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Cementable implant crowns composed of cast superstructure frameworks luted to electroformed primary copings: an *in vitro* retention study

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Abstract

Objective: The aim of this *in vitro* study was to investigate, on ITI solid abutments, the retention values of single crowns fabricated using an alternative prosthetic solution: secondary cast superstructure luted to an electroformed primary coping.
Materials and methods: Fifty standard 4.1 mm ITI implants and 5.5 mm high ITI machined abutments were assembled and mounted in acrylic resin. Implant/abutment assemblies were randomly divided into two groups. In the test group, primary galvanic caps were directly fabricated on implant abutments (A.G.C. Micro machine), and a secondary cast noble alloy superstructure was luted on each primary galvanic cap with a resin cement (Nimetic Cem). In the control group, prefabricated burn-out caps were used for casting the metal frameworks. Test and control crowns were cemented using a resin cement (Panavia 21). After storage at 37° for 24 h, the specimens were subjected to a pull-out test using an Instron universal testing machine. The load required to dislodge each sample and the respective mode of failure were recorded. Means and standard deviations of loads at failure were analyzed using ANOVA. Statistical significance was set at $P \leq 0.05$.
Results: The retention values ($\pm$ SD) of loads at failure were 67.26 ($\pm$ 16.61) for the test group and 44.03 ($\pm$ 9.45) for the control group. In the test group no separation occurred between the electroformed (galvanic) primary cap and the secondary superstructure.
Conclusions: The results showed that this prosthetic solution is superior on retentive performance than the conventional cast framework. An added clinical advantage of this novel method is its potential to provide a totally passive fit.

Further *in vitro* and *in vivo* studies involving multiple-unit restorations are needed in order to more generally validate this prosthetic concept.

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An important objective in the implant prosthodontic procedure is to achieve passive fit and marginal precision of the framework (Taylor et al. 2000; Brägger et al. 2001).

The difficulty of routinely and consistently achieving a passive and precise fit between an implant and a lost-wax framework is well documented in the dental literature (Jemt 1995, 1996; Jemt & Book 1996; Wee et al. 1998; Jemt et al. 1999; Watanabe et al. 2000; Ortorp et al. 2003; Takahashi & Gunne 2003; Yoko et al. 2003; Karl et al. 2004).

Potentially detrimental tensile, bending or compressive forces are introduced into an implant-supported rehabilitation through misfitting and consequential lack of passive fit (Jemt 1991; Clelland et al. 1995; Smedberg et al. 1996; Pietrabissa et al. 2000; Watanabe et al. 2000; Kunavisarut et al. 2002; Karl et al. 2004).

The biological and mechanical problems possibly correlated to prosthesis misfit have been questioned and it was suggested that the misfit may be more important in mechanical failure than in biological complications (Adell et al. 1981; Jemt 1991; Kohavi 1993; Kallus & Bessing 1994; Carr et al. 1996; Jemt & Book 1996; Smedberg et al. 1996; Jemt & Lekholm 1998; Jemt et al. 2000).

To minimize prosthetic complications, it is recommended to follow an accurate and meticulous implant prosthodontic protocol to optimize metal framework adaptation (Taylor 1998; Wee et al. 1999; Taylor et al. 2000; Brägger et al. 2001).

The conventional lost-wax technique, generally used to create prosthetic superstructures on implant abutment, often results in warpage and lack of passivity (Jemt 1995, 1996; Jemt & Book 1996; Riedy et al. 1997; Jemt et al. 1999; Watanabe et al. 2000; Ortorp et al. 2003; Takahashi & Gunne 2003; Yoko et al. 2003; Karl et al. 2004).

Moreover, to obtain the passivity and marginal precision, the one-piece multi-unit metal framework has to be frequently sectioned and conventionally soldered (Sutherland & Hallam 1990; Thoupos et al. 1995; Zervas et al. 1999; Watanabe et al. 2000; Hatano et al. 2003).

Alternatively, very effective 'high-tech' combined approaches have been proposed: the spark erosion technique (Van Roekel 1992a, 1992b; Rubeling 1999; Renner 2000; Contreras et al. 2002), laser welding (Sjogren et al. 1988; Riedy et al. 1997; Iglesia & Moreno 2001; Jemt et al. 2003) and computer numeric controlled (CNC) milling of titanium frameworks (Andersson et al. 1989; Jemt et al. 1999; Ortorp & Jemt 2002; Ortorp et al. 2003).

In recent years, a simple treatment modality has been developed: using intraoral luting of a framework to primary crowns. This allows to create, in a clinical setting, a precise and passive framework fit (Aparicio 1994, 1995; Weigl 2000).

