Original Research
Dental Materials

The effect of the die material used in the indirect technique on the fracture resistance of a restored molar

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Abstract: The aim of this study was to evaluate the effect of different die materials used in the indirect resin composite restorative technique on the fracture resistance and failure mode of restored molars and compare it with the direct resin composite restorative technique. Two flexible die silicone materials for dental models (Die Silicone – Voco and Scan die – Yller) and a type IV dental stone material (Fujirock EP – GC) were evaluated. Sixty third molars were selected and divided into four groups: indirect resin composite restoration – Die silicone (IRCR-DS); indirect resin composite restoration – Scan die (IRCR-SD); indirect resin composite restoration – Fujirock EP (IRCR-FR), and direct resin composite restoration (DRCR). Class II MOD cavities were prepared with 5 mm of buccolingual width and depth. The specimens were restored and subjected to an axial compression load until fracture, and the data were analyzed by one-way ANOVA and Tukey's HSD test (α=.05). The fracture mode was classified into restorable and unrestorable fractures. Fracture resistance values were influenced by the die material used for the IRCR fabrication and by the restorative technique ($p<.001$). Fracture resistance mean values and standard deviation were: IRCR-DS: 1835.5 ± 324.0 A; IRCR-SD: 1732.5 ± 384.1 AB; IRCR-FR: 1419.3 ± 318.8 BC; and DRCR: 1100.6 ± 224.9 C. Restorable fracture was more prevalent. IRCR with flexible die casts promoted higher fracture resistance and lower prevalence of unrestorable fractures.

Keywords: Flexural Strength; Composite Resins; Dentistry.

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Introduction

Direct resin composite restorations (DRCR) have been widely used in recent decades.[1] The improvement of mechanical and adhesive properties associated with tooth structure preservation has contributed to their use in large mesio-occlusal-distal (MOD) tooth cavities in the conservative approach employed in modern dentistry.[2] Large MOD tooth cavities restored with resin composite have shown a higher failure rate in posterior teeth when compared to small cavities.[3-6] Large MOD tooth cavities are identified by the presence of multiple restored surfaces or when the width of the isthmus exceeds one-third of the distance between the facial and lingual cusp tips, involving a large tooth area.[7-10]

Although a similar clinical performance is found in some studies on the use of direct and indirect techniques to restore large MOD tooth cavities in posterior teeth,[10-12] the direct technique has several challenges such as poor marginal adaptation and difficulty in obtaining an appropriate occlusal anatomy and interproximal contact.[13,14] This process could be more easily performed with indirect resin composite restorations (IRCR) to restore MOD cavities.[14-16] In addition, the indirect technique may decrease polymerization shrinkage stress because the resin composite is usually cured in a cast model.[17]

The polymerization of resin composites is inherently followed by volumetric shrinkage, which causes stress.[17,18] Shrinkage stresses can compromise the bonded interfaces and they are commonly associated with cuspal flexure, postoperative sensitivity, microleakage, secondary caries, and other symptoms.[19-21] Polymerization shrinkage stress depends on multiple factors, such as radiant exitance, mechanical properties of resin composite, geometry and extension of the cavity, and the restorative technique used.[18] This inevitable volumetric shrinkage has its origin in the polymer network formation during the polymerization reaction. The volumetric shrinkage behavior can be divided into two phases: pre- and post-gel shrinkage.[19,20] During pre-gel shrinkage, an initial rearrangement of monomers (viscous flow) can relieve stress development.[20,21] Therefore, the volumetric shrinkage phase that causes residual stresses is called post-gel shrinkage. In the post-gel shrinkage phase, a semi-rigid polymer network is formed, prevents further rearrangement of monomers, and is consequently responsible for the residual shrinkage stress when the composite is bonded to a tooth. The IRCR allows polymerization shrinkage of the composite to occur in a cast model, and as the composite is not bonded to it, free shrinkage reduces the polymerization stress.[22,23] Furthermore, additional polymerization can also promote better polymerization of the resin composite at all depths of restoration.[24,25]

The indirect technique can be performed either with ceramic or resin composite materials.[17,26] Although ceramic inlays are the first choice for most clinicians, the use of resin composite is a viable option in terms of shorter treatment time and costs.[27,28] Restorations can also be performed on dies with different pouring materials (flexible die or stone cast). Both materials can be used in the dental office for the indirect resin composite technique and eliminate laboratory costs. However, the indirect resin composite technique using a flexible die is faster and easier than the use of a stone cast, which reduces the time spent to fabricate the restoration.[9,16,29]

