requires a mandatory distance of 11 mm from the point of load application (the hemispherical loading device, that is, a titanium cap of 6.0 mm diameter) to the nominal bone level (Fig. 1).

In the static load test, the Ultimate Failure Load (UFL) and the maximum bending moment of each specimen were calculated by analyzing the loading curves. Each specimen, at the end of the test, was examined and checked through photographs.

Fatigue failure consisted of implant fracture or loading device displacement (distortion higher than 4 mm right from the point of reference as depicted in Fig. 1).
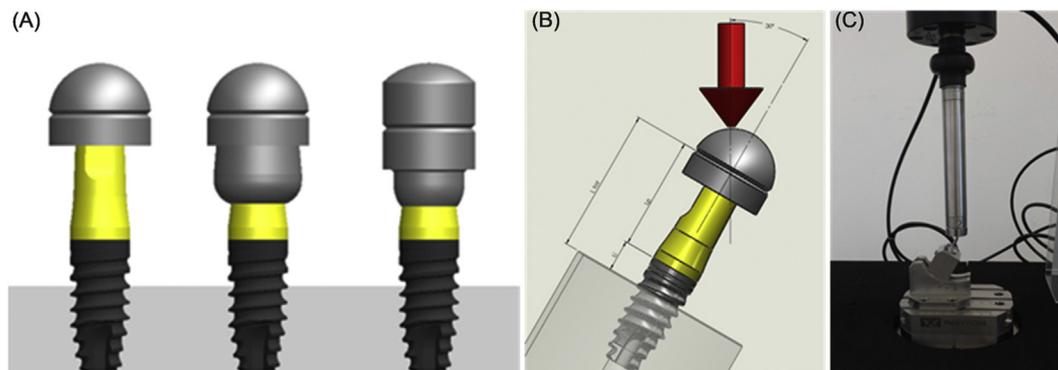
Figure 1   Three configurations: (A) AL: abutment Level without ferrulized neck; (B) IL_S: implant Level with ferrulized neck and screw-retained crown; (C) IL_C: Implant Level with ferrulized neck and cement-retained crown. (B) Schematic of test set-up for systems (ISO14801:2016). Ltot: distance from the center of the hemisphere to the clamping plane, Lp: nominal bone level, Li: exposed screw threads. (C) Loading apparatus Instron ElectroPuls® E10000.

Materials

The present study describes the behavior dental implant of a single brand and type (Sweden & Martina, Padua, Italy). Fourteen specimens were prepared for each group (Table 1). The following settings were set for all configurations (Fig. 2):

AL: transmucosal 3.8 mm implant, 3.3 mm abutment. Abutment-Level finishing line with non-ferrulized neck design;

IL_S: transmucosal 3.8 mm implant, 3.3 mm abutment. Implant-Level finishing line with 0.5 mm ferrulized neck design and screw-retained crown;

IL_C: transmucosal 3.8 mm implant, 3.3 mm abutment. Implant-Level finishing line with 0.5 mm ferrulized neck design and cement-retained crown (All Stone Cement, Sweden & Martina).

Procedures

Static load test

To simulate the full dynamical process of dental implant placement, the implant bed was prepared to step by step into a poly-methyl methacrylate matrix (Plexiglas®, Röhm GmbH, Darmstadt, Germany) up to the implant length, according to the implant drilling sequence as recommended by the manufacturer. Fixtures were deeply placed into the implant bed with a torque up to 100 N cm. Finally, they were embedded in the acrylic glass matrix up to 3.0 ± 0.5 mm below the nominal bone level of the implant (abutment-implant junction) to simulate bone loss around the implant; moreover, the abutment had to be long enough to allow the center of the hemisphere to protrude by 8.0 ± 0.5 mm beyond the implant neck. Specimens (three repeated measurements for each configuration) were subjected to static loading, carried out in a fatigue test machine (Instron ElectroPuls® E10000, Instron Industrial Products, Bucks, UK) with $30 \pm 2°$ angle between the implant axis and the direction of force transfer (setting: rate of loading of 2 mm/min with a 20 N preload). According to some clinical studies, non-axial-positioned (or tilted) dental implants had an inclination range from 10 to 30°[8,9]; whereas an angle of inclination of from about 30 to about 45° was preferred and processed only for *in silico* studies.[10−12] And this was the reason why the ISO14801:2016 protocol suggested a value of 30°. The load was applied to the specimen until failure occurred (fracture or device displacement).

