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RESEARCH AND EDUCATION

Retention of bonded titanium copings fixed to implant abutments

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ABSTRACT

Statement of problem. Conical abutments can be laser welded to the abutment base to compensate for differing implant axes. As laser welding requires expensive equipment, alternative methods for bonding the conical abutment part with the abutment base should be considered.

Purpose. The purpose of this in vitro study was to evaluate the retention of Ti-6Al-7Nb copings bonded adhesively to Ti-6Al-7Nb abutments and to compare it with the stability achieved by laser welding.

Material and methods. A total of 104 two-part Ti-6Al-7Nb specimens were prepared and divided into 13 groups with 8 specimens each. In this 2-part study, 3 luting resins (Panavia F 2.0 [PF]; Multilink Automix [MA]; Superbond C&B [SB]) were used with or without metal priming (PR). The laser welding group (LW) served as the control. After storage for 1 or 150 days (150 days with thermal cycling [TC]), push-out retention and welded joint stability were tested. The data were analyzed with ANOVA and the Tukey HSD multiple comparison tests.

Results. The choice of resin, thermal cycling, and metal priming had a significant effect on resin push-out retention. LW provided the strongest retention, followed by PF, MA, and SB. For PF and SB, TC decreased retention. PR did not lead to higher retention but provided better bonding stability when TC was applied.

Conclusions. The retention values suggest that considering the maximum mastication forces, resin bonding is an appropriate substitute for the laser welding method. (J Prosthet Dent 2016;115:26-34)

The use of titanium alloys in prosthodontic practice has increased substantially in recent years because titanium provides excellent biocompatibility and adequate corrosion resistance. Additionally, the laboratory techniques have improved.[1-4] Titanium alloys (Ti-6Al-4V) were originally developed as alternatives to pure titanium with improved mechanical properties.[5,6] Nevertheless, the long-term biocompatibility of the alloy has still to be established.[7] Additionally, the cytotoxicity of elemental vanadium remains problematic.[8] Another titanium alloy (Ti-6Al-7Nb), developed originally for hip, knee, and wrist joint applications,[9] has been reported to be better than pure titanium in terms of wear resistance,[10] strength,[10,11] ductility,[11] and machinability[12] while still providing biocompatibility[13] and corrosion resistance.[14] Furthermore, Ti-6Al-7Nb has demonstrated comparable mechanical properties and better corrosion resistance than the Ti-6Al-4V alloy.[11,15] On the basis of these favorable laboratory and clinical results, the Ti-6Al-7Nb alloy is currently available as a dental casting alloy.

Different options are available for anchoring prostheses on osseointegrated implants in the edentulous mandible. Because of longer survival rates and less maintenance, fixed suprastructures on implants are preferable.[16,17] However, sometimes for financial, strategic, or hygienic reasons,[18] removable dental prostheses are the first choice of clinicians when they are planning prosthetic rehabilitations for patients with edentulism.[19,20] Removable suprastructures can be retained on osseointegrated implants with a variety of

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Clinical Implications

Dental laboratories and clinics do not need to buy an expensive laser welding machine because adhesively bonding the components with luting resins seems to be sufficient for clinical use. For long-term stability, the surfaces should be primed.

attachments.[21-23] Tapered telescopic crowns, which for years have been applied on natural teeth as a retainer for removable dentures,[24-26] could also serve as implant attachments.[27-32] Tapered telescopic crowns produce friction only in the fully seated position. As soon as the outer crown is dislodged from its terminal position, friction is lost,[33] potentially preventing excessive forces being applied on implants.

The Kieler Compensating Konus implant abutment system was developed in the Department of Prosthodontics at the University of Kiel in the early 1990s.[34] This concept has also been validated in in vitro studies by other research groups.[27-29] Its clinical use was revived in recent years when implants in both jaws were restored successfully with compensating conical abutments and their respective suprastructures (Ankylos SynCone; Dentsply-Implants).[30-32] These concepts produced implant survival rates between 97% and 98% and a prosthesis survival rate of 100%.[30-32] However, because conical telescopic crowns have been used, a remaining difficulty is to set the retentive forces within an appropriate range.[25]

To compensate for differing implant axes, the conical abutment is laser welded to its abutment base. Although the Ti-6Al-7Nb alloy has relatively low rigidity,[35] it might be an alternative to conventional dental alloys when used for conical implant abutments.[36] Because laser welding requires expensive equipment, alternative methods of bonding the conical abutment part with the abutment base have been considered to make the method usable without a dental laser welder. Tensile strengths and retention tests are thought to be important because most luting agents are brittle and prone to tensile failure.[37] However, only limited information is available concerning the retention of contemporary bonding systems to Ti-6Al-7Nb.[38,39]

The purpose of this in vitro study was to evaluate the push-out retention of contemporary resin bonding systems (with and without metal primers) to Ti-6Al-7Nb alloy and its retention after a storage time of up to 150 days with thermal cycling (TC) and to compare it with the welded joint stability of laser welding. The null hypotheses to be tested were the bonded resin push-out retention to the Ti-6Al-7Nb alloy is not influenced by the use of metal primers and different storage conditions (thermal cycling) and that the resin push-out retention to Ti-6Al-7Nb alloy is equivalent to the joint stability of laser welding.