The marginal fit is insured by the primary caps (Weigl suggested an electroformed gold cap directly fabricated on the implant abutments) and the secondary structure can easily be fabricated in one single piece. In order to obtain the prosthetic passivity, the secondary structure is subsequently intraorally luted to the primary caps.

The 'Weigl technique' is also cost effective and less operator dependent (Weigl 2000).

The purpose of this study was to test the retention and mode of failure, on ITI solid abutments, of single crowns fabricated using a secondary cast framework luted to a primary galvanic cap vs. the retention of single crowns fabricated with a conventionally cast framework.

More particularly, the aim of the study was to test the null hypothesis that there is no difference in retention between traditional cementable implant crowns and implant crowns based on electroformed primary coping.

Material and methods

Fifty 10 mm-long and 4.1 mm-wide ITI solid screw implants (Institut Straumann AG, Waldenburg, Switzerland) were mounted, using a dental surveyor, in a self-polymerizing acrylic block (Repair Material, Dentsply International, Milford, DE, USA). Standard 5.5 mm-long, 8° tapered machined abutments (Institut Straumann AG) were placed on each implant and torqued to 35 N cm. The implant/abutment assemblies were arbitrarily divided in two groups. In the test group (Fig. 1), 25 primary galvanic crowns were directly and individually fabricated on the implant abutments using the A.G.C. Micro machine (Goldbad, Wieland, Pforzheim, Germany). In order to limit the electroforming deposition just to the abutment and implant shoulder, all other metallic surfaces were isolated with resin. Deposition of metallic ions was carried out for 720 min. The thickness of the resulting galvanic coping was approximately 0.2 mm. A secondary superstructure was fabricated on each primary galvanic cap by waxing directly to the galvanic cap. The position of the margin of this secondary structure was located approximately 0.4 mm coronally to the finish line of the galvanic cap (Figs 2 and 3). A thin (100–150 μm) layer of spacer (Tru – Fit Thinner, Geo.Taub Products and Fusion Co. Inc., Jersey City, NJ, USA) was applied over the primary galvanic cap before the superstructure wax-up. A wax loop was added to the occlusal portion of the waxed structure to be used later for retentive testing. The wax patterns were sprued, invested in a phosphate-bound envelope (Hi-Temp, Whip Mix Co., Louisville, KY, USA) with 100% special liquid and then cast with noble alloy (Protocol, Williams-Ivoclar, Amherst, NY, USA) by one investigator. After removal with hydrofluoric acid in an ultrasonic cleaner, the internal aspect of the casting was inspected under a stereomicroscope (Model BM 38834, Meiji Techno, Tokyo, Japan) at × 10, and surface irregularities were removed with a small round carbide bur. The external and internal surface of the galvanic cap and the internal side of the secondary superstructure were sandblasted with 5 atm air abrasion (50 μm aluminium oxide particle size for 30 s). All galvanic crown/secondary structure couples and their corresponding implant/abutment assembly were numbered. The secondary structure was cemented to the respective galvanic cap directly on the abutment using a resin cement (Nimetic Cem, Espe Dental AG, Seefeld, Germany) with a load of 5 kg maintained for 10 min over the crown according to ADA specification 96. Cement excess was removed with a scaler.

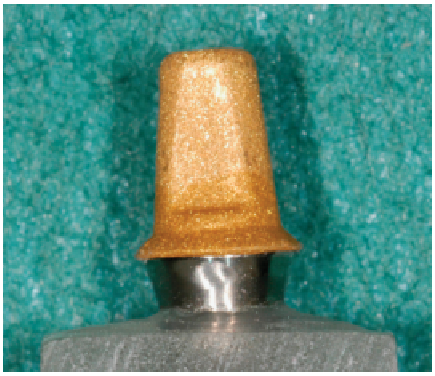

Fig. 1. Primary galvanic coping, directly fabricated on an implant–abutment complex.

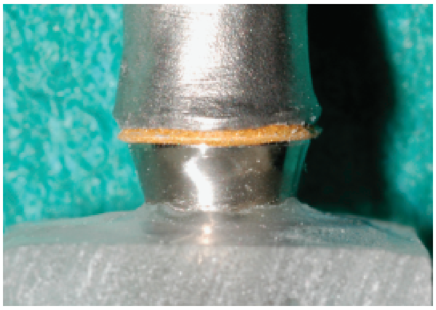

Fig. 2. The margin of the secondary structure is located above the finish line of the galvanic cap.