Power analysis was employed to determine the sample size with 90% power at the 0.05 significance level, based on
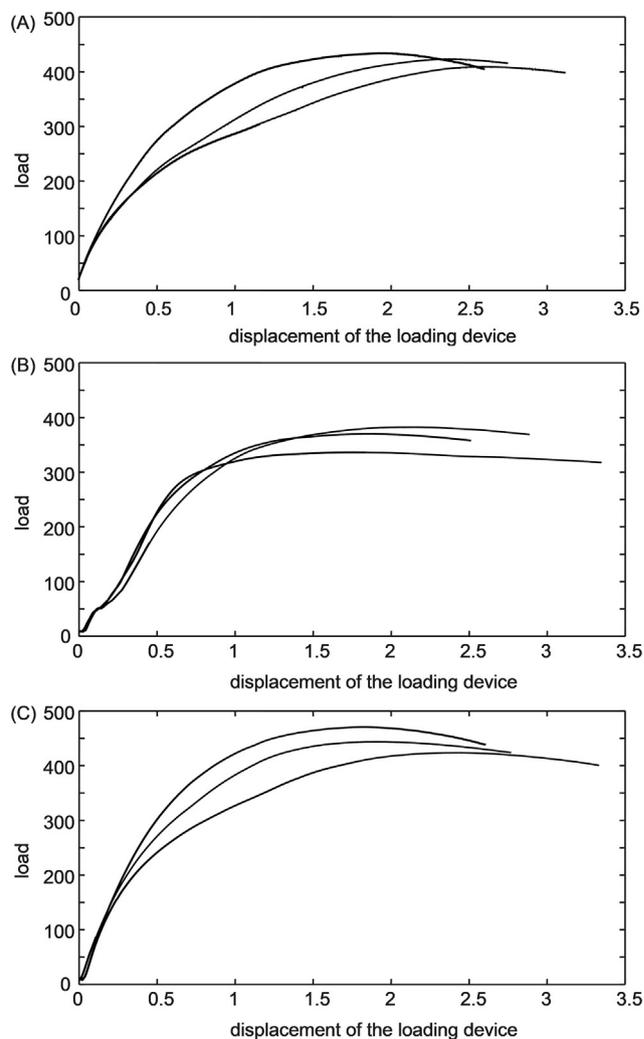
Figure 2 View of load—displacement curves for (A) AL: Abutment Level without ferrulized neck; (B) IL_S: Implant Level with ferrulized neck and screw-retained crown; (C) IL_C: Implant Level with ferrulized neck and cement-retained crown. Permanent deformations occurred after maximum load/displacement of the loading device.

the results reported in previous study concerning the effect of external hexagon height on the fatigue life of titanium dental implants.[13] Results suggested that a sample size of 3 subjects per group (or less) was required to detect significant differences on the outcomes among groups (with or without ferrulized neck design).

Table 1 Implants and components used in the study with the ultimate failure load and maximum bending moment, and failure modes in a static load test. (A) AL: Abutment Level without ferrulized neck; (B) IL_S: Implant Level with ferrulized neck and screw-retained crown; (C) IL_C: Implant Level with ferrulized neck and cement-retained crown.

Configuration	Fixture	Abutment	Material	Ultimate failure load (N)	Bending moment, (N mm)	Failure mode
AL	LA-ZT-380-130	A-ABU-330-1	CP-Ti grade 4	421.6 ± 12.5	2318.8 ± 68.8	Deformation
IL_S	LA-ZT-380-130	A-ABU-330-1	CP-Ti grade 4	362.8 ± 23.8	1995.4 ± 130.9	Deformation
IL_C	LA-ZT-380-130	A-ABU-330-1	CP-Ti grade 4	445.7 ± 23.6	2451.4 ± 129.8	Deformation

Cyclic load test

As per the ISO guideline, for each setting of the cyclic load test sample a mean value of the UFL was required. As per the load test, each specimen (two repeated measurements for each setting) was embedded in the poly-methyl methacrylate matrix. According to the ISO14801:2016, the specimen geometry used for the cyclic loading test was the same as the static loading test which was described in the previous section (Fig. 1). The initial setting for each configuration group was 80% of the respective mean UFL value. Then the test was run at the following levels (70%, 60%, 50% and so on). An alternate load was applied with frequency of 15 Hz.

