Micro-Shear Bond Strength of Novel MDP Calcium-Fluoride–Releasing Self-Adhesive Resin Cement After Thermocycling

Aliaa Mahrous, DDS, MDS, PhD1
Mohamed M. Radwan, DDS, MDS, PhD2
Samah Mohamed Kamel, DDS, MDS, PhD3

The purpose of the present study was to (1) investigate the micro-shear bond strength and failure mode of a novel methacryloxydecyl-dihydrogen-phosphate (MDP) calcium-fluoride–releasing self-adhesive resin cement (TheraCem, BISCO) to a tooth structure (enamel and dentin) and to yttrium-stabilized zirconia after thermocycling, and to (2) compare the results with a universal non–MDP-containing self-adhesive resin cement (RelyX Unicem, 3M ESPE) as a control. Enamel and dentin specimens (20 discs each) were obtained by using a diamond saw (IsoMet 4000, Buehler) with copious water coolant. Twenty zirconia plates were obtained from IPS e.max ZirCAD blocks (Ivoclar Vivadent) and sintered in an inFire HTC speed high-temperature furnace (Dentsply Sirona). Resin-cement micro-cylinders were created on the bonded surface and filled with the tested cements (n = 10 for each surface/cement combination): Group A (control) used non–MDP-containing RelyX, while group B (tested cement) used MDP-containing TheraCem MDP. Cements were left to self-cure for 5 minutes. All specimens were thermocycled for 5,000 cycles (THE-1100, SD Mechatronik). Micro-shear bond strength was measured using a universal testing machine, and debonded surfaces were examined for failure mode analysis with all morphologic and ultrastructure changes using a scanning electron microscope (Quanta 250 Field Emission Gun, FEI) attached with an energy dispersive x-ray (EDX) unit. The results were statistically analyzed. TheraCem had a slightly higher micro-shear bond strength (MPa) value than RelyX. Within enamel, TheraCem (6.46 ± 1.37 MPa) had a significantly higher mean µ-SBS value than RelyX (3.04 ± 0.99 MPa) (P = .002). Similarly, TheraCem in dentin (10.67 ± 1.27 MPa) had a significantly higher mean value than RelyX (6.46 ± 1.74 MPa) (P = .014). As for zirconia, TheraCem (39.76 ± 1.18 MPa) had a significantly higher mean µ-SBS value than RelyX (27.04 ± 1.92 MPa) (P < .001). Using MDP-containing calcium-fluoride–releasing self-adhesive resin cement (TheraCem) may improve bond strength to all tested substrates (enamel, dentin, and zirconia) and can be considered a promising cement for many clinicians. Further clinical studies are required to provide long-term clinical success data. Int J Periodontics Restorative Dent 2020;40:445–455. doi: 10.11607/prd.3992

The clinical success of any adhesive resin cement can be primarily evaluated by proper marginal sealing of the adhesive with both the restoration and tooth structure. The ideal adhesive cement must have sufficient strength, biocompatibility, good wettability, and dissolution resistance. In conventional resin cements, a pretreatment procedure is required to achieve adhesion, but the procedure is complicated, as bond strength is weakened when the moisture-proofing or dentin wettability is not properly maintained.1,2 A self-etching system was developed to use a new type of adhesive resin cements that eliminated the need for a separate priming step,3 simplified the treatment procedures, and prevented the collapse of the collagen fibers in the dentin through acid-etching. The self-etching system has recently attracted the interest of researchers and clinicians as it was recommended not only for tooth-tissue bonding and composites but also for most of the indirect restorations such as zirconia and glass-ceramics.3,4 However, the permeation of moisture through the adhesives can cause the bond strength to deteriorate when hardening is delayed. To overcome this problem, self-adhesive resin cements that combine the adhesives and cements were developed.5 These cements became the
most widely used adhesives, as they offer the mechanical, esthetic, and adhesive advantages of typical resin cements and do not require pre-treatments due to their acidic functional monomer.6

The basic bonding mechanism to tooth structure depends on mineral exchange by resin monomers that form micromechanical interlocking in the surfaces.2 Bonding durability of these adhesives have been studied to explain the adhesion mechanism with tooth structure (enamel and dentin), and it was reported that the type of acidic monomer in adhesives may play a major role in producing a stable chemical bond, with methacryloxydicyl-dihydrogen-phosphate (MDP)-containing materials making the most stable bond. MDP bonds to hydroxyapatite and results in an intermediate layer consisting of two MDP molecules, with methacrylate groups being directed towards each other while phosphate groups are directed away from each other, and calcium salts are deposited between the layers of their phosphate groups.5,6

