Improving the Fit of Implant Prosthetics: An In Vitro Study

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Purpose: *Accurate and passive fit between a prosthesis and its supporting implants has been considered a prerequisite for successful long-term osseointegration. The objective of this in vitro study was to evaluate the strain development during tightening of a five-unit screw-retained superstructure constructed using five different methods.* **Materials and Methods:** *Five-unit screw-retained fixed partial prostheses (n = 25) were fabricated on three implants embedded in an epoxy resin block using five different methods: (1) cobalt-chromium (Co-Cr), plastic cylinders, one-piece cast; (2) Co-Cr, plastic cylinders, framework sectioned, preceramic laser-welding soldering; (3) gold-platinum (Au-Pt), gold cylinders, one-piece cast; (4) Au-Pt, gold cylinders, framework sectioned, preceramic laser-welding soldering; (5) Co-Cr, one-piece cast, and cementation to "passive abutments" (Southern Implants) after final finishing and polishing. Strain gauges (SG) were attached to the fixed partial prosthesis (FPP) and to the resin block to measure the stress created during screw tightening.* **Results:** *The combination of Co-Cr alloy and plastic cylinders in a one-piece cast showed such an inadequate fit among the fabricated methods that this group was excluded from the remainder of the experiment. Specimens of Au-Pt cast on gold cylinders in one piece showed higher strain development than the other groups used in this study, with strains ranging from 223.1 to 2,198.1 μm/m. Sectioning and soldering significantly improved the overall fit. FPPs of Co-Cr in a one-piece cast cemented to "passive abutments" produced the best level of fit, with the least strain development in the prosthesis and the resin block (59 to 204.6 μm/m).* **Conclusion:** *Absolute fit of superstructures on implants is not possible using conventional laboratory procedures. Cementing FPPs onto prefabricated cylinders directly onto the implants significantly reduces strain development compared to the other fabrication methods.* INT J ORAL MAXILLOFAC IMPLANTS 2013;28:XXX–XXX

Key words: *implant prosthesis, laser welding, passive abutments, passive fit, soldering, strain gauges*

Implant-supported prostheses can serve as a third dentition after permanent teeth have been lost. However, such prostheses require that certain protocols are followed during implant surgery and restorative treatment.[1–5] An important factor in the success of implant-supported restorations is the fit between a suprastructure and the implant platform or implant abutment. A poor fit may induce tensile, compressive, and bending forces when the prosthesis is connected, which may result in mechanical complications such as loosening or breakage of the prosthetic screws, distortion or breakage of the restoration, and even implant fracture.[6–9] Those stresses may remain even after several years in function. Moreover, the existing microgap between an implant and an abutment or superstructure allows accumulation of microorganisms, which may introduce biologic problems in the surrounding tissues. Therefore, an accurate fit of prosthetic components to implants has been considered a prerequisite for successful long-term osseointegration.[6–15]

However, the literature is inconsistent regarding the level of fit that is considered acceptable. Brånemark[10] was the first to define "passive fit," thereby also addressing the issue of strain development. He reported that a microgap of 10 μm is acceptable, which was later confirmed by others.[16] Klineberg and Murray[17] reported that a gap larger than 30 μm at more than 10% of the circumference of the abutment-implant interface is unacceptable. However, according to Jemt and Book[11] and Jemt,[18] a gap up to 150 μm does not cause

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any long-term clinical complications and is therefore clinically acceptable. This has been confirmed by animal and clinical studies, which indicated that nonpassive prostheses do not necessarily experience biologic complications.[16,19–23] It is possible that a biologic tolerance exists between the implant and the surrounding bone, which permits a certain degree of misfit. However, because the acceptable degree of marginal fit and the tolerance variation between individuals are yet to be established, clinicians should try to achieve an optimal fit.[21,24,25]

Numerous methods to achieve a passive fit have been reported. With cement-retained restorations, the intervening cement fills the gap and may therefore compensate for possible misfit.[26–30] Recent research, however, shows that there is no scientific evidence that cement-retained restorations have a better fit than screw-retained prostheses.[31–34] Additionally, cementation involves problems with retrievability, dissolution of the cement, increased microgaps, and the removal of cement residues.[26,28,35–37]

