Deformation of Implant Abutments After Framework Connection Using Strain Gauges

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When a cylinder is connected to an abutment it is expected that abutment and cylinder will be subjected to compression forces throughout their periphery because of the clamping force exerted by the screw. The deformation resultant of this compression should be measurable and uniform along the periphery of the abutment. Considering that multiple retainers connected to each other can affect the fit of a framework, as well as the use of different alloys, it is expected that the abutments will present different levels of deformation as a result of framework connection. The aim of this study was to evaluate the deformation of implant abutments after frameworks, cast either in cobalt-chromium (CoCr) or silver-palladium (AgPd) alloys, were connected. Samples ($n = 5$) simulating a typical mandibular cantilevered implant-supported prosthesis framework were fabricated in cobalt-chromium and silver-palladium alloys and screwed onto standard abutments positioned on a master-cast containing 5 implant replicas. Two linear strain gauges were fixed on the mesial and distal aspects of each abutment to capture deformation as the retention screws were tightened. A combination of compressive and tensile forces was observed on the abutments for both CoCr and AgPd frameworks. There was no evidence of significant differences in median abutment deformation levels for 9 of the 10 abutment aspects. Visually well-fit frameworks do not necessarily transmit load uniformly to abutments. The use of CoCr alloy for implant-supported prostheses frameworks may be as clinically acceptable as AgPd alloy.

Key Words: implant frameworks, prosthesis fit, strain gauges

INTRODUCTION

One of the objectives in fabricating implant-supported restorations is the production of frameworks that exhibit passive fit when connected to multiple abutments.[1–3] The term "passive fit," with regard to the relationship of a prosthetic framework to its underlying

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implant abutments, appears with regularity in the literature.[4,5] As yet, no definition or parameter has been established as to what constitutes a passive fit.[2,6] Restorative dentists have the task of obtaining a passive fit with no accepted clinical parameters for horizontal, vertical, or angular discrepancies. Thus, the goal is to create a fit as accurate as is clinically possible to avoid bone strain resulting from uncontrolled loading of implants through the framework.

One of the obstacles in producing passive fit is the clinical and laboratory variables inherent to the prosthetic treatment itself. Because of that, inaccuracies are considered inherent and inevitable when currently available materials and techniques are employed. Even assuming that all procedures are correctly executed, there are clinical and laboratory factors that contribute to the final distortion of the prosthesis[5,7]: (1) impression procedures, (2) pouring of master cast, (3) waxing of framework, (4) casting procedures, and (5) addition of acrylic or porcelain.

The vertical gap of abutment-prosthesis interface has been described as acceptable when kept around 10 μm.[8] In order to follow this principle, electronically machined prosthetic cylinders are used to precisely fit onto the abutments. Because of the high cost of gold alloy and some of its mechanical and physical properties, alternative alloys have been proposed for fabrication of prosthetic components.[9]

Cobalt-chromium (CoCr) alloys have become the standard alloy for removable partial denture frameworks since they were first introduced in dentistry in the 1930s. Compared to gold alloys, CoCr alloys are harder and present a lower specific weight (density), good tarnish and corrosion resistance, lower cost, higher modulus of elasticity (stiffness), and higher fusing temperature. However, they exhibit less definition of details, more difficulty on finishing and polishing, greater casting shrinkage and also require special casting equipment.[10,11] More recently, CoCr alloys have been used for fabrication of implant components.

When a free-standing cylinder is connected to an abutment, it is expected that abutment and cylinder will be subjected to compression forces throughout their periphery because of the clamping force exerted by the screw. The deformation resultant of this compression should be measurable and uniform along the periphery of the abutment and is influenced by the fit between abutment and cylinder. Considering that multiple retainers connected to each other can affect the fit of a framework, it is expected that the abutments will present different levels of deformation as a result of framework connection. Studies have demonstrated that the pattern of stress distribution on the abutments depends on the alloy type used in the framework.[4,12–17] The purpose of this study was to verify the pattern of deformation when a multiple retainer framework cast either in CoCr or silver-palladium (AgPd) alloy is connected to the abutments.

Materials and Methods

A round master-cast was fabricated in steel, following the model proposed by Chao et al.[18] Five holes were drilled on the upper side of the master-cast where implant replicas (3.75 mm) were placed. From the central perforation, 4 others were made 7 mm apart from center to center (Figure 1). Implant replicas were fit on each hole with its upper portion leveled to the master-cast surface. Each implant analog was fixed by Allen screws (model M3X10mm), transfixing the master-cast horizontally. Standard 4-mm abutments were then screwed into the replicas with 20 Ncm torque, using a previously calibrated electronic torque controller device (Nobel Biocare, Gothenburg, Sweden).

