

Fracture Resistance of Cement-retained, Screw-retained, and Combined Cement- and Screw-retained Metal-ceramic Implant-supported Molar Restorations

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ABSTRACT

Aim: To compare fracture resistance between the cement-retained (CR), screw-retained (SR), and combined cement- and screw-retained (CCSR) metal-ceramic (MC) implant-supported molar restorations and the fracture mode after vertical loading simulation.

Materials and methods: Thirty MC molar restorations were fabricated on thirty tilted dental implants that were repositioned using prefabricated or universal castable long abutments (UCLA) with 15° of angulation divided into three groups of ten specimens each. Group C: CR, group S: SR, and group CS: cement- and screw-retained. The crowns in group CS were adhesively bonded extraorally, and composite resin was used to fill the screw access holes (SAHs) in groups S and CS. Subsequently, all the specimens were tested for fracture resistance. A scanning electron microscope (SEM) evaluation of the fracture mode was also performed. Mean values of fracture loads were calculated and compared in Newtons (N) using one-way ANOVA and Tukey *post hoc* test ($p < 0.05$) for each group.

Results: Mean fracture load values were 2718.00 ± 266.25 N for group C, 2125.10 ± 293.82 N for group S, and 2508.00 ± 153.59 N for group CS. Significant differences were found between group S and the other groups on fracture load values. However, no significant differences were found between groups C and CS ($p = 0.154$). The failures were at MC framework interfaces on mesiolingual cusps.

Conclusions: Cement and CCSR MC molar restorations showed comparable fracture resistance using abutments with 15° of angulation. However, SR design showed significantly the lowest values of resistance. Screw access hole did not significantly affect the fracture resistance of cemented MC molar restorations. All the specimens exhibited mixed adhesive fractures at the mesiolingual cusps.

Clinical significance: Combined cement- and screw-retained restorations (CCSRs) incorporate the simplicity of the cement method and the retrievability of the screw method, offering good resistance, allowing the removal of the excess of cement before clinical placement of the restoration, and providing another alternative for dental implant rehabilitation.

Keywords: Dental casting techniques, Dental implants, Implant-supported dental prosthesis, Metal ceramic alloys.

The Journal of Contemporary Dental Practice (2020): 10.5005/jp-journals-10024-2884

INTRODUCTION

Dental implants have been approved for their predictable success in complete dentures,¹ partial dentures,² and single-tooth restorations³ using metal-ceramic (MC) design due to their durability, aesthetics, strength, and less plaque adhesion.⁴ Classically, the retention of an implant crown can be accomplished by screw-retaining the crown on the implant or on a screw-onto implant abutment, or by cementing the crown on prefabricated or computer-aided design/computer-aided manufacturing (CAD/CAM) abutments.⁵

Screw-retained restorations (SRRs) offer the major advantage of retrievability for oral hygiene assessment and peri-implant probing, and present only one margin at the implant-abutment interface.⁶ They are more indicated when the interocclusal distance is limited and biological problems are not common.⁷ However, SRRs require complex lab procedures and the fracture or chipping of the layering porcelain is their principal mechanical complication owing to the presence of the SAH in the occlusal surface.^{8–10}

Cement-retained restorations (CRRs) show better occlusion and esthetics, and they offer the possibility of more passive fit in multiple implants with splinted frameworks.¹¹ Also, severely divergent implants can be restored.¹² The evidence suggests that some residual cement may remain in the peri-implant sulcus and it is an important etiologic factor that can lead to implant failure.^{13,14}

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How to cite this article: Malpartida-Carrillo V, Tinedo-López PL, Ortiz-Culca F, *et al.* Fracture Resistance of Cement-retained, Screw-retained, and Combined Cement- and Screw-retained Metal-ceramic Implant-supported Molar Restorations. *J Contemp Dent Pract* 2020;21(8):868–873.