The spark erosion technique (SAE Dental) uses high voltages while the fitting surface of the restoration is gradually melted until a "good" fit is achieved. However, a highly complicated and expensive armamentarium is needed. Moreover, extra casts with specific abutment replicas that act as electrodes are necessary, increasing fabrication time and cost. Spark erosion improves fit but changes the elemental composition of the alloy used via carbon and copper uptake from the dielectric fluid and electrodes, respectively.[38–41] In addition, a porous surface with a rough texture is created, in contrast to conventionally finished surfaces.[42] Copper is a metallic element with high dissolution in biologic environments that affects the biocompatibility of alloys.[43,44]

Astra Tech (Astra Tech Dental) has developed a method called "Cresco Ti precision," in which the framework is soldered on prefabricated abutments by laser welding. The literature confirms that the "Cresco Ti" method has the potential to reduce marginal gaps between implants and superstructures.[45–50] Its major disadvantage, however, is that it requires extra armamentarium and devices, which increases the overall treatment cost.

With the advancement of computer-aided design/computer-assisted manufacture (CAD/CAM) technology, various techniques have been developed to fabricate improved, consistent, and predictable restorations and to manage framework materials such as titanium, precious or base metal alloys, and zirconia ceramics. Recent research has shown that the fit is at least as passive as that of conventional implant frameworks, although the high cost associated with CAD/CAM systems and laboratory fabrication is a disadvantage.[51–54]

Because there are no clinical techniques to effectively measure passive fit, and procedures in framework fabrication are unable to provide a fixed, implant-supported restoration with an absolutely passive fit, research in this field continues.[21,28,52,55] Therefore, a new "passive abutment" (Southern Implants) was created to improve the fit of screw-retained, implant-supported frameworks. The purpose of the present study was to compare the strain development of five-unit screw-retained fixed partial prostheses supported by three implants when cast in one piece, sectioned and soldered, or attached to passive abutments using two different alloys.

MATERIALS AND METHODS

Framework Fabrication

Three tapered implants, 4 mm in diameter and 15 mm in length (IBT15, Southern Implants), were embedded parallel to each other with the aid of a parallelometer in the center of a curved epoxy resin block (R&G Faserverbundwerkstoffe), which exhibited mechanical properties similar to those of trabecular bone (flexural modulus of 2.8 GPa).56 Implants were positioned 1 mm supracrestally to allow clear observation of the microgap. The three implants were marked from mesial to distal as 1, 2, and 3 (Fig 1). **[AU: Since the groups are designated A to E, it might have been confusing to also have the implants A, B, C, so the implants have instead been numbered 1, 2, 3. The relevant strain gauges were renamed accordingly.]** The resin block was left for 3 months to ensure dimensional stability without any further polymerization shrinkage. Furthermore, to ensure that the resin block had a constant dimension, the triangle's area (ABC, standard corners of the external hexagon of the implants) was measured 10 times randomly during the course of the experiment using an optical traveling microscope (± 0.001 mm, STM Measuring Microscope, Olympus Optical Co).

Thirty plastic cylinders, 30 gold cylinders, and 15 "passive abutments" were attached to the implants using laboratory screws and cut to a height of 7.5 mm (± 0.1 mm) using a fine-grit diamond disk on a parallelometer's handpiece at low speeds. The resin block was scanned using a CAD/CAM scanner (Zeno, Wieland Dental + Technik), and a five-unit screw-retained implant prosthesis, representing three premolars (abutments) and two molars (pontics), was designed and milled from burnout plastic with the CAM milling unit. Thus, 25 identical plastic patterns (0.99 ± 0.001 g, coefficient of variation = 1%) were manufactured, thereby eliminating factors such as design, bulk, total profile, and connectors that may influence the distortion of the framework. The patterns were designed in a tele-

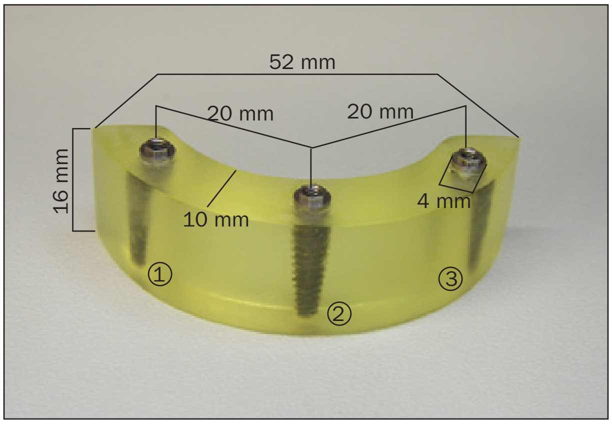

Fig 1 Resin block with the three implants embedded (± 0.1 mm).