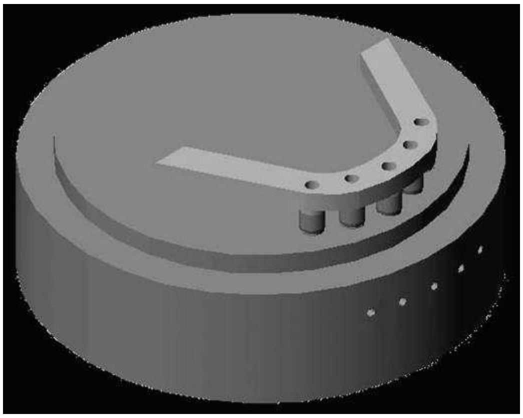

Figure 1. Schematic drawing of the master-cast showing the framework connected to the abutments.

Plastic cylinders were cast in CoCr alloy (group I) and fixed on each abutment by titanium screws. Plastic patterns were used because cobalt-chromium alloy cannot be cast directly onto gold cylinders because of their different melting points. The cylinders were cast separately so that the casting failure of one cylinder did not compromise the casting of the entire framework. A bar was waxed (hard inlay wax, Corning's Waxes, Corning Rubber Co Inc, Ronkonkoma, NY) simulating a typical fixed complete arch framework (60 mm long × 6 mm wide × 4 mm height) with a cantilever arm of 15 mm length on both sides. A silicone matrix was fabricated around this waxed framework to help standardize the dimensions of the samples.

The wax pattern was removed from the master-cast, fixed in a crucible former with a silicone ring adapted to its base. A microfine phosphate investment (Talladium Micro-Fine 1700, Talladium do Brasil Inc, Comércio de Materiais de Prótese Odontológica, Curitiba, PR Brazil) was used according to manufacturer's specifications. After setting time, the ring with invested pattern was placed into a casting furnace (Radiance, Jelrus, Melville, NY) for wax elimination, and the temperature was raised to 870°C for 1½ hours. An adequate amount of CoCr alloy (Rexillium NBF, Jeneric/Pentron Incorporated, Wallingford, Conn) was placed in the crucible and cast evenly and gradually, using a torch (rpm 247.5, EDG OXI GLP, EDG Equipamentos, São Carlos, SP Brazil) with adequate ratio of propane and oxygen. Once the alloy reached the melting point, the centrifugal machine lock was released and the alloy was injected into the mold. Divesting was performed after cooling and, in order to remove debris of investment, the bar was sandblasted with a mixture of aluminum oxide and glass spheres with 60 lb/pol^2 and finished.

To perform the waxing procedure of the framework that would be cast in AgPd alloy (Pors-On 4, Degussa S.A., Guarulhos, SP Brazil) (group II), gold cylinders were placed and tightened into each abutment using titanium screws. The silicone matrix was positioned on the master-cast and casting wax (hard inlay wax, Corning's Waxes) was flowed into it. The assembly was held in place until the wax was completely cooled. Investing, casting, and finishing were completed as for group I, except that the required temperature for wax elimination for the AgPd alloy was 760°C. All castings (5 for each group) were made in 1 single piece. The frameworks were positioned on the abutments fixed to the master model and were manually tested according to the single screw test proposed by Jemt[19] in order to verify the presence of any jiggling movement. Only frameworks with good adaptation to the abutments as verified visually were considered approved. Frameworks that did not meet this criterion were discarded and a new one was cast. Two linear strain gauges (KFG – 02-120-C1-11, Kyowa Electronic Instruments Co Ltd, Tokyo, Japan) were fixed with cyanoacrylate (Strain Gages Cement CC – 33A, Kyowa Electronic Instruments) on the mesial and distal aspects of each one of the 5 abutments (Figure 2). Strain gauges were connected to a data acquisition board (SC – 2042 – SG, National Instruments Corp, Austin, Tex) that sent the signal to a reading board

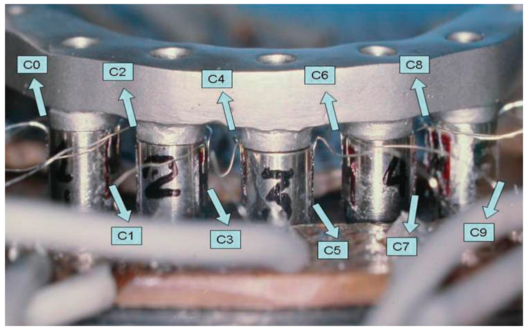

FIGURE 2. Strain gauges fixed on the mesial and distal aspects of the abutments and the framework attached to the master-cast to perform the test. Each strain gauge corresponds to a channel numbered C0 to C9.

(PCI – MIO – 16XE – 10, National Instruments) which was installed on a desktop computer. Inputs from the 10 strain gauges were analyzed with the aid of LabVIEW FDS version 5.1 for Windows (National Instruments). Each strain gauge corresponded to a channel on the data acquisition board.