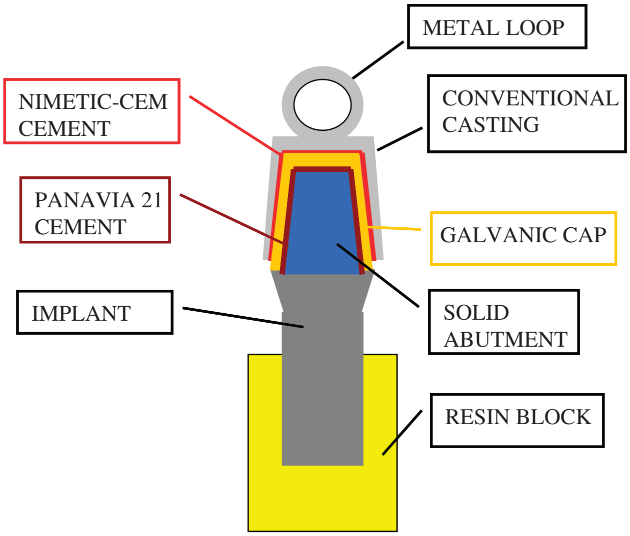

Fig. 3. Test group.

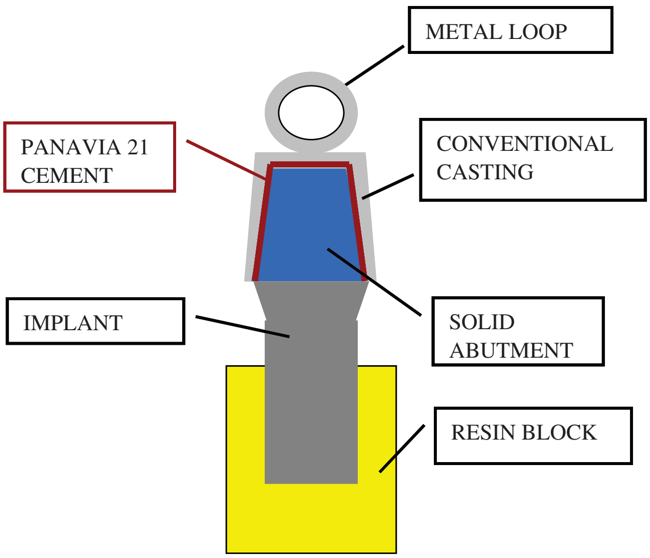

Fig. 4. Control group.

In the control group 25 cast crowns (Fig. 4) were made using prefabricated burn-out caps (Institut Straumann AG). A loop of wax was added to the occlusal surface of the caps to allow for the subsequent retention test. All plastic caps were invested, cast, disinvested and inspected using the same procedure and materials as described for the secondary structures in the test group. Each implant/abutment assembly and corresponding cast crown were numbered. All laboratory procedures were performed by one investigator.

All crowns (test and control) were cemented onto the respective implant/abutment assemblies using a resin cement (Panavia 21, Kuraray Medical Inc., Kurashiki, Okayama, Japan). During cementation, a load of 5 kg was maintained for 10 min over the crown according to ADA specification 96. Mixing and cementing procedures were carried out at room temperature by one investigator. Afterwards, the cemented implant–abutment–casting complexes were stored for 24 h at 37°C in a 100% humidity environment.

Specimens were then subjected to a pull-out test using an universal testing machine (Fig. 5) at a crosshead speed of 0.5 mm/min (Model 4204, Instron Engineering Corp., Canton, MA, USA). The load required to dislodge each coping was recorded, and the

Fig. 5. Sample placed in the Instron universal testing machine for the pull-out test.

***Table 1.* Mean values and standard deviations of loads required to de-cement copings**

Group	Mean (kgf)	Standard deviation
Control	44.03	± 9.45
Test	67.26	± 16.61

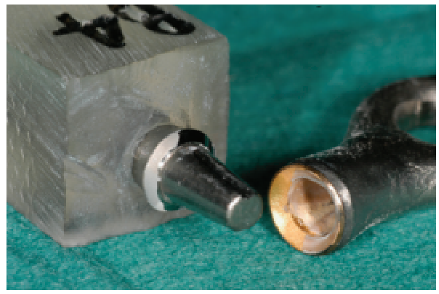

Fig. 6. Separation always occurred at the abutment–galvanic cap interface.

mean values for each group were calculated. Retention values were analyzed using the ANOVA test. Statistical significance was set at $P \leq 0.05$.

Results

Retention values are shown in Table 1. The test group showed a mean retention value higher (67.26 ± 16.61 kgf) than that of the control group (44.03 ± 9.45 kgf), and the difference was significantly different.