An individual test specimen would pass the test if it survived up to 5 millions of cycles. Otherwise, the test was considered failed. The number of cycles until failure was recorded.

Statistical analyses

Results of static and cyclic load tests to failure were entered into a database and analyzed (Database Toolbox, MatLab 7.0.1, Natick, MA, USA). Descriptive and statistical analyses were made by matrix laboratory tools package (Statistics Toolbox, MatLab 7.0.1). The normality of data was not confirmed by the Shapiro—Wilk test. Scheffe's multiple comparisons test was used for paired comparisons between static load groups. The effects on survival of the three configurations were evaluated with a non-parametric two-way repeated measures test (Friedman). The related p-values were registered. All measurements in text and Tables are given as means ± standard deviation. The methodology was reviewed by an independent statistician who set the level of significance at 0.01.

Results

Data regarding the ultimate failure load and the bending moment for the three configurations are shown in Table 1 and Fig. 2. The IL_C (ferrulized neck and cement-retained crown) showed higher but non-significant UFL (445.7 ± 23.6 N) than those of the two remaining configurations i.e. AL (without ferrulized neck, 421.6 ± 12.5 N) and IL_S (ferrulized neck and screw-retained crown, 362.8 ± 23.8 N). No fracture of the implant itself was found among the tested specimens; however in case of load displacement exceeding 4 mm, all the implant bodies appeared seriously deformed.

Data regarding the number of cycles to failure are shown in Fig. 3. Each Wöhler curve is a representation of the expected number of cycles without failure under loading sequences with decreasing load levels.

Similarly to the results of the static loading test, IL_C group survived 5 millions of cycles under load force of 245 N (55% of the UFL) which was higher than those reported for both the IL_S (55% of the UFL: 200 N) and AL groups (45% of the UFL: 190 N). Moreover, the curve of group IL_S appeared to be significantly different from those of the other two groups (IL_C group with FRIEDMAN, Chi-sq = 7.2; df = 1; P = 0.0073; and AL group with FRIEDMAN, Chi-sq = 9.85; df = 1; P = 0.0017). Fatigue-life of the group IL_S was one-half order of magnitude higher than those of the groups

IL_C and AL. Examples of failure mode of the specimens are shown in Fig. 4. Regarding the failure mode registered during cyclic loading, all the screws fractured in the thread region except for two specimens of the group AL (1 fracture of the abutment screw and 1 permanent deformation of the implant which survived to the end of the load cycles).

Discussion

The presence of significant differences between the single implant-supported screw-retained crown with ferrulized neck and other systems (with or without ferrulized neck) rejected the null hypothesis. Certainly, the strength of the implant systems investigated during cyclic loading depended on several factors: the abutment collar height affected torque loss of screw-retained devices;[14] the diameter of the abutment and the type of crown retention (screw or cement retention) could affect the frequency of failure.[15,16] Ferrule in (endodontically treated) tooth preparation design, which consisted of a shoulder preparation with parallel coronal dentin walls, could lead to more favorable fracture patterns. Circumferential ferrule provided a level of structural reinforcement to resist the occlusal forces acting on a natural tooth.[17] Moreover, in silico studies suggested that endodontically treated teeth were often fragile without ferrule effect.[18,19]