Source of support: Nil

Conflict of interest: None

In the current literature, there is no consensus on which type of restorations is better. However, in a systematic review, SRRs exhibited fewer technical and biological complications compared to CRRs.¹⁵

A new technique for implant-retained restorations has been proposed incorporating the simplicity of CRRs and the retrievability of SRRs. This original technique is known as cement- and screw-retained implant prosthesis, cement- and screw-retained implant restoration, combination prosthesis, and screw-retrievable CR implant prosthesis.^{16–19} Combined cement- and screw-retained restorations allow to use a definitive cement and to remove the excess cement extraorally. Also, the abutment–crown interface can be polished preventing complications in the peri-implant sulcus. Some papers showed that CRRs had higher fracture resistance than CCSRRs because of the absence of SAH.^{20–22} However, recently some publications reported that the presence of the SAH in CCSRRs does not significantly compromised crown fracture resistance.^{23,24} Moreover, Honda et al.²⁵ demonstrated that CCSRRs using MC design are comparable to porcelain-layered zirconia-based restorations and indirect composite-layered zirconia-based restorations. To our knowledge, although this new approach is a promising prosthetic implant solution, there is no data on fracture resistance of MC CCSRRs using abutments with 15° of angulation, which are used for tilted implants when the clinical conditions impede to use dental implants in a straight position. Besides, there are no studies that have compared the fracture resistance and fracture mode of single-unit MC molar CRRs, SRRs, and CCSRRs.

Hence, the objective of this *in vitro* study was to investigate the fracture resistance of CCSR MC molar restorations compared with CRRs and SRRs using abutments with 15° of angulation. Moreover, the fracture mode and the patterns of fracture origin were also determined.

MATERIALS AND METHODS

This *in vitro* study was performed at the Faculty of Health Sciences of the Universidad Científica del Sur, Lima, Peru. The specimens consisted of 30 single-unit MC implant-retained restorations

(10 specimens per group) representing a mandibular right first molar according to previous similar studies.^{20–22,24}

The materials used in this *in vitro* study are shown in Table 1. One cylindrical Morse taper implant with 4.5 mm diameter and 10 mm length (Super Line Implant, Dentium, Seoul, South Korea) was connected to a 15° prefabricated titanium hexagonal abutment acting collectively as implant-15° abutment. This unit was aligned vertically at 90° to the horizontal plane in an iron holder using a dental surveyor (model 1000 N, Bio-Art, São Carlos, Brazil). This unit was used to simulate a clinical condition with a divergent implant where a 15° angled abutment was necessary to reposition the future crown in an ideal axial position. Autopolymerizing transparent acrylic resin (Vitacron, New Stetic, Antioquia, Colombia) was poured in the iron holder to cover the implant body up to the first thread. Then, a hexagonal impression post was connected to the implant to make an open-tray impression. Subsequently, an implant was screwed to the impression post, the iron holder was placed in the silicone registration, and the autopolymerizing acrylic resin was poured until the iron holder was filled. This procedure was repeated to connect 30 implants securing the same position in all of them. Twenty 15° angled prefabricated titanium hexagonal abutments and ten UCLA plastic metallic ring abutments were connected to thirty implants. All the abutments were cut 3 mm in length using rotary cutting instruments for mandibular right first molar replacement with bucco-lingual, mesio-distal, and occluso-cervical dimensions of 10.5, 11, and 7.5 mm.²⁶ Then, they were randomly divided into 3 groups ($n = 10$) according to the MC implant restoration design: CRR, SRR, and CCSRR.

CR MC Implant Restorations (Group C)

The opening of a 15°-angled abutment was blocked using sticky wax. Then, the abutment received a laser scanning antiglare spray to create an opaque surface. Using an extraoral scanner (Model Smart, Open Technologies, Rezzato, Italy), the 15° abutment was scanned to create a virtual CAD/CAM model pattern. Then, the model was obtained in order to get a silicone index of the crown. The CAD/CAM model pattern was used to fabricate the waxed frameworks unified to a thickness of 0.5 mm for all axial walls, 0.8 mm for the abutment