Fig 2 Casting imperfections have created a gap that is visible macroscopically (groups A and B).

Table 1 Methods and Materials Used for Framework Construction

Group	Description of framework
Group A	Co-Cr,* plastic cylinders, cast as one-piece framework
Group B	Co-Cr,* plastic cylinders, framework sectioned, laser-welding soldering
Group C	Au-Pt,** gold cylinders, cast as one-piece framework
Group D	Au-Pt,** gold cylinders, framework sectioned, laser-welding soldering
Group E	Co-Cr,* "passive abutments," cast as one-piece framework

*Co 60%, Cr 26%, tantalum 8.5%, molybdenum 4.5%, aluminum 3%, manganese 1%, hafnium 1% (Rex CC, Pentron Laboratory Technologies, LLC); **Au 83.5%, Pt 8%, lead 4.9%, **[AU: Is Pb/lead correct? Pd (palladium) was not meant instead? Please confirm.]** indium 2.5%, iridium 0.1% (Mentor G2, Dental Edelmetalle).

scoping manner, allowing freedom while seated on the cylinders and ensuring a passive fit before casting. The patterns were secured on the cylinders with pattern resin at the shoulder and at the occlusal surface.

Twenty-five frameworks were waxed and secured on a rubber crucible former, matching a casting ring exactly in the same position, with the aid of a silicone index. Investing (Picovest Universal, Picodent Dental-Produktions und Vertriebs) and casting (Hephaestus 210) were performed according to the instructions of the manufacturers. The screw-access holes of the fixed partial prostheses (FPPs) were milled with hand reamers to eliminate internal casting inaccuracies and to ensure free seating of the screws. This resulted in 10 gold-platinum (Au-Pt) and 15 cobalt-chromium (Co-Cr) frameworks. All procedures were performed by the same certified dental technician.

The 25 frameworks were allocated to five different groups according to construction method and material used (Table 1). The first observation was that the fitting surfaces of the cylinders of the one-piece Co-Cr frameworks (A and B) were completely unacceptable, even at a macroscopic level (Fig 2). The cylinders were therefore treated with a lapping tool consisting of a plastic stabilizer and a mandrel (Southern Implants), along with diamond abrasive paste in a rotary device at a speed of 1,000 rpm for three 1-minute cycles.

In the sectioned/soldering method, the one-piece cast frameworks were cut into three sections using 250-μm-thick diamond separating disks (Shofu) adjacent to the central implant (B). The three sectioned pieces were secured with long laboratory screws (10 Ncm) to the implants and soldered using laser welding (Laserstar T Plus, Bego). Appropriate solders were used for both the Co-Cr alloy (Co 63.5%, Cr 29%, molybdenum 5.5%, silicon 1%, manganese 1%; Wiroweld, Bego) and the Au-Pt alloy (Au 88%, Pt 9%, indium 1.5%; LWT88, The Argen Corporation).

All frameworks were layered with ceramic material (Avante, Pentron Laboratory Technologies). The total bulk of the ceramic veneering was copied from the first FPP to the others, with the aid of silicone indexes. Metal shoulders were polished using rubber wheels with implant analogs in place.

In group E, "passive abutment" titanium rings (Fig 3) were bonded to the frameworks using dual-curing cement after ceramic layering and polishing (ZL-Durobond, ZL-Microdent Attachments). The bonding surfaces of the titanium ring and the framework were abraded via 50-μm aluminum oxide sandblasting, and

Fig 3 "Passive abutment," titanium ring, and plastic cylinder for waxing.