In the literature, studies comparing different indirect techniques with resin composite and direct technique are sparse. Currently, most studies consist of clinical reports or technical descriptions.[9,16,30] Besides, there is no consensus on which indirect techniques or materials used for cast pouring promote better outcomes related to the biomechanical properties of the restorative complex and its comparison with the direct technique. Therefore, the aim of this *in vitro* study was to evaluate the effect of different die materials used for restorations with the indirect technique on the fracture resistance and failure mode of restored molars. Moreover, the study also aimed to compare the indirect techniques with the direct technique (DRCR). The null hypothesis tested was that the different die materials used for the indirect resin composite fabrication and the restorative technique (direct or indirect) would not affect the fracture resistance of the restored molars.

Methodology

Specimen selection and cavity preparation

This study was approved by the local Research Ethics Committee (Process: 05443918.9.0000.5083). Sample size calculation was based on data from previous studies, and it was determined to be n=10 for fracture resistance and failure mode.[31,32] Sixty extracted third molars were selected, cleaned with a rubber cup and fine pumice slurry, and stored in distilled water. The selected teeth should have an intercuspal width maximum deviation of no more than 10% of the determined mean. The measured buccolingual width varied between 9 mm and 11 mm and the mesiodistal width varied between 10 mm and 12 mm. Teeth with fractures or cracks were not included.

The teeth were embedded in autopolymerizing polystyrene resin cylinder (G4, Polipox, Cesário Lange, Brazil) 2 mm below the cervical limit, and the periodontal ligament was simulated with polyether impression material, resulting in a 0.2-mm to 0.3-mm thick layer (Impregum Soft, 3M Oral Care, St. Paul, USA).[33] The teeth were randomized and divided into four groups according to the die material and restorative technique used: a) Indirect resin composite restorations with die silicone (IRCR-DS); b) Indirect resin composite restorations with scan die (IRCR-SD); c) Indirect resin composite restorations with Fujirock EP (IRCR-FR); and d) Direct resin composite restorations (DRCR) (Table 1). Two flexible die silicone casts and one type IV stone cast were tested (Table 2).

MOD cavities were prepared in all specimens with buccolingual width of 5 mm and depth of 5 mm without proximal boxes (Figure 1A), by using a cavity preparation machine with a high-speed handpiece (605 C; KaVo Dental, Biberach, Germany) and a taper diamond bur (#3139, KG Sorensen, Barueri, SP, Brazil) under copious air-water spray (Figure 1B) and checked with a digital caliper.[33] The diamond bur was replaced every five preparations. After cavity preparation, a custom tray was made with acrylic resin (Duralay, Reliance, São Paulo, Brazil) for all IRCR groups for the impression procedure.

Impression and restorative procedures

Impressions were performed with irreversible hydrocolloid (Hydrogum 5, Zhermack, Badia Polesine, Italy) for IRCR-DS and IRCR-SD, following the manufacturer's instructions. An impression with polyvinyl siloxane (Virtual, Ivoclar Vivadent, Schaan, Liechtenstein) was performed for IRCR-FR and followed by cast pouring with the material corresponding to each group to obtain a definitive cast (Figure 2A, 2B, and 2C).

A polytetrafluoroethylene matrix to standardize the increment size was developed to fabricate restorations with the same volume (25.12 mm^3) in all increments (Figure 2D). The increment of resin composite was inserted in the matrix to standardize the size and volume of the increment before its insertion into the cavity. Prior to the

Table 1. Description of the experimental groups.

Number of groups	Restorative technique	Material used	Abbreviation
1	Indirect resin composite restorations	Die silicone cast (Voco)	IRCR-DS
2	Indirect resin composite restorations	Scan die cast (Yller)	IRCR-SD
3	Indirect resin composite restorations	Fujirock EP cast (GC)	IRCR-FR
4	Direct resin composite restorations	Tooth	DRCR

Table 2. Summary of materials used.