Table 1: Materials assessed in this study

Material	Trade name	Components	Lot No	Manufacturer
Implant	Super line	Ti 99% (grade IV)	F22D10216	Dentium
Cement abutment	Dual milling abutment	Ti 99% (grade IV)	201609210007	Dentium
Screw abutment	Metal casting abutment	Plastic Cr–Co ring	201609210043	Dentium
Abutment screw	Titanium square	Ti 99% (grade IV)	201609321000	Dentium
Impression post	Impression hexagonal post	Ti 99% (grade IV)	201609312000	Dentium
Autopolymerizing acrylic resin	Acrylic	Methyl methacrylate, benzoyl peroxide initiator 0.3%, hydroquinone 0.006%	208404	New stetic
Casting alloy	Wironia	Ni 64.5%, Cr 22%, Mo 10%	73724	Bego
Feldspathic porcelain	VITA VM13	SiO ₂ , Al ₂ O ₃ , Na ₂ O, K ₂ O, etc.	66660	VITA
Self-adhesive resin cement	RelyX U200	Base paste*, catalyst paste ⁺	634614	3M ESPE
Bonding agent	Single-bond adhesive	Dimethacrylate resins, HEMA, vitrebond copolymer, ethanol, initiators, fillers	N764207	3M ESPE
Filling material	Filtek Z350 XT	Bis-GMA, UDMA, TEGDMA, Bis-EMA resins, fillers	7018A2B	3M ESPE

*Base paste: methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological additives

⁺Catalyst paste: methacrylate monomers, alkaline fillers, silanated fillers, initiator components, stabilizers, pigments, additives

HEMA, 2-hydroxyethyl methacrylate; bis-GMA, bisphenylglycidyl dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; bis-EMA: ethoxylated bisphenol-A dimethacrylate

shoulder, 1 mm for the occlusal surface, and 30 μ m for cement space. The waxed frameworks were invested and were placed in a furnace (Meditherm 100 AN, Bego, Bremen, Germany) following the instructions of the manufacturer. Ni–Cr alloy was melted, and the frameworks were casted using an induction casting apparatus (Fornax T, Bego, Bremen, Germany). The frameworks were divested, and the sprues were cut with a disk. Then, they were calibrated to confirm the thickness and were sandblasted with 110 μ m of pure aluminum oxide particles. Before the porcelain was applied, the frameworks were seated onto the implants to inspect the marginal adaptation visually with a sharp probe and with the use of a digital light microscope under $\times 40$ magnification (Model T-1050, Ken-A-Vision, Kansas, USA). Later, the layering feldspathic porcelain (VITA VM[®] 13, Vident, Bad Säckingen, Germany) was applied to the metal frameworks. After that, the specimens were fired in a porcelain furnace (Vacumat 6000 M, VITA, Bad Säckingen, Germany). Then, a digital caliper (IP67, Mitutoyo, Illinois, USA) was used to verify the thickness, and the specimens were glazed. Finally, to ensure that the veneering porcelain was crack-free, the finished restorations were tested under $\times 40$ magnification.

SR MC Implant Restorations (Group S)

Waxed frameworks reproducing the anatomy and the required dimensions were processed using the CAD/CAM method described above for group C. A perforation of 3 mm was done on the occlusal surfaces using an electric wax knife to access the UCLA cylinder, and after that, a silicone index was made. The waxed frameworks with 3 mm hole were seated on the UCAs acting collectively as waxed UCAs. Subsequently, waxed UCAs were sprued, invested, and casted. Finally, the precision of the frameworks and the porcelain application were checked with the same methods previously mentioned.

Cement- and Screw-retained MC Implant Restorations (Group CS)

The same procedure for group C was followed, except for a perforation of 3 mm that was made in the occlusal surface wax with an electrical wax knife representing the diameter of the abutment screw. A screwdriver tip was connected to the abutment screw head to maintain the SAH after casting and porcelain veneering procedures. Then, a silicone index was made and the procedure was followed by the methods described earlier.

Cementation of Restorations to Implant Abutments

The abutment screws were torqued to 35 N in groups C and S using the torque wrench (SCB 10 IT, Dentium, Seoul, South Korea) as recommended by the manufacturer. The screws were retightened after 5 minutes to counteract the effect of screw-settling phenomenon preventing the screw-loosening under compressive load,²⁰ and the channels were filled with cotton pellets. In group C, the crowns were bonded to the abutments with self-adhesive resin cement (RelyX U200, 3M ESPE, Neuss, Germany), and the excess cement was removed with a no. 12 blade after light-polymerizing.