Even if the effect of fatigue on ferrulized implants are not well-known or disclosed finite element analysis showed that the position of the finishing line did not affect the torque loss. The stress in the screw appeared to be in the group implant-level (20.81 MPa) lower than the other (22.747 MPa).[6] However, capability for eliminating the problem of screw loosening or fracture could be a factor regarding behavior of the implant—abutment interface. The three configurations used the same implant system (unique manufacturer) and the load-bearing capacity ranged from 336 to 470 N. The values were in line with those reported on the static fracture resistance when implant diameter, laboratory environment, the skill of technician had been taken into account. Implant diameter had a high effect on the static loading results: the maximum load of the mini-implant before fracture (2.3 mm with UFL of 131.35 ± 12.99 N) was significantly lower, compared with that of standard diameter implants (4.0 mm or higher with UFL of 565.64 ± 185.46 N).[20] About static loading test, ferrulized cement-retained configuration (IL_C) seemed to have a lower risk of fracture than the screw-retained ones (with or without ferrulized neck). This was partially verified by the fact that a cement-retained prosthesis could significantly produce less peri-implant strain when compared to the screw-retained one.[3]

The dynamic endurance of the ferrulized screw-retained configuration appeared to be better than those of the abutment-level and the ferrulized/cement-retained group. Ferrulized screw-retained configuration could be subjected, at least, to some load cycles equal to five times the other ones. A possible explanation could be that the misfit of the cement-retained implant single crown was greater than screw-retained one; moreover the misfits were reduced by cyclic loading.[16] Again, the ferrule effect could

confer a further benefit: to cover the gap between the abutment and the implant and so to reduce the micro-movements.[16]

Limitations and strengths of the present study were mainly related to the sample size and test setting. Fatigue tests on commercially pure titanium dental implants need to have a single mandated standard (UNI EN ISO 14801:2016). The standard recommended a minimum number of specimens (14) for each configuration.

Even if the sample size seems to be inadequate, an *in vitro* design experiment minimizes the variability of the results of the fatigue tests. On the contrary, biologic confounding factors related to the bone-implant interface (bone deformation or fracture, and loss of mechanical stability) tend to dwarf the true effect of static and cyclic loading. An *in vivo* experimental design offers higher clinical significance, but dental implants in living organisms cannot undergo fatigue tests. As said, forces acting
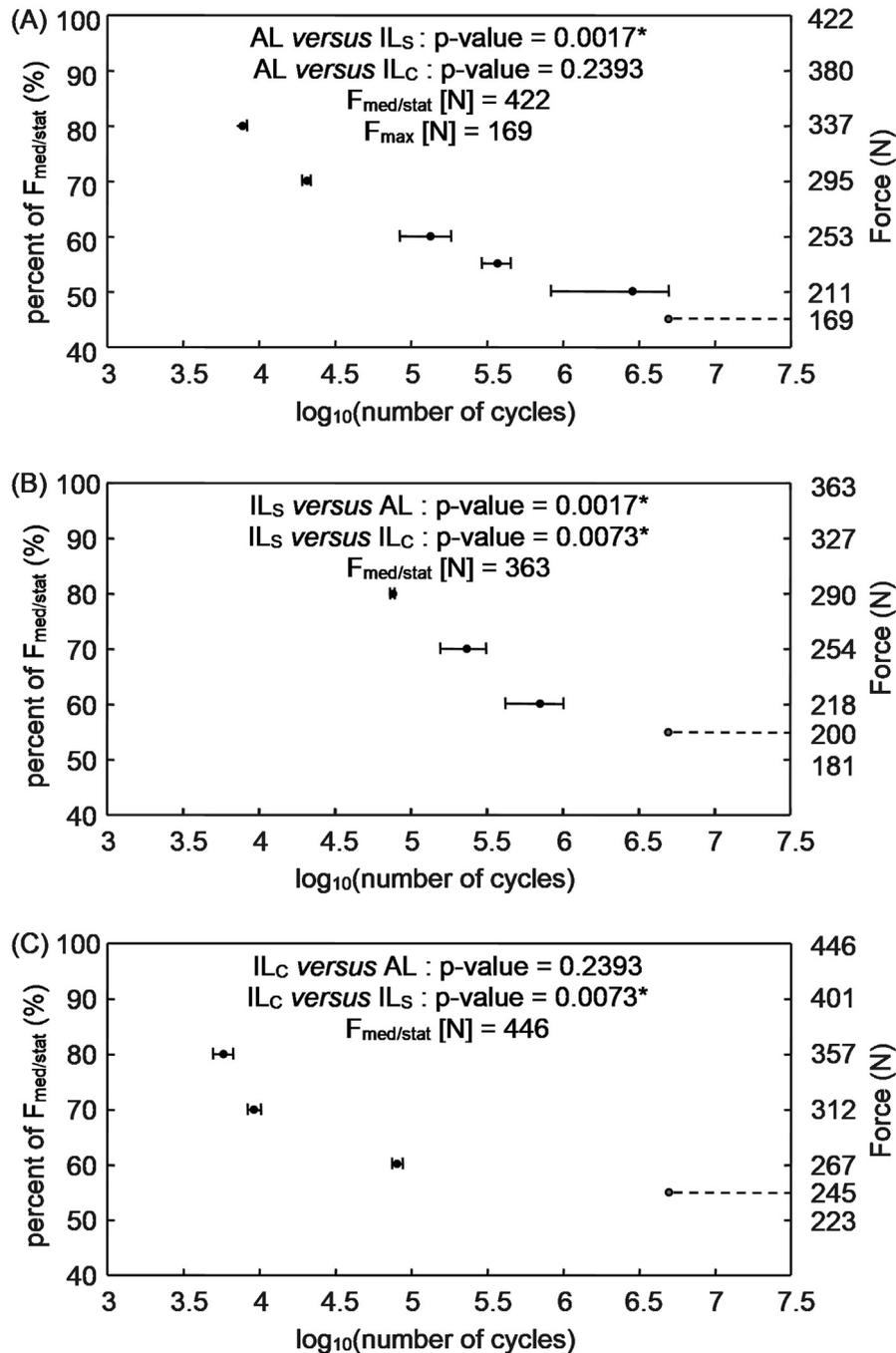
Figure 3   Results of cyclic load test. The significant pair-wise difference between 2 groups was marked by asterisk (*). The red point was the maximum value of the force for which the prosthetic system guarantees 5 millions of cycles. (A) AL: Abutment Level without ferrulized neck; (B) IL_S: Implant Level with ferrulized neck and screw-retained crown; (C) IL_C: Implant Level with ferrulized neck and cement-retained crown.