Before connection of the frameworks, all strain gauge readings were set to 0. This procedure was performed before testing each framework to avoid interference with the results caused by the stress of abutment screw tightening. Frameworks belonging to group I were tested first followed by group II frameworks. Because of the small amount of deformation expected on the abutments, as demonstrated in a previous study,[17] possible damage to the abutments after each test was disregarded. Human improvement via repetition was also ignored because of the relatively small number of specimens (5 for each alloy).

To facilitate the reading procedure, implant replicas were numbered from 1 to 5, counterclockwise. The sequence for tightening the retention screws was the same proposed by Jemt,[19] in this order: 2-4-3-1-5. At first, screws were hand-tightened using a screwdriver until offering a slight resistance, and then a 10 Ncm torque was applied by an electronic torque controller device (Torque Controller, Nobel Biocare). The absolute values of specific deformation on each aspect of abutments were recorded, and the results were submitted to statistical analysis using the Mann-Whitney *U* test.

RESULTS

Absolute values of specific deformation (in microstrains - $\mu\varepsilon$) generated on each side of the abutments with the frameworks cast either in CoCr or AgPd alloys are presented in Tables 1 and 2, respectively.

The Mann-Whitney *U* statistical test (SigmaStat for Windows, Jandel Corporation, San Rafael, Calif) was carried out in pairs, in order to analyze the difference or similarity between groups I and II (Table 3). Only one significant difference was found on the mesial aspect of abutment number 4 (channel 6) where more deformation was recorded for the silver-palladium framework.

DISCUSSION

Precise fit between the implant and abutment and between abutment and framework are important factors in determining the long-term success of implant-supported restorations. When fit is poor, tensile,

TABLE 1

Results (in $\mu\varepsilon$) of the 5 samples cast in CoCr alloy (group I)*

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
SP 1	−0.20	+0.20	−0.07	−2.10	−3.06	+0.80	−0.70	+1.50	+1.50	−0.40
SP 2	+0.50	−0.05	−3.60	+2.70	+8.60	+0.80	−0.90	+0.60	−0.50	−0.07
SP 3	−0.09	−0.06	+0.26	−2.50	−9.20	+0.03	+0.22	−0.90	−0.20	−17.29
SP 4	−1.81	+0.39	+0.30	−1.60	−4.70	+0.16	−0.08	+16.5	−0.30	−0.25
SP 5	−3.12	+0.07	−0.10	−1.50	−7.90	+5.30	+0.40	+0.40	−0.23	−0.32

*SP indicates sample; C, channel. Negative values: compression; positive values: tension.

TABLE 2

Results (in με) of the 5 samples cast in AgPd alloy (group II)*

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
SP 1	−0.07	−0.07	−0.11	−0.30	+1.40	+1.32	+0.93	−3.00	+0.68	−1.38
SP 2	−0.08	+0.12	−0.73	+1.40	−1.80	+0.10	+1.07	+0.30	+0.10	+4.10
SP 3	−0.11	−0.12	−0.43	−0.70	−1.20	+0.87	+0.82	−1.10	+0.66	+0.31
SP 4	+11.84	−0.50	+0.17	−2.30	−0.30	+1.19	+1.60	+0.40	−0.79	−0.12
SP 5	−0.07	−0.13	−0.51	−3.00	+10.2	+0.64	+2.00	−1.00	+1.00	+0.30

*SP indicates sample; C, channel. Negative values: compression; positive values: tension.

compressive, and bending forces may be introduced into the system and may result in loosening of the prosthesis or abutment screws, distortion or breakage of the restoration, and microfractures of the implant body. In this situation it is believed that loss of osseointegration may occur.[20]

The marginal fit of a prosthetic restoration can be analyzed in 3 axes (horizontal, vertical, and angular); however, the majority of studies on marginal fit consider only the vertical axis, which means that the term ''passivity of fit'' is usually described in the literature as synonymous with vertical fit.[21–23] The use of strain gauges allows the observation of deficiencies of fit as they will produce different patterns of abutment deformation.

In this experiment it was observed that the frameworks of both groups generated strains on abutments when torque was applied. The deformation was not uniform among the abutments with a great variation of tension and compression forces. The result is in accordance with Carlsson[24] who emphasized that it is impossible to obtain an absolutely passive marginal fit since screw tightening develops a slight deformation of the prosthetic restoration and/or bone, resulting in some kind of stress in the system. Because of the unpredictability of the biologic response of implants to static loads, it is advisable that the framework should be sectioned and soldered to provide passive fit. The frameworks used in this study were cast in one single piece, which may have contributed to the stress patterns observed. A test comparing the stress observed after framework sectioning and soldering is under way and may help clarify this issue.