Table 1. Compositions of alloys, metal primers, and resin materials

Material	Component	Composition	Manufacturer
Titanium-alloy $TiAL_6NB_7$	-	86.4% titanium, 5.7% aluminum, 7.5% niobium (mass%)	Zapp
Alloy primer		MDP, VTD	Kuraray Co
Metal/zirconia primer		Phosphonic acid acrylate; ethoxylated bis-EMA	Ivoclar-Vivadent AG
Panavia F 2.0	A-Paste	BPEDMA, MDP, DMA	Kuraray Co
	B-Paste	Ba-B-Si-glass, silica containing composite resin	
Multilink Automix	A-Paste	HEMA, dimethacrylates, fillers, BPO	Ivoclar-Vivadent AG
	B-Paste	HEMA, dimethacrylates, fillers, ytterbium trifluoride	
Superbond C and B	Catalyst	4-META, MMA, PMMA, TBB	Sun Medical Co
	Monomer	4-META, MMA	

MDP, 10-metacyloyloxydecyl dihydrogen phosphate; VTD, 6-(4-venylbenzyl-n-propyl) amino-1,3,5-triazine-2,4-dithione; Bis-EMA, bisphenol-A-ethoxy dimethacrylates; BPEDMA, bisphenol-A-polyethoxy dimethacrylate; DMA, aliphatic dimethacrylate; HEMA, hydroxyethyl methacrylate; BPO, benzoyl peroxide; 4-META, 4-methacryloyloxyethyl trimellitate anhydride; MMA, methylmethacrylate; PMMA, polymethyl methacrylate; TBB, tri-n-butylborane.

MATERIAL AND METHODS

The bonding systems tested in this study consisted of Panavia F 2.0 with Alloy Primer, Multilink Automix with Metal/Zirconia Primer, and Superbond C&B with Alloy Primer. The composition of the materials is summarized in Table 1. The design of the prefabricated telescopic crown abutment system is illustrated in Figure 1A. To mimic the telescopic crown abutment system for the current study, the 2-part specimens (Fig. 1B) were cut from 5.0 mm diameter Ti-6Al-7Nb cylinder sticks and milled to shape (Emcomat; Emco). The diameter of the male part was 20 μm smaller than that of the female part to ensure a 10 μm resin bonding space around the male pole (Fig. 1C). A total of 104 pairs of specimens were prepared. Ninety-six specimens were divided into 3 equal groups, 1 for each resin to be tested. The remaining 8 specimens were used to test the joint stability of laser welding, which served as the control.

The bonding surfaces of all male and female parts were airborne-particle abraded with 50-μm aluminum oxide particles at a pressure of 0.25 MPa for 15 seconds at a distance of approximately 20 mm. Afterwards, all specimens were ultrasonically cleaned in 96% isopropanol for 3 minutes. After airborne-particle abrasion, each resin group, with a total of 32 specimens, was equally divided into 2 subgroups, with 1 of each resulting subgroups being treated with the respective primer. All groups were then bonded with the respective resin. All bonding procedures were executed according to the manufacturer's instructions. Throughout the polymerization time, an alignment apparatus consisting of parallel