Adhesive resins with added calcium and phosphate ions can act as a reservoir on the tooth surface, as these ions are released in acidic media to facilitate the remineralization that may positively affect the shear bond strength with the tooth surface.7,8

As ceramic materials continue to evolve, they have become the first option for many clinical cases, especially with patients’ increasing esthetic demands. On the other side, the use of ceramics in long-term restorations have been limited till the introduction of high strength ceramics which possess unique and excellent mechanical properties. Nowadays, zirconia is commonly selected in restorations all over the world. It’s well documented that, zirconia restorations can be cemented by any traditional cements, but the reliable adhesion of adhesive resin cement to zirconia improves the marginal seal, retention and subsequently the fracture resistance of the restoration.9

During the last 15 years, many studies discussed the bonding challenges of zirconia restorations that face clinicians daily; zirconia has an inert surface which complicates obtaining the required micro-retention bond.10,11 Many trials were conducted to increase zirconia adhesive bond strength. Silica coating, airborne-particle abrasion, and laser and acid etching have all been tested, with no significant improvement in resin-zirconia bond strength reported.9,12 Researchers have reported that the functional monomer 10-MDP contains primers that may positively affect resin-zirconia bond strength.

The improvement of the bond strength between zirconia and resin substrate is obtained through chemical bonding with the oxide layer.13,14 MDP monomers contain functional phosphate ester groups that directly form a chemical bond to the metal oxides of zirconia. The first MDP-containing material was owned by Kuraray Company.15

Interestingly, many studies discussed how an MDP-containing primer, conditioner, or adhesive cement may affect the zirconia bond strength.15,16 The bond strength of MDP-containing materials may be affected after artificial aging or thermocycling, as MDP molecules lack bonding stability.15,16

The aim of the present study was to investigate the micro-shear bond strength of new MDP-containing calcium-fluoride-releasing self-adhesive resin cement (TheraCem, BISCO) to tooth structure (enamel, dentin) and zirconia after thermocycling as compared to non–MDP-containing self-adhesive resin cement (RelyX Unicem, 3M ESPE). Furthermore, the study analyzed debonded surfaces to detect the failure mode with all structural and morphologic changes.

The first null hypothesis tested was that the micro-shear bond strength of new MDP-containing calcium-fluoride-releasing self-adhesive resin cement (TheraCem) will be significantly higher than non–MDP-containing self-adhesive resin cement (RelyX Unicem). The second hypothesis was that TheraCem will have higher bonding to enamel, dentin, and zirconia substrates.

**Materials and Methods**

The study was divided into two different parts: the first part was concerned with evaluating the enamel and dentin bonding using different types of cement while the other part was related to evaluating zirconia-ceramic bonding. All groups (n = 10) were subjected to micro-shear bond strength test and failure mode analysis, with all morphologic and ultrastructure changes on the debonded surface.
Enamel and Dentin Specimen Preparation

A total of 40 freshly extracted non-caries mandibular permanent first and second molars were collected for the present study. The selected molars should have an intact enamel surface, no cracks, and no previous treatment with chemical agents. All molars were ultrasonically cleaned to remove all debris, calculus, and periodontal tissues. The roots were trimmed off using a diamond saw (IsoMet 4000, Buehler) with copious water coolant. The teeth were stored in 0.5% chloramine solution in a refrigerator at 4ºC and used within 1 month of extraction.

For the enamel specimen preparation, 20 molars were used to obtain enamel discs by sectioning the teeth buccolingually using the diamond saw with copious water coolant. For the preparation of dentin specimens, the occlusal surfaces of the remaining 20 molars were cut to the midcoronal part of the dentin without exposing pulpal tissue.

All prepared enamel and dentin specimens were embedded in split, cylindrical Teflon (Sturbridge Metallurgical Services) molds filled with self-cure acrylic resin, with the bonding site facing up for testing. After complete setting of the self-cure resin, molds were carefully removed, and specimens were kept in 100% humidity at 4ºC until cementing time.