In group CS, the abutments were fixed to an analog acting as a holder. After that, the crowns were cemented extraorally to the abutments using a self-adhesive resin cement, finger pressure, and light-polymerizing (Fig. 1). The excess cement was removed with the blade, and the interface abutment-crown was polished with a paste (Universal Polishing Paste, Ivoclar Vivadent, Schaan, Germany) and with a wheel (Dia-Finish L Wheel, Renfert, Hilzingen, Germany) (Fig. 2). Thereafter, the crowns cemented on the abutments were

fixed on the implants, and the occlusal screws were torqued. Finally, in groups CS and S, the SAHs were filled with cotton pellets and the composite resin (Filtek Z350, 3M ESPE, MN, USA) was placed on the top.

Fracture Resistance Testing

The fracture resistance testing was performed using a computer-controlled universal testing machine (Model CMT-5L, LG, Seoul, South Korea) with a controlled load at a cross-head speed of 0.5 mm minute⁻¹. A stainless steel rod with a spherical tip of 6 mm diameter was left in simultaneous contact with the buccal and lingual cusps applying a parallel force to the longitudinal axis of the specimens. All the specimens were loaded from 0 N until fracture, and the load values were recorded at the moment of fracture (Fig. 3).

Fracture Mode and Patterns at the Fracture Origin

After fracture resistance testing, the fracture interface of specimens was observed using a digital light microscope under $\times 40$ magnification. Representative specimens were sputter with osmium for 30 seconds and were observed with a SEM (Model Inspect S50, FEI, Oregon, USA) under $\times 100$ magnification. The mode of fractures was classified as adhesive (failure at the MC framework interface) or cohesive (failure within the ceramic).²⁷

Statistical analysis of the data was performed using SPSS 22 (SPSS Inc., Chicago, Ill) software for windows. The Shapiro–Wilk test was analyzed to evaluate normality. Fracture resistance mean values were calculated for the 3 groups and were compared by using one-way ANOVA test followed by the Tukey *post hoc* test ($p < 0.05$).

RESULTS

The results of load and mode fracture testing are shown in Table 2. The highest mean fracture resistance value occurred in group C (2718.00 ± 266.25 N) followed by group CS (2508.00 ± 153.59 N) and group S (2125.10 ± 293.82 N). One-way ANOVA test showed a significant difference between the 3 groups ($p = 0.000$). The results of Tukey *post hoc* test revealed significant differences in load fracture values between the group S and the other groups. However, the difference between group C and group CS was not significant ($p = 0.154$). The results are shown in Table 2.

Regarding the fracture mode, all specimens exhibited mixed adhesive fractures at the mesiolingual cusps. The detachment of

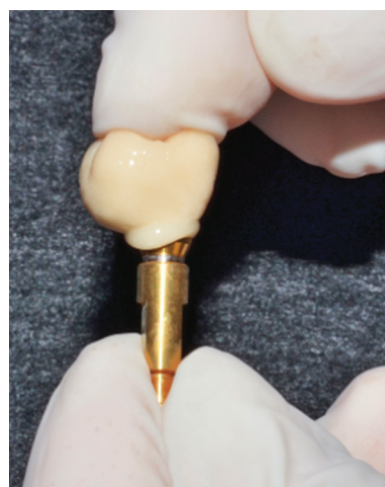


Fig. 1: Finger pressure for combined cement- and screw-retained metal-ceramic implant-supported molar restoration

the ceramic was smaller in group C specimens compared to the other groups with slight parts of metal framework exposures. Moreover, group C showed a limited extent of microcracks with smooth edges around paramarginal areas. Contrarily, group S showed many microcracks generated at the level of the SAH with rough edges. Group CS showed mixed microcracks with smooth and rough edges (Fig. 4). Complete fracture of the restorations, screw bending, screw fracture, or implant neck distortion was not observed in any of the specimens examined.

DISCUSSION

The present *in vitro* study compared the fracture resistance of CR, SR, and CCSR MC molar restorations using abutments with 15° of angulation. Similar methodology has been reported by Mokhtarpour et al.²² and Hussien et al.²⁴ who evaluated the fracture resistance of CR and CCSR in all ceramic restorations. However, currently, MC restorations are still considered the gold standard in implant-supported prosthetic treatments^{4,25} and would be interesting to know the function of the combination prosthesis in this type of restoration. In this study, abutments with 15° of angulation which are required frequently for tilted implants when the clinical conditions impede placing implants in a straight position due to anatomic limitations and atrophic ridges were used. The use of tilted implants avoids common approaches as guided bone regeneration, block grafts, lateralization of the inferior alveolar nerve, and alveolar distraction osteogenesis techniques are often accompanied by unpleasant complications, morbidity, increased cost, and uncomfortable postsurgical period for the patients.^{28,29}