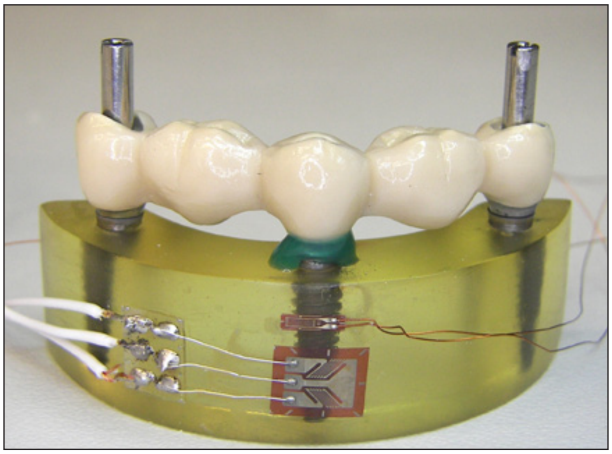

Fig 4 An FPP in place during cementation of the titanium rings one at a time (implant 2). SGs on the external surface of the epoxy resin block are also shown.

Fig 5 The SGs are attached to the tissue surface of the FPP connectors.

cement was applied to each surface. The titanium rings were screwed to the implants by hand tightening laboratory screws, and then the structures were cemented to the titanium rings. Each time cement was applied, an air-blocking gel was used to prevent oxygen inhibition. The cement was bench cured according to the setting time indicated by the manufacturer (Fig 4). After setting, any excess cement was removed using rubber wheels at low speed.

Strain Measurement

Strain gauges (SGs) were used to measure stress levels (Kyowa Electronic Instruments). Four uniaxial SGs, each 2 mm in length (120 Ω, type KFG-2N-120-C1-11N15C2), were attached to the tissue surface of the FPP connectors, producing four quarter-bridge circuits (Fig 5). The four SGs were coded as SG-1, SG-1/2, SG-2/3, and SG-3, according to their proximity to implants 1, 2, and 3. Two uniaxial SGs, each 5 mm in length (120 Ω, type KFG-5-120-C1-11N15C2), were attached to the external and internal surfaces, perpendicular to the midline and parallel to the long axis of the resin block, to produce two active half-bridge circuits (SG-bending). This sensor measured the deflection of the long axis of the resin block throughout the experiment. One final biaxial SG (0 deg/90 deg and 120 Ω, type KFG-2-120-D31-11) for torque measurement was attached to the external surface across the midline of the block (SG-torsion) (Fig 4). The three wires of the torque gauge were connected to produce two active half-bridge circuits.

The FPPs were secured by hand tightening the gold screws (GSS2 and GSS3, Southern Implants) a half-turn short of the initial termination. All of the SGs were then set to zero. The final tightening at 32 Ncm was performed by one operator using a digital torque meter with an accuracy of 0.1 Ncm (model BTGE200CN, Tohnichi Manufacturing). The screws were tightened in the following sequence: 2, 3, 1. New fixation screws were used for each FPP. The strains, in microstrain units (μm/m), were recorded using an electronic six-channel data acquisition system (Wheatstone bridge) and specific acquisition and control software (Advanced GeniDAQ, American Advantech Corporation) and saved in an Excel spreadsheet (Microsoft Corp) for further analysis. For each FPP, three readings were recorded, and a mean value was calculated. Positive and negative values were indicative of the direction of distortion (compression or tension). The absolute values of the final strain levels for each SG were used for further quantitative analysis.

Statistics

Initial examination of the data for the normality of distribution using a Q-Q plot showed that the data

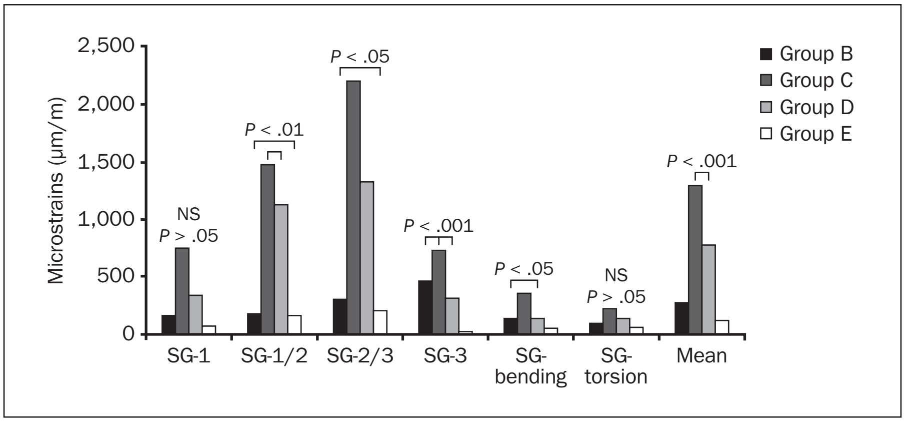

Fig 6 Mean strain readings. Brackets indicate homogenous subsets (*P* > .05).