Brand	Lot number	Manufacturer	Material class	Abbreviation
Die silicone	1833190	Voco	Addition-curing silicone for extraoral fabrication of dental models	IRCR-DS
Scan die	3074	Yller		IRCR-SD
Fujirock EP	131156000	GC	Type IV dental stone	IRCR-FR
Filtek Z350 XT	680905	3M Oral Care	Resin composite	Z350
Scotchbond Multi-Purpose Plus Adhesive	NC00803	3M Oral Care	Adhesive	SC-AD
	N921283	3M Oral Care	Primer	SC-PR
Rely X ARC	191560011	3M Oral Care	Resin cement	ARC

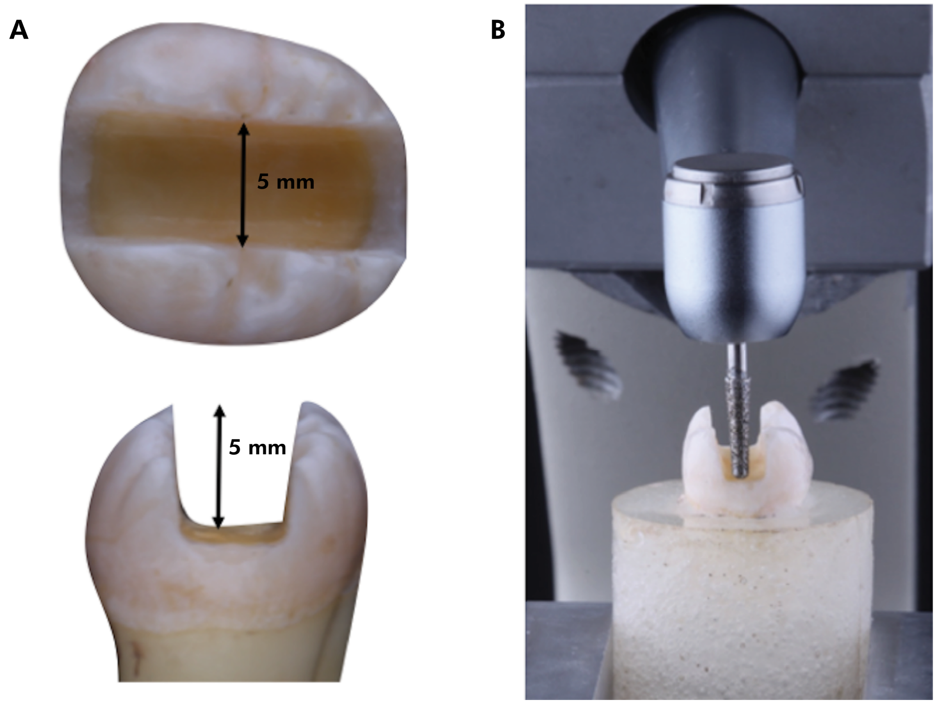

Figure 1. Tooth preparation and preparation machine. (A) Standard large MOD cavity and corresponding measurements. (B) Specimen during preparation positioned on the preparation machine.

IRCR-FR group restorations, cyanoacrylate (Superglue, Loctite, Düsseldorf, Germany) was applied in order to prevent excessive retention of the restoration by the cast. The superglue was also used to prevent damage to the stone cast because of its rigid characteristics and worked as a spacer material for the resin cement.[34] A nanoparticle resin composite (Filtek Z350 XT – A2B shade; 3M Oral Care, St. Paul, USA) was used for all groups and was incrementally inserted with 2-mm thickness and light-cured for 20 seconds with a polywave LED curing unit (Valo Cordless; Ultradent, Salt Lake City, USA) at 1,000 mW/cm^2 of irradiance. A total of 14 increments were used for the restorations, three in each proximal box (mesial and distal) and eight in the occlusal box. All IRCR (Figure 2E, 2F, and 2G) were subjected to an additional polymerization process in a polymerization device for 180 seconds with a 200W power lamp (Hi-Lite Power 3D, Kulzer, Hanau, Germany).