All samples in the test group showed a separation at the abutment–galvanic cap interface, and no cement failures have been observed at the galvanic cap–superstructure interface (Fig. 6).

Discussion

Long term success of implant therapy may require a dynamic equilibrium between biologic and mechanical factors.

Despite existing controversies over methods for evaluating implant framework fit (Kan et al. 1999), and also over the amount of misfit and consequential strain that can be tolerated without adverse effects (Klineberg and Murray 1985; Jemt & Book 1996), the biological and mechanical problems possibly correlated to fixed prosthesis misfit have been questioned (Adell et al. 1981; Jemt 1991; Kohavi 1993; Kallus & Bessing 1994; Carr et al. 1996; Jemt & Book 1996; Smedberg et al. 1996; Jemt & Lekholm 1998; Jemt et al. 2000).

In animal models (baboons, rabbits) and in human clinical studies, misfit does not seem to jeopardize osseointegration *per se* (Kallus & Bessing 1994; Carr et al. 1996; Jemt & Book 1996; Jemt et al. 2000).

Failure to achieve passivity and marginal precision, and subsequent stress on implant components (Smedberg et al. 1996; Kunavisarut et al. 2002; Karl et al. 2004), has been indicted as an etiologic factor in prosthetic complications such as mechanical fatigue fractures (Adell et al. 1981; Kohavi 1993), and screw loosening (Kallus & Bessing 1994). This often results in time consuming and cost repairs (Brägger 1999; Pjetursson et al. 2004). Consequently it has been suggested that a precise and passive fit between implant and metal framework may be necessary to ensure a satisfactory long-term clinical outcome (Kallus & Bessing 1994; Jemt & Book 1996; Wee et al. 1999; Taylor et al. 2000; Brägger et al. 2001).

The cause of an ill-fitting implant framework is multifactorial and may be determined by one or a combination of the following different factors: machining tolerance of implant components provided by the manufacturer (Ma et al. 1997), impression material (Wee 2000), implant impression technique (Assif et al. 1999; Vigolo et al. 2003; Naconecy et al. 2004), die material accuracy and the master cast technique (Wise 2001; Wee et al. 2002).

The conventional lost-wax techniques that are used to create implant-supported prosthetic superstructures may be inadequate in meeting the requirements of passive and precise fit (Jemt 1995, 1996; Jemt & Book 1996; Riedy et al. 1997; Jemt et al. 1999; Watanabe et al. 2000; Ortorp et al. 2003; Takahashi & Gunne 2003; Karl et al. 2004). Sectioning and subsequently traditional welding techniques are frequently employed to improve the cast accuracy and to reduce the stress, but a perfect marginal closure and a total passive fit cannot always be obtained (Jemt 1995; Clelland et al. 1996; Zervas et al. 1999; Watanabe et al. 2000).

Sectioning and traditional welding techniques are time consuming, and expensive, and they may reduce the mechanical performances of the prosthesis (Vallittu 1997; Watanabe et al. 1997). More recently, sophisticated and effective methods transferred from industrial technology to dentistry have been proposed to minimize misfit of the framework; they include laser-welding (Sjogren et al. 1988; Riedy et al. 1997; Iglesia & Moreno 2001; Jemt et al. 2003), spark erosion techniques (Van Roekel 1992a, 1992b; Rubeling 1999; Renner 2000; Contreras et al. 2002) and CNC milling of titanium frameworks (Andersson et al. 1989; Jemt et al. 1999; Ortorp & Jemt 2002). Some of these procedures can be combined and they are able to create more precise frameworks, without the utilization of the lost-wax method (Riedy et al. 1997; Ortorp et al. 2003; Takahashi & Gunne 2003). Most of these techniques require costly equipments and are often complex; not infrequently the final cost of the restorations is increased (Contreras et al. 2002).

A simple, cheap and effective method of making lost-wax framework prostheses with a passive and accurate circular fit has been proposed by some authors (Aparicio 1994, 1995; Watanabe et al. 2000; Weigl 2000; Karl et al. 2004). They suggest the fabrication of a secondary lost-waxed structure to be luted, with a resin composite cement, to individual primary copings, previously manufactured on each single abutment.

Inaccuracies that may occur during the clinical and laboratory procedures are presumed eliminated by the luting process of the secondary superstructure to the primary copings.

Such luted FPDs showed less stress, than conventional cast suprastructures (Watanabe et al. 2000; Karl et al. 2004).