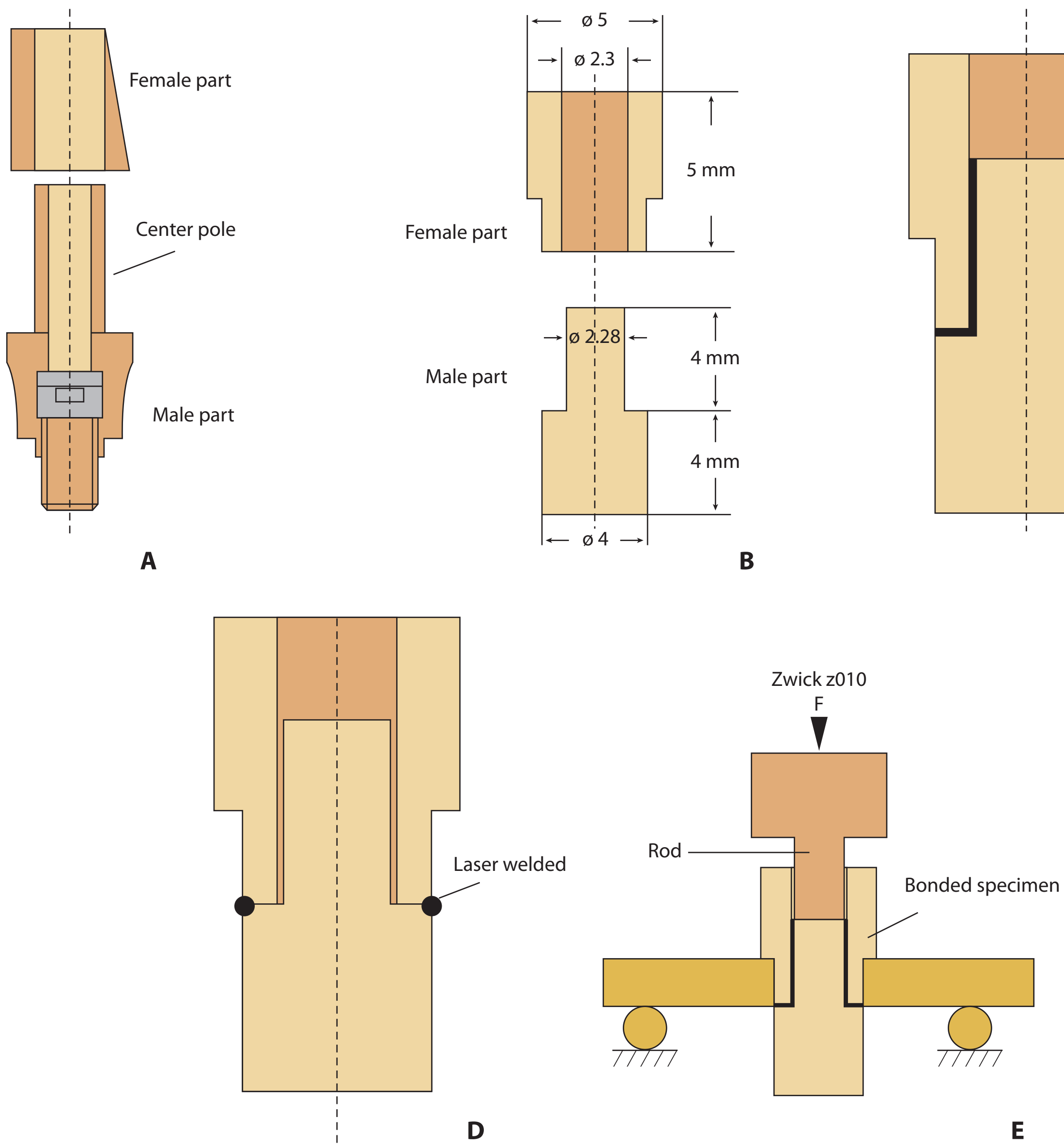

Figure 1. A, Schematic drawings of ready-made tapered telescopic crown abutment system (Kieler Compensating Konus). Female part (inner telescope) can be rotated around male part center pole. B, Experimental specimen design of male and female parts. C, Schematic drawings of resin-bonded specimens. Male pole was milled 20 μm narrower than diameter of female part to ensure 10 μm resin material space. D, Schematic drawings of laser welded specimens. E, Schematic drawings of push-out testing. Rod that pushes out male pole from female part hole was gripped by pin-vice of universal testing machine.

guides, a silicone pad, and an added load of 4.9 N was used. After polymerization, each resin group, with a total of 16 specimens, was further divided into 2 subgroups (each with 8 specimens). Before determining the retention/joint stability, the experimental groups were either stored in distilled water at 37°C for 24 hours or for 150 days with additional thermal cycling (37 500 times) between 5°C and 55°C and a dwell time of 0.5 minutes.

For the control group (laser welding), the cervical gaps between the male and female parts were circumferentially laser welded (Dental-Laser DL2000; Lasertech) at 270 V and a pulse length of 2.5 ms. All the welded spots overlapped by approximately 10% to produce a tight seal (Fig. 1D).

Retention and welded joint stability were measured by using a push-out test at a crosshead speed of 1.0 mm per minute in a universal testing machine (Zwick Z010/Tn2A; Zwick) (Fig. 1E). The forces (in N) at failure were recorded, and the retention (in MPa) was calculated from the peak load at failure divided by the specimen surface area. Resin retention data were analyzed with 3-way

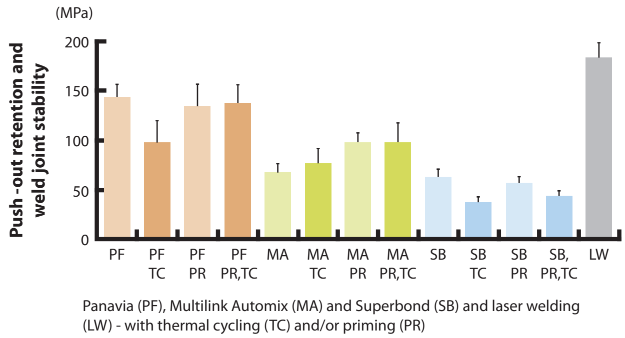

Figure 2. Means and SD of retention testing results of 13 groups.