Ideally, the expected result for a perfectly fit framework would be the presence of some level deformation by compression resultant of the forces exerted by the cylinders onto the abutments as they both are screwed to each

TABLE 3

Mann-Whitney *U* statistical test carried out in pairs to analyze the difference or similarity between groups I (n = 5) and II (n = 5)

	Group I			Group II				
Channels	1st Quartile, 25%	2nd Quartile, 50% Median	3rd Quartile, 75%	1st Quartile, 25%	2nd Quartile, 50% Median	3rd Quartile, 75%	*P* Value	Significant
C_0	0.1725	0.5000	2.14	0.0700	0.0800	3.04	.2222	
C_1	0.0575	0.0700	0.2480	0.1075	0.1200	0.2230	.4206	
C_2	0.0925	0.2600	1.1250	0.1550	0.4300	0.5650	.5476	
C_3	1.5750	2.1000	2.5500	0.6000	1.4000	2.4800	.4206	
C_4	4.2900	7.9000	8.7500	0.9750	1.4000	3.9000	.1508	
C_5	0.1280	0.8000	1.9300	0.5050	0.8700	1.2200	.6905	
C_6	0.1850	0.650	0.7500	0.9030	1.0700	1.7000	.0159	X
C_7	0.5500	0.9000	5.2500	0.3750	1.0000	1.5800	.6905	
C_8	0.2230	0.3000	0.7500	0.5200	0.6800	0.8430	.5476	
C_9	0.2050	0.3200	4.6200	0.2550	0.3100	2.0600	.9999	

other. The results in Tables 1 and 2, however, show that there was a combination of compressive (negative values) and tensile (positive values) forces on the abutments, which means that there was not a perfect abutment/cylinder contact on their entire periphery. Where there was an actual contact between the components resulted in deformation by compression, while tension denotes that there was a gap between them. The combination of tension on one side and compression on the other side means that the cylinder is not fully seated onto the abutment as it would seem visually.

The wide variation of deformation to which the abutments were subjected may not be uniquely associated with vertical misfits. Millington and Leung[25] reported that the increase in vertical external misfit does not yield the proportional and linear increase of the forces exerted on the abutments. The authors suggested that horizontal and angular internal misfits, whose detection is difficult, contribute to the instability of the screws and generate tension forces on the implant components. The same was observed by Şahin and Çehreli,[26] who also highlighted that an acceptable marginal fit between the components does not mean the achievement of a passive fit. Helldén and Dérand[27] and Tan et al[28] stated that the distortions may be masked when the tightening torque is applied to the screws, leading the framework to seem well-fitted and yielding external preload tensions on the system. Such distortions, which are difficult to detect, associated with laboratory procedures and the connection of multiple abutments by means of a cast framework may be responsible for the variability of the results observed in this study.

A similar level of abutment deformation for frameworks cast either in CoCr or AgPd alloy was observed. In only 1 channel (C_6 – abutment number 4) there was a statistically significant difference. Differences of machine tolerances between components or cast procedures could be the reason for this event. Nevertheless, such difference was not interpreted as relevant since deformation in the opposite side of the same abutment (C_7) was similar between the 2 groups. What could be regarded as relevant would be the percentage of tension/compression values appearing in each group. Deformation by compression forces was present 60% of the time in group I and 50% of the time in group II, a slightly better performance for CoCr frameworks. But because of the low magnitude of the results, these values might well be within the limits of clinical tolerance.[17]

It appears that there is a clinically significant association between prosthetic misfit and screw loosening.[29] However, results are not conclusive because in well fit prostheses, screws can get loose and in poorly fit prosthetic restorations screws can remain tightened. Screw failures can be related to misfit of prostheses and considered operator dependent since tightening, clinical evaluation, and fit of components are subjective variables. Screw loosening incidents increase when a nonpassive framework is forced to fit through screw tightening. The framework produces separating forces in the system trying to return to its original shape. In this situation there is no protection against fatigue because any external load applied to separate the prosthesis from the abutment causes further strains on screws which are not dissipated when compressive stress in the joint is relieved.[30]

During the development of an alternative technique for a given treatment, aspects that are related to its safety, efficacy, and effectiveness must be analyzed. Due to its well-kwon biocompatibility, the use of a CoCr alloy enables its usage on the fabrication of implant-supported prostheses. Nevertheless, clinical studies must confirm the laboratory results regarding the appropriateness of its use. In addition, studies considering sectioning and soldering of the framework must be conducted to investigate improvements in prosthesis fit.

Conclusions

Under the conditions of the present study the following conclusions could be drawn: (1) visually well-fit frameworks did not produce uniform deformation of the abutments upon tightening, and (2) there was no evidence of significant differences in median abutment deformation levels for 9 of the 10 abutment aspects. In this respect the use of CoCr alloy for implant-supported prostheses frameworks may be as clinically acceptable as AgPd alloy.

Abbreviations

CoCr: cobalt-chromium
AgPd: silver-palladium

Acknowledgments

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