were positively skewed. Logarithms produced values that were close to a normal distribution. These logarithmically transformed data were used in the following analyses: one-way multivariate analysis of variance (MANOVA) between groups and one-way analysis of variance (ANOVA) for each SG measurement, followed by the Student-Newman-Keuls test (at *P* = .05) for post hoc multiple comparisons between groups. The Levene test was applied to test the homogeneity of variances in one-way ANOVA. A binomial test was also performed to analyze the distribution of the positive and negative values. The analyses were performed with the SPSS for Windows statistical package (SPSS 16, SPSS Inc).

RESULTS

Group A was excluded from the evaluations of fit because all of the frameworks in the group failed to fit on the implants unless finger pressure was applied. One-way MANOVA between the groups with dependent variables and the logs of the SG measurements revealed that the differences were statistically significant (*P* = .008 using Wilks lambda, *P* < .001 using Roy's largest root). The results indicated by MANOVA justified the further use of a one-way ANOVA for each dependent variable to ensure that false-positive results were excluded.

A binomial test revealed that the positive and negative values—and hence, the direction of distortion (tension or compression)—were equally distributed (*P* > .05). The results of the statistical analyses and the comparison between groups for each SG are presented graphically in Fig 6. The mean values of strains (in μm/m) for groups B, C, D, and E are presented in Table 2.

There were no significant differences between the different groups for SG-1 (*P* > .05). SG-1/2 showed significant differences (*P* < .01), with B, E < C, D. SG-2/3 showed also significant differences between groups (*P* < .05), with B, E < C, D and C > D. Measurements of SG-3 were highly significantly different (*P* < .001), with E < B, C, D.

SG-bending values were significantly different between groups (*P* < .05), with E < C. No significant differences were found between SG-torsion measurements for the different groups.

The mean SG values for the different frameworks were significantly different (*P* < .001), with B, E < C, D and E < B. Overall, although this was not statistically significant in all cases, group E showed the lowest strain measurements for all of the SGs (Fig 6, Table 2).

DISCUSSION

The fit of a framework is determined by the impression method and material, the dimensional stability of the master cast, and the fabrication process of the prosthesis. The latter is especially important when fabricating a conventional framework by means of the lost-wax method.[36,57–60] Wax has the highest coefficient of thermal expansion of all dental materials, and its dimensional stability is subject to air temperature changes.[28,61,62] However, in combination with pattern resin for the fabrication of a framework pattern, it may produce good results under certain conditions. During investing and casting, distortions occur, which are difficult to eliminate.[63–65] These expansions and shrinkages are affected by framework design (eg, bulk and total profile, span length and curve); the technique and apparatus used during casting; the type of alloy; and the

Table 2 Mean Strain Readings (in µm/m ± Standard Deviations) (n = 5)

Group	SG-1	SG-1/2	SG-2/3	SG-3	SG-bending
Group B	162 ± 76.3	175.8 ± 152.6	300.3 ± 186.5	459.8 ± 558.7	133.8 ± 93.8
Group C	745 ± 1,046.3	1,472 ± 1,312.3	2,198.1 ± 1,723.5	729.3 ± 621.9	352.9 ± 313.7
Group D	338.2 ± 298.1	1,123.8 ± 616.7	1,326.4 ± 1,020.2	312 ± 187.8	138.7 ± 91.1
Group E	74.1 ± 68.6	166.5 ± 87.5	204.6 ± 150.3	22.1 ± 26.1	51.3 ± 43.9

*~115.74 MPa; **~15.08 MPa.

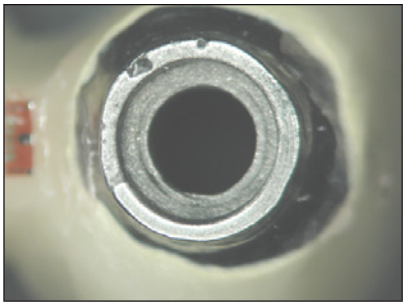

Fig 7 Voids and pores remain after treatment of the fitting surface (group B).