Table 2. Three-way ANOVA and 1-way ANOVA results

Source of Variation	Sum of Squares	Degrees of Freedom	F	*P*
Three-way ANOVA				
Thermal cycling (I)	3396	1	16.7	.001
Resin (II)	97899	2	240.5	<.001
Priming (III)	4378	1	21.5	<.001
(I)*(II)	3315	2	8.1	<.001
(II)*(III)	2583	2	6.3	.003
(I)*(III)	1878	1	9.2	.003
(I)*(II)*(III)	3528	2	8.7	<.001
Residual	17100	84		
Total	883079	96		
One-way ANOVA				
Group	184085	12	74.5	<.001
Residual	18751	91		
Total	202836	103		

analysis of variance (MANOVA) and post hoc tests (Tukey HSD multiple comparison test) at a 5% level of significance. The comparison between the resin retention values and the laser weld stability was conducted using 1-way analysis of variance (ANOVA) (α=.05).

The debonded male parts were examined under a light microscope (Makroskop M420; Wild) at ×12 magnification to assess the mode of failure. Furthermore, after sputtering the specimens with a 20-µm gold alloy conductive layer, representative specimens of each group were also examined with a scanning electron microscope (SEM) (XL30CP; Philips) with an acceleration voltage of 15 keV and a working distance of approximately 10 mm.

RESULTS

The means and standard deviations of the results of the retention testing are shown in Figure 2. The results of ANOVA and the Tukey HSD multiple comparison post hoc tests are summarized in Tables 2 and 3. Compared with the push-out retention, laser welding provided significantly higher stability/retention (P<.001). The choice of resin and the factors thermal cycling and priming significantly influenced push-out retention (P<.001). All 3 factors (resin, thermal cycling, and priming) showed significant interactions ($P\leq$.003).

In groups without thermal cycling, only Multilink specimens showed a significant positive effect of the metal primer ($P\leq$.005). In groups with thermal cycling, only Panavia showed a significant effect of priming ($P\leq$.001). With regard to the effect of thermal cycling, Panavia and Superbond without priming exhibited a significant decrease in push-out retention values after thermal cycling ($P\leq$.03). Figure 3 shows the light microscope images and Figure 4 shows the SEM images. Bonding surfaces showed exclusively cohesive failure modes.

DISCUSSION

The first null hypothesis that the push-out retention to the Ti-6Al-7Nb alloy is not influenced by priming procedures and storage conditions was rejected. The second null hypothesis that the resin bonding method does have equivalent strength/stability to the laser welding method on Ti-6Al-7Nb alloy was also rejected.

It has been difficult to set the retentive forces within an appropriate range with conical telescopic crowns.[25] To avoid these difficulties, prefabricated tapered telescopic crown abutment systems have been developed.[31,32,34] The abutments of these systems consist of 2 parts. The male part is connected to the implant fixture and is oriented in the axial implant direction. The female part, which is tapered externally, is placed onto the male part. The female part can rotate around the male part to allow the practitioner to adjust the denture insertion direction and to compensate for varying implant angulations. After attaching the female parts, both parts are mechanically connected. Treatment with tapered telescopic implant-supported crowns can be a clinical option with reduced technical complexity and costs.[27,30-32]

Among all 3 tested resins, the MDP (10-metacyloyloxydecyl dihydrogen phosphate)-containing composite resin, Panavia, showed the highest push-out retention values. Retention values did not decrease significantly for Panavia even after thermal cycling if priming was used, while they decreased significantly without priming. The phosphate monomer in Panavia was probably the reason for the stability of the bonding interface. The phosphate ester group of the MDP is supposed to bond directly to metal oxides at the surface.[40]

Multilink demonstrated lower push-out retention values compared with Panavia. The current results were similar to another study[39] and studies that tested retention to tooth-colored posts[41] and to ceramic.[42] Comparing the different Multilink groups, push-out retention remained stable even after thermal cycling. It seems that the phosphoric acid acrylate in the metal/