For groups IRCR-DS, IRCR-SD, and IRCR-FR, the restoration was made in the respective casts and, if necessary, it was adjusted with abrasive discs to ensure complete passive seating of the restorations into the cavity (Sof-Lex Pop-on, 3M Oral Care, St. Paul, USA). The inner surface of the restorations was cleaned with 37% phosphoric acid (Condac, FGM, Joinville, Brazil) for 30 seconds, rinsed with water spray, and dried out for 30 seconds, and then a silane coupling agent (Prosil, FGM, Joinville, Brazil) was applied for 60 seconds. For the tooth substrate, an etch-and-rinse adhesive system was chosen. The MOD preparation was etched with 37% phosphoric acid (Condac, FGM) for 30 seconds in the enamel and 15 seconds in the dentin, rinsed with water spray for 30 seconds, and dried out with absorbent paper. After that, the activator (Scothbond Multi-purpose Plus Activator, 3M Oral Care) was applied and dried for 10 seconds, followed by the primer (Scothbond Multi-purpose Plus Primer, 3M Oral Care), also applied and dried for 10 seconds. The catalyst (Scothbond Multi-purpose Plus Catalyst, 3M Oral Care, St. Paul, USA) was then applied. The restorations were luted with a dual-cured resin cement (RelyX ARC, 3M Care, St. Paul, USA), followed by excess cement removal and light-cured with the polywave LED

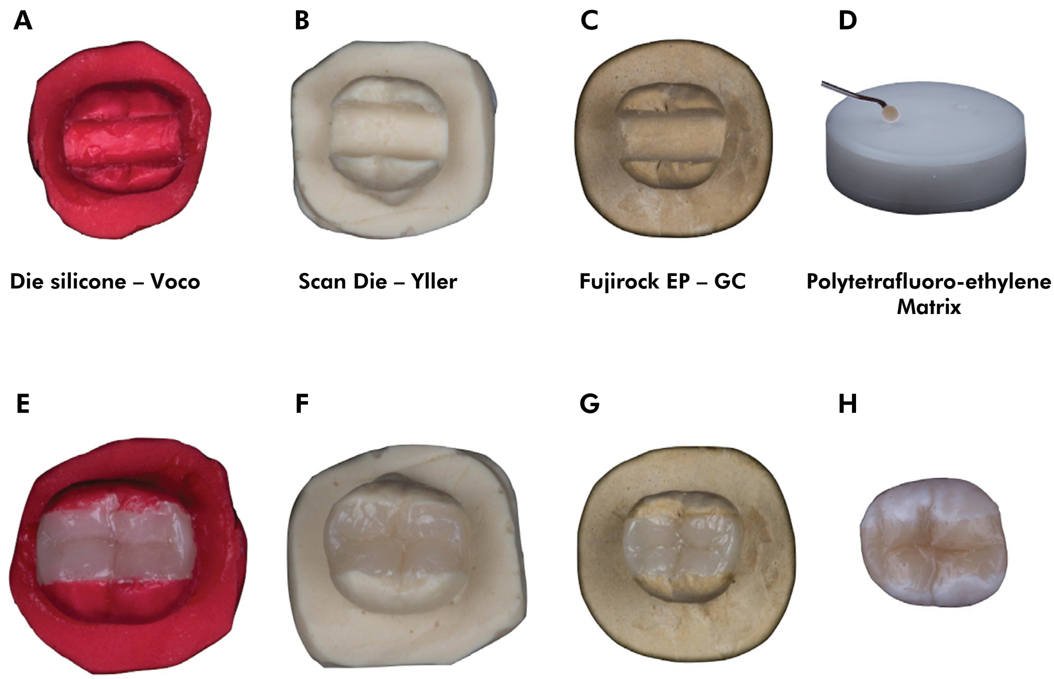

Figure 2. Cast models, polytetrafluoroethylene matrix, and models with restorations. (A) Die silicone – VOCO. (B) Scan die – Yller. (C) Fujirock EP – GC. (D) polytetrafluoroethylene matrix. (E) ICCR-DS. (F) ICCR-SD. (G) IRCR-FR. (H) DRCR.

curing unit (Valo Cordless) for 20 seconds on each tooth surface: mesial, occlusal, and distal.

For DRCR, the adhesive process was different. In this group, the MOD preparation was etched with 37% phosphoric acid (Condac, FGM, Joinville, Brazil) for 30 seconds in the enamel and 15 seconds in the dentin, rinsed with air-water spray for 30 seconds, and dried out with absorbent paper. The primer (Scothbond Multi-purpose Plus Primer, 3M Oral Care) was applied and dried for 10 seconds and followed by the adhesive (Scothbond Multi-purpose Plus Adhesive, 3M Oral Care, St. Paul, USA). The excess was removed with air spray and the adhesive was light-cured for 20 seconds. After that, the restorations in the DRCR group were performed with the conventional incremental placement technique also using the polytetrafluoroethylene matrix to standardize the size and volume of each increment.