The technique proposed by Weigl (2000) suggested the fabrication of primary copings directly on single abutments by an electroforming galvanic process.

The electroforming technology involves the electrolytic deposition of gold ions. The major advantage of the galvanic process is its simplicity, improved marginal precision, biocompatibility and resulting cost effectiveness (Vence 1997).

The location of the junction between the primary galvanic coping and the secondary structure is approximately 0.4 mm above the finish line of the galvanic cap. Thus, as indicated by Weigl, the secondary structure can easily be fabricated in one single piece considering that the final marginal accuracy of the entire structure is determined by the primary galvanic coping.

Weigl suggested 'a slight horizontal play' between the framework and the primary copings and, consequently, a lower precision can be accepted for the cast metal superstructure.

There are no *in vitro* or clinical studies in the literature to date that evaluate this innovative technique on ITI prosthetic components.

In this *in vitro* comparative study on ITI solid abutments, the crowns performed with the 'Weigl approach' showed highest retention values (pull-out test) compared with 'conventional' cast crowns. This may be a consequence of the surface roughness created by sandblasting the internal portion of the galvanic cap (Squier et al. 2001).

One of the most critical points of this approach is the mechanical stability between the primary galvanic crown and the secondary superstucture.

In our study all the separations in the test group occurred at the interface between galvanic caps and abutments and never between the electroformed primary cap and the secondary superstructure. This may be explained either by the retentive ability of the roughened external surface of the galvanic cap and/or the internal portion of the secondary superstructure (Squier et al. 2001), and/or by the use of a specific composite cement (Nimetic Cem), especially developed to lute telescopic or conical crowns to a cast framework.

The retention values showed by the control group are similar to the findings of Mansour et al. (2002) as expected by the conformity of the protocol.

Conclusions

A simple, cost-effective, non-operator-dependent method able to perform lost-wax frameworks which are precise and passive on implants is desirable in dental practice.

FPDs fabricated with separately cast superstructures luted to primary copings manufactured on implant abutments caused significantly lower stress than those developed using one piece cast or cast-split soldering (Watanabe et al. 2000; Karl et al. 2004).

Weigl 2000 stated that direct electroformed primary caps intraorally joined with a secondary lost-waxed superstructure can provide a passive and precise fit of an implant supported prosthesis.

The retention values associated with this prosthetic alternative approach on ITI solid abutments have not been reported in the literature.

Within the limitation of our *in vitro* study, the results suggest that, on single crowns, this prosthetic option is superior in the retentive performance compared with a conventional cast framework, and no separation occurred between the electroformed (galvanic) primary coping and the secondary superstructure.

Further *in vitro* and *in vivo* study are needed to validate this innovative prosthetic method on ITI planning in ordinary practice.

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要旨

目的：本インビトロ研究の目的は、ITI 充実型アバットメントにおいて、電鋳した一次コーピングに二次鋳造上部構造をセメント合着するという新規の補綴方法を用いて製作した単冠の維持力を測定することであった。

材料と方法：５０本の４．１ｍｍ径標準 ITI インプラントに５．５ｍｍ高の ITI 機械研磨アバットメントを装着し、アクリル・レジンにマウントした。インプラント／アバットメントの複合体を、無作為に以下の２群に振り分けた；試験群は、一次ガルバニック・キャップをインプラント・アバットメントに直接装着し（A.G.C Micro machine）、貴金属合金で鋳造した二次上部構造を各一次ガルバニック・キャップにレジン・セメントで合着した（Nimetic Cem）。対照群は、既製の焼却用キャップを用いて、メタルのフレームワークを製作した。試験群と対照群のクラウンは、レジン・セメント（Panavia 21）を用いて合着した。２４時間３７℃で保存した後、Instron universal 試験機を用いて標本の引き抜き試験を行った。各標本を脱離させるのに要した荷重と個々の破折（脱離）の様式を記録した。脱離時の平均荷重と標準偏差は、ANOVA を用いて分析した。統計学的有意差はｐ≦０．０５と設定した。

結果：脱離時荷重の維持力（±SD）は、試験群では６７．２６（±１６．６１）、対照群では４４．０３（±９．４５）であった。試験群では電鋳めっきした一次キャップと二次上部構造の間での分離は生じなかった。

結論：これらの結果は、同補綴方法は従来の鋳造フレームワークに比べ維持力が優れていることを示した。同新規の方法のもう一つの臨床的長所は、完全な受動適合性を付与できる点である。複数歯の修復治療の条件下でさらなるインビトロとインビボ研究を行い、同補綴治療のコンセプトを広く検証する必要がある。

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