Table 3. Tukey HSD multiple comparison test results

Resin	PR	TC	1	2	3	4	5	6	7	8	9	10	11	12	13
PF	-	-		***	-		***	***	***	***	***	***	***	***	***
	-	+	***		***	***	**	-	-	-	***	***	***	***	***
	+	-	-	***		-	***	***	***	***	***	***	***	***	***
	+	+	-	***	***		***	***	***	***	***	***	***	***	***
MA	-	-	***	**	***	***		-	**	**	-	**	-	-	***
	-	+	***	-	***	***	-		-	-	-	***	-	**	***
	+	-	***	-	***	***	**	-		-	***	***	***	***	***
	+	+	***	-	***	***	**	-	-		***	***	***	***	***
SB	-	-	***	***	***	***	-	-	***	***		*	-	-	***
	-	+	***	***	***	***	**	***	***	***	*		-	-	***
	+	-	***	***	***	***	-	-	***	***	-	-		-	***
	+	+	***	***	***	***	-	-	***	***	-	-	-		***
LW	-	-	***	***	***	***	***	***	***	***	***	***	***	***	

**P*<.05, ***P*<.01, ****P*<.001.

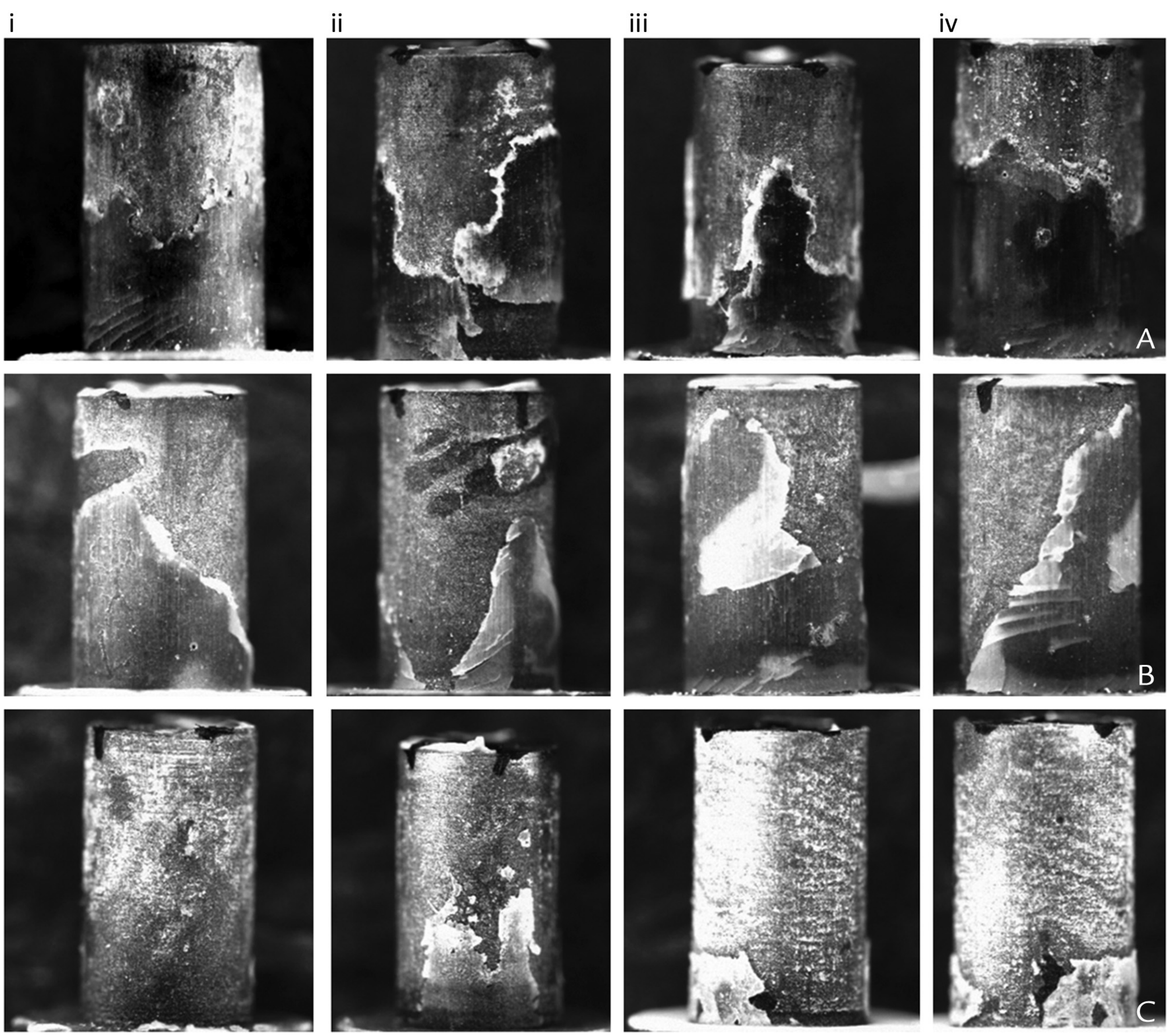

Figure 3. Light microscope images of debonded surfaces of male poles (representative specimens) bonded with different substances. A, Panavia (PF). B, Multilink Automix (MA), C, Superbond (SB). i, Without priming (PR), without thermal cycling (TC). ii, Without priming, with thermal cycling. iii, With priming, without thermal cycling. iv, With priming, with thermal cycling.