In this study, the mean fracture loads of groups C, S, and CS (2718 N, 2125 N, 2508 N) exceeded the maximum physiological occlusion forces reported on several investigations, namely, Calderon et al.³⁰ (424 N to 587), Palinkas et al.³¹ (234 N to 344 N), and de Abreu et al.³² (424 N to 630 N). However, these results are common in these types of *in vitro* studies.³³ The results of this study revealed significant differences between the groups tested. However, no significant differences in fracture resistance between groups C and CS were observed. Hence, the presence of a SAH does not have a significant effect on the strength of MC cemented crowns where 15° tilted abutments were used. These results are not in agreement with the findings reported by Mokhtarpour et al.²² Nevertheless, these authors evaluated CCSR design in all ceramic central incisors that could have influenced the results.

Fracture resistance of CR and CCSR MC molar restorations were previously compared in studies reported by Al-Omari et al.²⁰ and Shadid et al.²¹ who concluded that CCSR had significantly the lowest values. However, two reasons could justify the differences between the previous studies and this study. First, zinc phosphate cement for cementing the restorations over the abutments was used which is different to self-adhesive resin cement used in this study. Second, the SAH was not filled. In this study, a cotton pellet was used to cover the SAH under the composite resin because this combination is one of the most used on prosthodontic departments.³⁴ Derafshi et al.²³ support the findings of this study. They concluded that there were no significant differences in fracture resistance between CR and CCSR MC molar restorations using straight abutments. Moreover, da Rocha et al.³⁵ reported that SAH had not compromised the retention of metal copings over



Fig. 2: Polishing the abutment-crown interface of combined cement- and screw-retained metal-ceramic implant-supported molar restoration



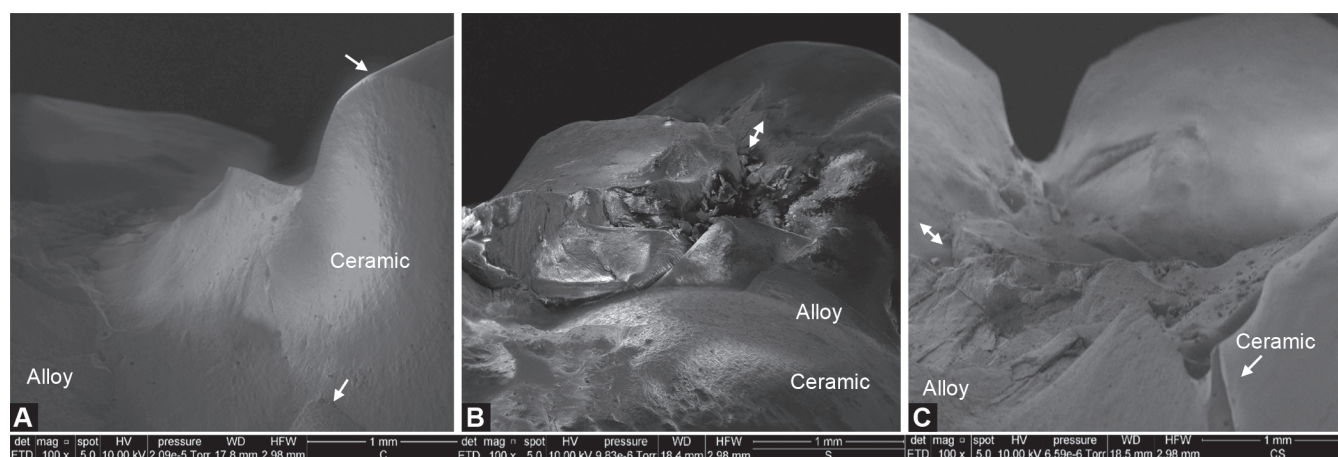
Fig. 3: Experimental set-up for fracture resistance testing

Table 2: Fracture load results in N and fracture mode testing of metal-ceramic implant-supported molar restorations

Group	n	Mean*	SD	CI	Maximum	Minimum	Fracture mode	
							No. of specimens	
							AF	CF
C	10	2718.00 ^a	266.25	2907.74–2528.25	3,043	2,284	10	0
S	10	2125.10 ^b	293.82	2335.28–1914.91	2,576	1,699	10	0
CS	10	2508.00 ^a	153.59	2618.17–2398.42	2,731	2,292	10	0

C, cement-retained MC implant-supported molar restorations; S, screw-retained MC implant-supported molar restorations; CS, combined cement- and screw-retained MC implant-supported molar restorations; AF, adhesive fracture; CF, cohesive fracture.