Figure 4 Failure modes in a static load test: (A) AL: Abutment Level without ferrulized neck; (B) IL$_S$: Implant Level with ferrulized neck and screw-retained crown; (C) IL$_C$: Implant Level with ferrulized neck and cement-retained crown.

on dental implants, during the phase of occlusal contact (chewing, swallowing and biting), or on the working side, during the lateral movements of the jaw, could have a very significant effect on the whole response of the dental implant-retained crowns. On the contrary, the fatigue test equipment used for the present study is adjusted to ensure that the location, direction, and magnitude of the applied force are carefully monitored and kept constant. This can ensure that the method delivers reliable research results with a reasonably small uncertainty or error in terms of bias and variance despite the wide range of components.

Future researches may need to improve the current understanding of behavior of dental implants supporting prosthesis restorations as close as possible to the real clinical situation. So qualified technicians may set up the machine for fatigue testing so as to mimic occlusal and lateral force too. The consequence is that there is no generalization from nonclinical to clinical phase. At any rate in the present experimental conditions, it seems certain that the ferrulized implant produces increased resistance to failure. It is, therefore, considered that other studies are required to confirm present results.

The limitations of the study might be the small number of specimens in each individual group which could affect the significance. However, a power analysis on data from Gil and co-workers about significant effects of different external hexagon heights on the fatigue life of titanium dental implants suggested that size required by the UNI EN ISO 14801:2016 standard were more than enough for a significant analysis.[13] In conclusion, it was observed that a ferrulized dental implant with cement-retained crown provides the highest resistance to static fracture. On the other hand, a ferrulized dental implant with screw-retained crown increases dynamic endurance. According to the standard UNI EN ISO 14801:2016, the tests do not match the clinical practice. The results depend on the technologies used. With the same implant system and test configuration, different machines (i.e. hydraulic versus electric), software and operators could provide different data.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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