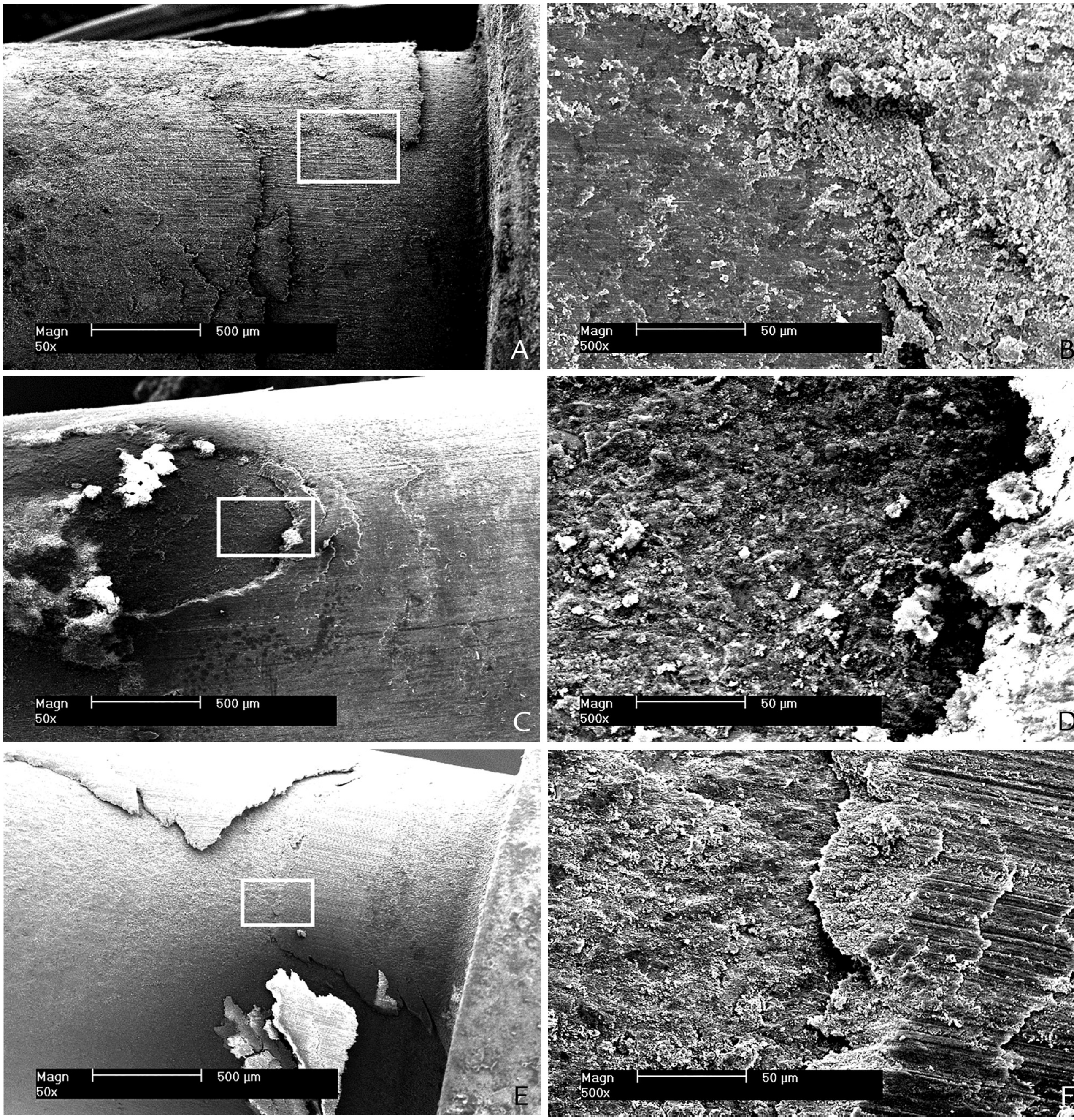

Figure 4. Contrast of SEM micrograph of debonded male pole surfaces. A, Panavia (PF) with priming (PR), without thermal cycling (TC). B, Magnified portion of Fig. 4A. C, Multilink Automix (MA) with priming, without thermal cycling. D, Magnified portion of Fig. 4B. E, Superbond with priming, without thermal cycling. F, Magnified portion of Fig. 4E.

zirconia primer (MZP) was able to create a stable chemical bond to Ti-6Al-7Nb alloy surface oxides.