Fracture resistance and failure mode

After 24 hours, the specimens were subjected to an axial compression load on a mechanical test machine (Instron 3367, Instron Corp, Norwood, USA) with a 6-mm diameter metal sphere at a crosshead speed of 0.5 mm/min at the center of the occlusal surface. The load required (N) to fracture the specimens was recorded by a 5KN load cell hardwired to the software (BlueHill 3, Instron Corp, Norwood, USA). Fracture resistance data were checked for homoscedasticity and were analyzed by one-way ANOVA and Tukey's honestly significant difference (HSD) test ($\alpha = 0.05$). A stereomicroscope (Leica, Ecafix, Tokyo, Japan) at 40x magnification was used to determine the failure mode, which was classified into: 1- restorable fractures and 2- unrestorable fractures. The cementoenamel junction was considered for fracture classification. Fractures that occurred above the cementoenamel junction or 1 mm below it were considered restorable. Fractures that occurred 2 mm below the cementoenamel junction were considered unrestorable.

Results

The mean fracture resistance (N) values and standard deviation (SD) are shown in Table 3. The one-way ANOVA showed that the different die materials used for the IRCR fabrication and the restorative technique (direct or indirect) influenced fracture resistance ($p < 0.001$).

The IRCR-DS group showed higher fracture resistance than that of the other groups. The teeth restored with die silicone casts (IRCR-DS and IRCR-SD) were not significantly different from each other ($p = 0.887$) and were statistically different ($p < 0.001$) from the direct technique restoration group (DRCR). The DRCR group presented the lowest fracture resistance, but it was not statistically different ($p = 0.132$) from the group restored with stone cast (IRCR-FR).

The failure mode distribution for the different groups is presented in Figure 3. The IRCR-DS and IRCR-SD groups had higher incidence of restorable fractures than did the IRCR-FR and DRCR groups. All groups presented a low percentage of unrestorable fractures.

Discussion

The null hypothesis that the different die materials used for the indirect resin composite fabrication and the restorative technique (direct or indirect) would not affect the fracture resistance of the restored molars was rejected because the one-way ANOVA

Table 3. Mean fracture resistance (N) values (SD) and results of Tukey's HSD test.

Restorative technique	Fracture resistance (n)	Tukey's test (HSD)
Indirect resin composite restorations –Die silicone (Voco) – (IRCR-DS)	1835.5 ± 324.0	A
Indirect resin composite restorations – Scan die (Yller) – (IRCR-SD)	1732.5 ± 384.1	AB
Indirect resin composite restorations – Fujirock EP (GC) – (IRCR-FR)	1419.3 ± 318.8	BC
Direct resin composite restorations – (DRCR)	1100.6 ± 224.9	C

Different uppercase letters in the rows indicate statistical difference; Tukey's honestly significant difference test ($p < 0.05$).

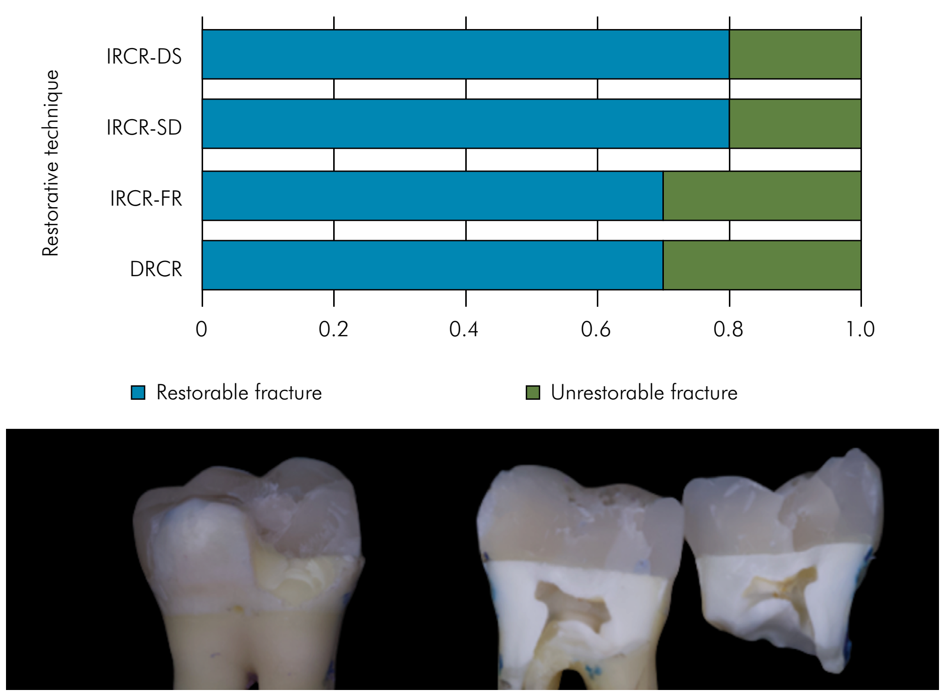

Figure 3. Failure mode distribution.