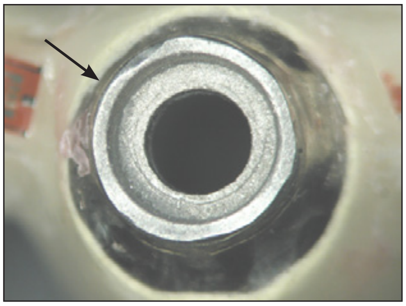

Fig 8 A gold cylinder with a "platform switch" effect caused by finishing and polishing (group C).

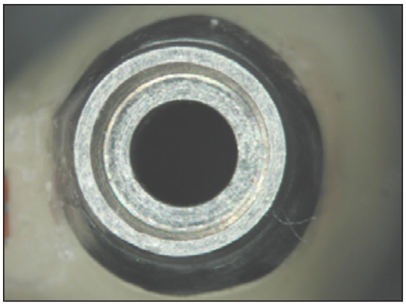

Fig 9 Fitting surface of a "passive abutment" (group E).

experience of the dental technician. If the appropriate protocol is followed, the distortion caused by the aforementioned factors is probably small and clinically insignificant. However, a combination of distortions in different dimensions can result in significant misfit at the abutment-implant interface.[21,28,59,66–69] The resin block and the experimental FPP in this study were designed in such a manner (ie, number of implants, length, curve, bulk, profile, and connectors) that deformation of the block or the FPP would be maximized even by a small misfit. It is well known that deformation of the bone during the connection of implant prostheses depends upon the fit and flexibility of the prosthesis and the tightening force. A rigid cast will induce more stress with the same degree of misfit than will a flexible cast, even without loading.[18,70] Moreover, an intermediate abutment enhances the misfit.[71–73]

On the other hand, a flexible framework can provoke porcelain fractures. The increased number of veneer complications in implant-supported restorations compared to prostheses supported by natural teeth may be partially attributed to the induced stresses and deformation during framework fabrication.[74]

The combination of plastic cylinders and Co-Cr alloys in a one-piece cast of a multiple-unit FPP resulted in substantial misfit. This confirms earlier reports of gaps of approximately 100 µm occurring upon casting multiple-unit FPPs, making passive fit impossible.[59,69,75–78] Pretreatment of the fitting surface improved the quality of the fit only partially and did not eliminate all casting imperfections (Fig 7).

In contrast, the combination of premachined gold cylinders and Au-Pt alloy performed better, with the one-piece castings from group C fitting at least at a macroscopic level. This is probably a result of the better dimensional stability of high noble alloys compared to that of base metal alloys and the superior performance of gold cylinders.[57,67,75,79–82] This is in agreement with previous reports on one-piece cast frameworks.[59,69,75–78] Of course, the gold cylinders must be treated with care during both finishing and polishing procedures because it is possible to induce damage, even with rubber wheels. If the external axial walls sustain a loss of mass, then only a "platform-switching" effect will be produced (Fig 8). If the length of the fitting collar decreases, a gap and a surface that does not fit may then result.

Segmenting and soldering cast frameworks is commonly done by clinicians to improve fit, most often with larger multiple-unit constructions.[78,83–87] Soldering has been reported extensively in the literature; with the introduction of laser welding, even better results with less variability may be obtained.[88–90] In this study, preceramic laser welding improved the fit for both alloys, which is in agreement with earlier reports.[78,89] For the Au-Pt alloy, this was significant only for SG-1/2 (Fig 6). Also, an improved fit could be achieved by sectioning and laser welding Co-Cr frameworks. Although this

SG-torsion	Mean
96.2 ± 39.7	274.5 ± 130.6
223.1 ± 198.4	1,286.1 ± 912.4*
132.8 ± 147.1	775.4 ± 428.4
59 ± 26.5	116.8 ± 38.3**

study focused on the fabrication method and material of the framework, measurements were done after ceramic layering to include assessment of its effect on stress development. The firing cycles, especially degassing and final glazing during ceramic layering, have a negative effect on the dimensional stability of the prosthesis. This distortion is a result of changes in the metal and contraction of the fired porcelain, especially in the body of a curved long-span FPP. In addition, soldering may also cause dimensional changes during ceramic veneering.[32,41,87,91,92]