With regard to Superbond, the manufacturer's instruction suggests the application of metal conditioner only for noble metals. However, a study which evaluated the adhesive performance of Ti-6Al-7Nb alloy bonded with combinations of 9 surface preparations and 3 acrylic resins showed that Superbond can provide a significantly different bond strength, depending upon the applied primer and particularly after thermal cycling.[38] Considering these results, the current study used alloy primer (AP).[38] However, in contrast to the previous study,[38] the current results demonstrated that the primer application had no statistically significant effect on the push-out retention values regardless of thermal cycling. A possible

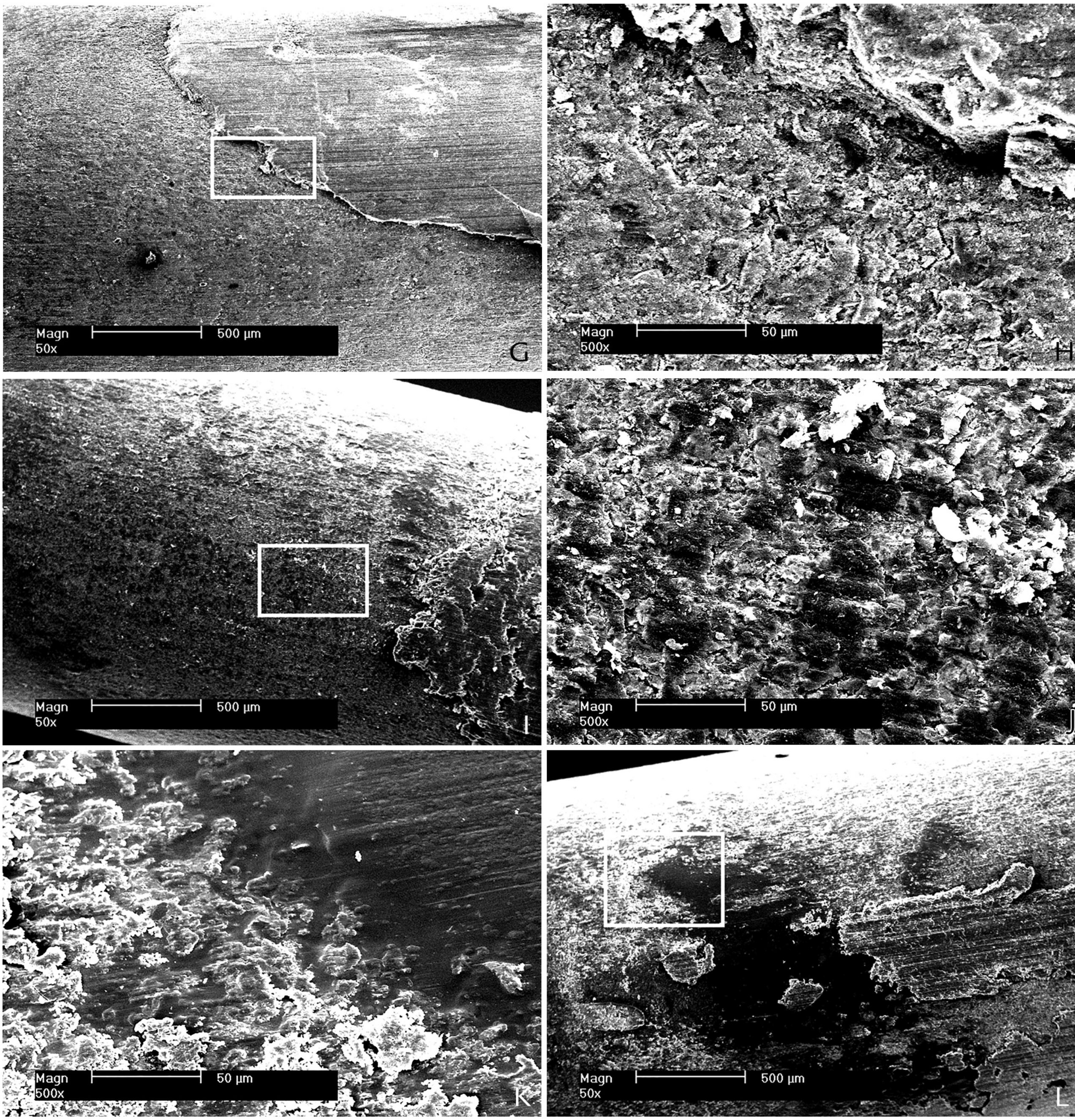

Figure 4. (*continued*). G, Panavia (PF) without priming, with thermal cycling. H, magnified portion of Fig. 4G. I, Multilink Automix (MA) without priming, with thermal cycling. J, magnified portion of Fig. 4I. K, Superbond (SB) without priming, with thermal cycling. L, magnified portion of Fig. 4K.

explanation might be that push-out retention has not been entirely dependent on the chemical bond to the metal surface but also on the mechanical properties of the bonded resin material itself, for example, micromechanical interlocking.