showed that there were significant differences ($p < 0.001$). IRCR-DS and IRCR-SD promoted higher fracture resistance than that of IRCR-FR and DRCR ($p < 0.001$). No difference was found between IRCR-DS and IRCR-SD ($p = 0.887$). IRCR-DS and IRCR-SD were performed in a flexible die cast, which combines an appropriate dimensional stability and flexibility, allowing removal of the restoration from the cast without damage to the restoration or cast.[29] In addition, a relief in the cast prior to the resin composite restoration is not required as this flexibility favored adaptation and probably contributed to the higher fracture resistance found. In another study, a randomized clinical trial indicated that IRCR and DRCR were acceptable in terms of durability after a 24-month follow-up,[10] but some indicated better outcomes for IRCR in large MOD cavities,[3] including a study with a three-year follow-up.[15]

Intermediate fracture resistance mean values were observed for the IRCR-FR group. A stone cast is a rigid model. Based on its structural characteristic, it is necessary to perform a relief before fabricating the restoration to prevent damage to the restoration or to the stone cast.[30] The relief may generate a thicker resin cement layer that should be filled with resin cement. Some studies that evaluated the influence of the resin cement layer demonstrated that thicker layers negatively influence the mechanical behavior as the cementation layer is considered the weakest point for this type of restoration.[29]

The DRCR promoted the lowest fracture resistance ($p < 0.001$). DRCR were performed with the incremental placement composite technique and was not subjected to an additional polymerization process because it should be performed intraorally. Large MOD tooth cavities are associated with weakened cavity walls. A large part of shrinkage stress in large MOD cavities performed by the direct technique is transmitted to the remaining tooth walls, contributing to the risk of higher levels of deformation and cusp flexure, generating lower fracture resistance.[19] Some previous studies have indicated that size and configuration of the cavity affect the amount of tooth deformation and that MOD cavities are a critical situation caused by the loss of tooth rigidity with removal of the marginal ridges.[3,19,22,35]

Failure mode was not significantly influenced by the restorative techniques, although IRCR-DS and IRCR-SD exhibited a lower percentage of unrestorable fractures than did the IRCR-FR and DRCR. A lower prevalence of unrestorable fractures in IRCR-DS and IRCR-SD can also corroborate that flexible die casts promote better adaptation to the cavity. On the other hand, all the restorations in this study were performed with only one resin composite to prevent material bias between the groups and to allow observing the influence of the cast model material. Resin composite is a material with similar mechanical properties when compared to dentin, especially regarding the elastic modulus. This property favors a better mechanical behavior of the tooth-restoration complex, resulting in a lower number of catastrophic fractures in all groups analyzed.[23,36,37]

There are some limitations in this *in vitro* study such as the application of static loads and absence of aging protocols. Although static loading does not simulate the natural forces present in the masticatory function and the importance of thermomechanical cycles, this study design was selected to prevent external factors that may affect the outcomes. Only one composite, bonding system, and cavity configuration were selected, thus eliminating the influence of any material and configuration, with exception of die material, on the outcomes. Based on our findings, indirect resin composite restorations (especially those with flexible die casts) are presented as a viable option, when compared to the direct composite resin technique and ceramic restorations, for patients who need restorations of large single-tooth MOD cavities. Through this technique, the clinician can achieve fast results in a cost-effective manner because the technique is not so expensive as the restorative procedure with ceramics. In addition, several suggestions for improvement of this technique also have been published.[16] However, the results of our laboratory study should be complemented with future studies, including prospective clinical studies, to evaluate the size and thickness of the resin cement line, gap formation, and misfit in order to better understand the differences between the tested die materials and the clinical behavior of the restorations.

Conclusion

Notwithstanding the limitations of this *in vitro* study, IRCR-DS and IRCR-SD promoted higher fracture resistance and presented a lower percentage of unrestorable fractures.

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