Prior to the cementing procedure, the enamel and dentin specimens were polished with wet silicon-carbide sandpaper (grit size 600; SAIL Brand) for 30 seconds to standardize a smear layer on the bonded surface. The silicon-carbide paper was changed after every 10 specimens. Finally, all specimens were washed with distilled water and dried with oil-free air.

Zirconia Specimen Preparation

A total of 20 zirconia ceramic plates were obtained from IPS e.max ZirCAD blocks (Ivoclar Vivadent) using the diamond saw with copious water coolant. Zirconia specimens were sintered in an inFire HTC speed high-temperature furnace (Dentsply Sirona). The plates were embedded in split cylindrical Teflon molds filled with self-cure acrylic resin with the bonding site facing up for testing. The bonded zirconia surfaces were all polished with 600-, 800-, and 1,200-grit silicon-carbide paper (SAIL Brand) under continuous use of water coolant. Finally, zirconia specimens were ultrasonically cleaned in distilled water for 5 minutes before bonding procedures.

Bonding Procedures for All Substrates

Resin-cement cylinders (0.75-mm diameter × 1-mm height) were created using translucent mold (TYG-030 Tygon tubing, Saint Gobain Performance Plastic) positioned over specimens and filled with the tested cements: RelyX Unicem for group A (control), and TheraCem for group B (test). A total of 60 cylinders were created: 10 per tested surface for each cement type (30 tubes for each cement group and 10 per surface/cement combination). Both groups were left to self-cure for 5 minutes, according to the manufacturers’ instructions. Resin-cement cylinders were exposed by using a surgical scalpel blade (No. 15, Swann-Morton) to remove the molds. Before testing, all resin-cement micro-cylinders were checked for defects at the bonding interface.

All specimens (n = 10 for each surface/cement combination; enamel, dentin, and zirconia) were immersed in water at 37ºC for 24 hours. Using a thermocycling device (THE-1100, SD Mechatronik), the specimens were then thermocycled for 5,000 cycles between 5ºC and 55ºC with 60 seconds of dwell time at each bath before testing.

Micro-Shear Bond Strength Test

Each specimen with its bonded resin micro-cylinder was fixed with tightening screws to the lower fixed compartment of the mechanical testing machine (Model 3345, Instron) with a 5-kN load cell. A mono-bevel chisel-ended rod was aligned with the loading axis of the upper movable compartment of the machine at a crosshead speed of 0.5 mm/minute to apply the shearing load as close as possible to the resin micro-cylinder base. The load required for debonding was recorded in Newtons using a computer software (Bluehill Lite Software, Instron). Micro-shear bond strength was calculated from the following equation:

\[
\tau = \frac{P}{\pi r^2}
\]
Where \( \tau \) is the micro-shear bond strength (MPa); \( P \) is the load at failure (N); \( \pi = 3.14 \); and \( r \) is the radius of the micro-cylinder (mm).

**Scanning Electron Microscope**

After debonding, three specimens of each group were randomly selected, and the debonded surfaces were examined for failure mode analysis with all morphologic and ultra-structural changes using a scanning electron microscope (SEM; Quanta 250 Field Emission Gun, FEI) attached with an energy dispersive x-ray (EDX) unit with an accelerating voltage of 30 kV, \( \times 14 \) magnification (up to 1,000,000), and a secondary electron detector for the gun. Failure mode was categorized as adhesive, cohesive, or mixed. Numerical data were explored for normality by checking the data distribution, calculating the mean and median values, and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed parametric distribution, so it was represented by mean and standard deviation (SD) values. Independent \( t \) test was used for different intergroup comparisons. The significance level was set at \( P \leq .05 \) for all tests. Statistical analysis was performed with SPSS version 25 (IBM) for Windows.

**Results**

The following values are expressed as mean ± SD. The results showed that the micro-shear bond strength of the tested cement TheraCem (18.96 ± 4.36 MPa; test group) had a slightly higher value than RelyX Unicem (12.18 ± 3.13 MPa; control group) \( (P = .177) \).

Within enamel, TheraCem (6.46 ± 1.37) had a significantly higher micro-shear bond strength value than RelyX (3.04 ± 0.99) \( (P = .002) \). Similarly, TheraCem within dentin (10.67 ± 1.27) had a significantly higher micro-shear bond strength than RelyX (6.46 ± 1.74) \( (P = .014) \) (Fig 1). For both groups, the cement’s dentin micro-shear bond strength values were statistically significantly higher than the enamel values \( (P = .031 \) and \( P = .001 \) for RelyX Unicem and TheraCem, respectively). Regarding zirconia, micro-shear bond strength for TheraCem was significantly higher than for RelyX (39.76 ± 1.18 and 27.04 ± 1.92, respectively) \( (P < .001) \) (Fig 1).