This might explain why the laser-welded Co-Cr frameworks showed less strain development than laser-welded Au-Pt frameworks. It seems paradoxical because the dimensional stability of high noble alloys and premachined cylinders is better than that of base metal alloys and plastic cylinders. On the other hand, the stiffness and resistance to deformation of base metal alloys during ceramic veneering are superior.[57,67,75,79–82] It seems that the rigidity of the material is more valuable than the dimensional stability of the materials itself. Additionally, laser welding uses solders with similar compositions and properties as the framework alloy and affects only a small zone.[93] However, these results confirm the previously reported inability of soldering to create absolute passive fit.[78]

In group E, "passive abutments" were incorporated into the framework at the end of laboratory fabrication, immediately prior to the final clinical appointment with the patient. By this time, a framework will display consistent dimensions because all dimensional changes have already occurred. Intraoral fit is dependent only on the accuracy of the impression and master cast.

Although the present literature lacks studies investigating "passive abutments" for direct comparison, the process of joining implant prostheses to prefabricated abutments after the completion of the restoration has been previously reported. Parel[85] **[AU: Reference #85 is not Parel but Lundquist and Carlsson. There is no Parel reference in the References; did you wish to add one?]** suggested the incorporation of intermediate cylinders on the framework using an autopolymerizing resin. According to the Cal technique (Attachments International, Inc), titanium cylinders are incorporated into the framework by cementation on the cast or intraorally.[14,94,95] An increasing number of studies has recommended cementing or soldering implant prostheses onto prefabricated cylinders.[93,96,97]

Watanabe et al[25] compared the fit of one-piece castings, soldering techniques, and the "passive fit method" (IMZ, Friadent), in which a fabricated superstructure is joined to titanium copings by the use of adhesive resins. The strains were significantly lower with the "passive fit method" than with other fabrication methods. Karl et al[32] reported that screw-retained FPPs cemented to prefabricated gold cylinders on the model induced less strain than all other types of prostheses, including cement retention. One reason may be that the gold cylinders are not exposed to the deterioration caused by casting, divesting, and polishing. These findings are supported by the present investigation, as group E frameworks showed less strain development than the other groups. Moreover, the milled fitting surface of the titanium rings of "passive abutments" is preserved, as these are cemented to the restoration after final finishing and polishing (Fig 9).

The fact that SG-bending values were statistically significantly different between groups, whereas SG-torsion values were not, could only be attributed to the geometry of the FPPs and the resin block. Several methods have been developed to fabricate passive FPPs, such as CAD/CAM and Cresco Ti. However, these are complex fabrication methods and often require expensive equipment. The idea of incorporating prefabricated abutments on implant frameworks immediately before the final insertion represents a simple and reliable choice. Because the price of gold has increased significantly in recent years, the use of Co-Cr alloys offers the advantage of lower cost, as well as improved biocompatibility and resistance to corrosion resulting from a protective surface layer of chromium oxide (Cr_2O_3). Co-Cr alloys also have good casting properties, a high modulus of elasticity, and only the single disadvantage of difficulty of adjustments because of the high hardness.[19] In addition, Hjalmarsson[98] reported comparable clinical outcomes for implant level prostheses made of porcelain-veneered Co-Cr and acrylic resin–veneered titanium prostheses made at the abutment level.

The passive abutments were cemented on the model according to the manufacturer's instructions. With regard to intraoral cementation, it seems difficult to control subgingival moisture and remove the cement.[35] Apart from strain development, the passive abutments have excellent fitting surfaces because they are constructed by milling and are cemented to the restoration after final finishing and polishing (Fig 9). However, more research is needed to fully understand the intraoral behavior of the cement (eg, strength, solubility, porosity, and accumulation of bacterial plaque).

CONCLUSIONS

Within the limits of this study, it was clear that a true passive fit could not be achieved with any of the methods used. One-piece castings showed the largest misfit, which could be improved by sectioning and soldering. One-piece cobalt-chromium castings using plastic cylinders should be avoided by clinicians. Soldered cobalt-chromium ceramic-veneered fixed partial dentures exhibited less strain development when compared with gold alloy structures, emphasizing the importance of structural rigidity of the frameworks. The least stress was created when passive abutments were used. The passive abutment is a simple and economic method to achieve well-fitting frameworks independent of framework material or fabrication method.

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