*Identical letters indicate no statistically significant differences (Tukey *post hoc* test, $p < 0.05$).



Figs 4A to C: Representative SEM images after fracture resistance testing: (A) group C showing fracture patterns of smooth edges (one-tailed white arrow); (B) group S showing fracture patterns of rough edges (two-tailed white arrow); (C) group CS showing fracture patterns of smooth and rough edges (one- and two-tailed white arrows)

the implant abutments. In implantology, it is important to evaluate the marginal fit between CR and CCSR metal copings to have a better understanding of the cementation accuracy. The decrease on fracture strength found in SR MC restorations compared with CR restorations is in accordance with previous studies reported by Sailer et al.⁹ and Zarone et al.³⁶ However, it is impossible to make a direct comparison because of the use of different instruments and materials. SEM observations confirmed the mixed adhesive mesiolingual cusp fractures observed with digital light microscopy. The presence of microcracks around the SAH with rough edges was evident in S and CS groups. However, smaller fractures were observed around the microcracks in the last group. Group C showed limited extent of microcracks with smooth edges spread to the paramarginal areas, and these observations are in accordance with Zarone et al.³⁶ who realized a SEM fractographic analysis between SR and CR MC crowns and more microcracks at the level of the SAH in SR compared with CR restorations were found. An interesting point was that adhesive fractures occurred at the mesiolingual cusps in all the specimens that could have been influenced by the abutment access following the implant direction offset from the center of the occlusal surface towards the lingual cusps.

In this study, prefabricated and UCLA abutments were used similar to a previous clinical study of 12-year follow-up reported by Nissan et al.³⁷ These authors mentioned that SAH in CRRs improves the survival rates and lowers porcelain fracture and screw loosening. These results show that the retrievability of CRRs has an important impact on the cost of maintenance.³⁸

In 2015, Heo and Lim³⁹ proposed to use a specially designed abutment called SCRP for CR frameworks with SAHs on the occlusal surfaces. However, these new abutments lack long-term documentation.¹² The results obtained give greater confidence in the use of this new design for MC retrievable crowns cemented to a titanium abutment as an extraoral or intraoral cementation approach before abutment screw tightening. This type of restoration offers advantages over traditional implant-retained restorations such as retrievability and the ability to use definitive cement, removing the excess cement before clinical placement. Also, these restorations add an interface more capable of dissipating the forces between the implant-abutment connections. Therefore, CCSRRs will be an interesting option for patients with periodontal disease and overload bite.

This study had some limitations. The restorations evaluated did not undergo accelerated aging, such as thermocycling and physiologic fatigue loading. However, Gale and Darvell⁴⁰ stated that there is no consensus about the need of thermocycling use to evaluate *in vitro* specimens. Despite the meticulous protocol followed to achieve the standardization of the restorations, the control of the 3D slumping of porcelain was difficult during the firing process. Nonetheless, in an attempt to standardize the sample, the frameworks were obtained by CAD/CAM process and silicone indexes were used to compare the porcelain applications. Moreover, digital caliper and digital light microscopy were used to evaluate the adaptation between the framework and the porcelain over the abutment shoulder.

Although the results of this study are promising, additional *in vitro* and long-term clinical studies are necessary before developing detailed recommendations for the clinical use of CCSRRs. Also, SAH preparation techniques need innovations and more research as well as the evaluation with different esthetic materials.

CONCLUSION

No significant differences were found on the fracture resistance between cement and CCSR MC molar restorations using abutments with 15° of angulation, but SR design significantly showed the lowest values of resistance. Screw access hole did not significantly affect the fracture resistance of cemented MC molar restorations. All the specimens exhibited mixed adhesive fractures at the mesiolingual cusps.

ACKNOWLEDGMENTS

The authors want to thank the commitment and skills of the dental technician Stefano Romano for his professional support in the fabrication and standardization of all the specimens tested.

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