Using the SEM with EDX to examine the specimens (Fig 2) showed that in all tested enamel groups, the failure mode of the debonded enamel surface was mixed with many detached cement areas, with a less-homogenous cement spread in the RelyX group than in the TheraCem group. EDX analysis revealed increases in calcium and phosphorus concentrations in TheraCem group, indicating formation of calcium-phosphate deposits at the surface.

Regarding the debonded dentin surface (Fig 3), some empty dentinal tubules resulted in a mixed failure mode in the RelyX group, while the TheraCem group showed complete obliteration of the dentinal tubules, with resin tags indicating cohesive failure. EDX analysis showed an increase in calcium concentrations in TheraCem group, explaining formation of calcium precipitations at the surface.
failure mode was cohesive in most specimens within the resin cement in TheraCem but mixed in RelyX.

Zirconia surfaces (Fig 4a) showed a small area of RelyX cement covering less than 50% of the surface, with a few cement islands on the surface. TheraCem (Fig 4b) was spread more homogenously, covering more than 50% of the surface and having more islands of cement distributed over the remaining area. The islands in TheraCem were many and smaller but distributed in more areas as it was dragged off the surface, explaining the cohesive failure in most examined samples.

Higher magnifications showed a difference in the grain size of the RelyX group (Fig 4c). This difference was decreased in the TheraCem group (Fig 4d), which aided in better flowability and adhesion to zirconia. The failure mode was mainly mixed in both cements with an increased cohesive ratio at TheraCem.

**Discussion**

Due to the outstanding efficacy of resin cements, their clinical application has increased, and their simplicity was reported in many vivo and in vitro studies. Nevertheless, it is important to know that the market has many varieties of commercial brands of resin cements. To clarify, each category of adhesive resin cement has an individual and unique chemical composition that determines its interactions with the tooth structure and different restorative materials.

Self-adhesive resin cements can provide a reliable bond to dental structures while eliminating the etching procedure and need for bonding application. As their application is accomplished in one step, they save time and are very attractive to
The bonding mechanism of these adhesive resins relies on chemical reactions rather than on micromechanical retention.16 After the application of self-adhesive cement, the phosphoric acid methacrylate can cause demineralization of the hard dental tissues.2 However, despite the initial acidic pH (pH < 2.0), the tooth tissues can only be superficially demineralized.

As a result of the reaction between the phosphate groups and alkaline fillers with the hydroxyapatite from enamel and dentin, an increase in pH (up to 7.0) that neutralizes the acidity of the adhesive resin can be observed.

The resin acid groups chelate the calcium ions of the hydroxyapatite, creating true chemical bonding. In addition, carboxylic groups of polyalkenoic acid (found in RelyX Unicem) form chemical ionic bonds with the calcium present in the hydroxyapatite, positively influencing chemical bonding.3,17 Self-adhesive resin cements can partially dissolve the smear layer while keeping the smear plugs within the opened dentinal tubules.3,6 A thick smear layer may negatively affect the bond strength of self-adhesive cements, since the chemical bond is achieved with hydroxyapatite. Dentin acid-etched with phosphoric acid before the application of self-adhesive resin cement is detrimental to bond strength and must be avoided.9 Conversely, the application of mild acidic agents, such as 25% polyacrylic acid (same dentin conditioner used for glass-ionomer cements), might remove the superficially loosely bound fraction of the smear layer, thus improving adhesion.18

The current study tests the micro-shear bond strength of 1-mm bonded cross-sectional areas of resin cements with and without MDP (TheraCem and RelyX, respectively) to tooth structure (enamel and dentin) and zirconia. One can consider
this a simple method that permits efficient analyses of adhesive resins, regional and depth profiling of a variety of substrates, and conservation of teeth. When compared with microtensile bond strength, it was reported that specimens are pre-stressed only by removal from a mold.\textsuperscript{19}