Thermal cycling caused a significant decrease in push-out retention value in all groups except Multilink and Panavia with the use of a primer. This might be explained by the water absorption of polymethyl methacrylate in long-term storage, which seems to diminish the chemical bond between the resin and metal surface.[43]

The light microscope images (Fig. 3) revealed different thicknesses of residual resin cement at the debonded surface of the specimens. The conventional method of calculating the failure mode percentages (cohesive/adhesive) was not possible because SEM images revealed the entirely cohesive failure of the luting resins (Fig. 4). These results might have been caused by the strong affinity of oxidized Ti-6Al-7Nb surfaces to the adhesive agents. Moreover, the results could have been affected largely by the mechanical properties of the resins themselves, for example, diametric tensile strength. Tensile strengths and retention tests are thought to be important because most luting agents are extremely brittle and prone to tensile failure.[37] Several studies have reported the diametric retentive strengths of relatively new luting agents,[44,45] and the current results could be largely associated with these properties. Although the manufacturers have not provided technical data on diametric tensile strength, a possible explanation for the significantly lower results of Superbond is that polymerized Superbond has a chain polymer structure. It demonstrates plastic deformation against the load at the primary stage and then shifts to an elastic deformation until it fails. In contrast, the 2 other tested resins have a brittle cross-linked structure and exhibited an elastic deformation throughout the failure test.

In this study, the laser welding specimens were not subjected to a thermal cycling procedure because of the Ti-6Al-7Nb alloy's sufficient corrosion resistance.[14] Therefore, the specimens were tested directly after the laser welding procedure. Although all the resin-bonded groups showed significantly lower retention values than those of laser welding, the 3 Panavia groups (groups 1, 3, and 4) achieved approximately 75% of the strength of laser welding. However, these results cannot be directly transfer into the oral environment, where cyclic forces must be withstood. Nevertheless, comparing these push-out retention values to the assumable retention forces of tapered telescopic crowns,[33] the resins tested in this study provided enough resistance for clinical usage.

A clinical advantage of bonding the male and female part instead of laser welding is that the practitioner can attach the abutment intraorally because the prosthesis insertion direction is determined. Even in situations of additional implantation under existing prostheses, only minor alterations to the prosthesis would be necessary. This method could provide practitioners and technicians with multiple options.

CONCLUSIONS

The results of this in vitro study suggest that resin bonding can substitute for laser welding, as the 3 Panavia F groups achieved 75% of the laser welded strengths. Further in vivo studies are needed to evaluate the clinical long-term success.

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Noteworthy Abstracts of the Current Literature

The effect of air-abrasion and heat treatment on the fracture behavior of Y-TZP

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Objectives. This study evaluated how the flexural strength and fracture behavior of a zirconia-based ceramic (Y-TZP) were affected by pre- and post-sintering mechanical and thermal treatments.

Methods. Treatments included sandblasting with different particle size and type (30μm SiO2; 50 and 110μm Al2O3) and thermal conditioning. Two hundred bar-shaped specimens of pre-sintered Y-TZP ceramic (Lava Frame, 3M) were prepared (specimen dimensions: 25mm length×4mm width×0.7mm thickness) and divided into three groups (before sintering, after sintering and after sintering with heating treatment). The before sintering group specimens were airborne-particle abraded prior to dense sintering. Specimens from the after sintering group were airborne-particle abraded after sintering. The after sintering with heating treatment group specimens were submitted to a heating procedure after airborne-particle abrasion. The controls were the specimens that were sintered and not treated with any conditioning procedures. The specimens from all experimental conditions were analyzed by SEM, CLSM and XRD. All specimens were tested in four-point bending. Data were statistically analyzed using one-way ANOVA and Post Hoc tests (α=0.05). A Weibull analysis was used to analyze the strength reliability.

Results. Sandblasting pre-sintered zirconia before sintering significantly decreased the flexural strength, except when the smallest blasting particles were used (30μm SiO2). Phase transformation (t-m) was observed after sandblasting and reverse transformation (m-t) was observed after heating.

Significance. Sandblasting with 30μm SiO2 and 50μm Al2O3 allowed lower phase transformation. However, 30mm SiO2 presented better reliability.

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