Fig 4 Representative SEM ($\times$ 1,000 magnification) morphologic characterizations of the debonded zirconia surface, with cement precipitations of (a) RelyX and (b) TheraCem on the surface. A small area of RelyX cement (C) is shown covering less than 50% of the surface, with a few islands (black arrow) on the surface. TheraCem was spread more homogenously and covered more than 50% of the surface, with more islands of cement distributed over the remaining area (black arrow). The islands in TheraCem were many and smaller but distributed in more areas as it was dragged off the surface, explaining the cohesive failure in most examined samples. Higher magnifications ($\times$ 5,000) showed the differences in grain size of the (c) RelyX and (d) TheraCem groups. The difference decreased in the TheraCem group, which aided in better flowability and adhesion to zirconia.
This study examines the micro-shear bond strength of novel self-adhesive cements (test group; TheraCem) and compares it with the universal popular self-adhesive resin cement (control group; RelyX Unicem). The micro-shear bond strength with different substrates (enamel, dentin, and zirconia) resulted in no statistically significant differences among the groups. Thus, the first null hypothesis of the present study was rejected. The relative low bond-strength values obtained in both groups can be explained by the fact that “self-adhesive cements do not dissolve the smear layer and interact only superficially with the tooth structure.”

A few factors may contribute to this. First, the light-cured cement shows a high viscosity with limited penetration/interaction time. Second, self-adhesive cements need to be applied with some pressure to have a proper intimate adaptation to the surfaces. Third, the design of the micro-shear testing requires resin cylinders to be bonded to the tooth, but light curing of these relatively thick specimens might result in a high polymerization stress, causing resin contraction away from the bonded surface.

Moreover, micro-shear bond strength of self-adhesive resin cement is attributed to the type of multifunctional monomers, which may differ according to cement type. RelyX Unicem contains methacrylate phosphoric esters, whereas TheraCem contains a hydrophilic monomer (10-MDP) and calcium fluoride, both evidently having a low initial pH. Normally, the cements should be capable of demineralizing and infiltrating the tooth structure.

Nevertheless, only varying areas of etching were observed, and almost no distinct demineralization or hybrid layer formation was found after using self-adhesives. Therefore, chemical rather than micro-mechanical bonding is responsible for the dental adhesion of the resin components, especially 10-MDP, which was shown to chelate the calcium ions of hydroxyapatite crystals; this can explain the slight increase in micro-shear bond strength of TheraCem cement (MDP-containing) compared to RelyX (non–MDP-containing).

The results found that the micro-shear bond strength values of the cement (TheraCem and RelyX) with tooth structure (enamel, dentin) are lower than that of etch-and-rinse resin cements or 10-MDP self-etch resin cements, as supported by using SEM to detect failure modes: failure modes in enamel specimens were mixed but the adhesive mode was prominent. Subsequently, pretreatment of enamel with strong acid, such as 35% phosphoric acid, is highly recommended to improve bonding.

On the other hand, Han et al demonstrated that self-adhesive cements do not achieve a neutral pH for an extended period can adversely affect the dentin bonding of these cements. Nakamura et al found that certain self-adhesive cements have excellent mechanical properties in terms of flexural strength, elastic modulus, and water absorption, which attributed to the presence of 10-MDP.

MDP is the acidic monomer in PANAVIA (Kuraray), and its presence enhanced the bonding to the tooth structure, as reported in the present study (Table 1) and many others. The presence of MDP in the resin cement (TheraCem) yields a stronger micro-shear bond than the resin cement not containing MDP (RelyX Unicem).

The first part of the study investigates the micro-shear bond strength of two self-adhesive resin cements (TheraCem and RelyX) with tooth structure (enamel, dentin). It is found that the bond-strength values observed for the enamel were low for both groups (Table 1) because the bond strength of self-adhesive resin cements is lower than that of etch-and-rinse resin cements or 10-MDP self-etch resin cements, as supported by using SEM to detect failure modes: failure modes in enamel specimens were mixed but the adhesive mode was prominent. Subsequently, pretreatment of enamel with strong acid, such as 35% phosphoric acid, is highly recommended to improve bonding.

The results found that the micro-shear bond strength values of TheraCem group were significantly higher than RelyX in both enamel and dentin substrates (Fig 1 and Table 1). Self-adhesive cements initially have
a low pH, and the acid groups connect with calcium hydroxyapatite to form a stable bond between the methacrylate network and the tooth. Sodium, calcium, fluoride, and silicate ions that are released by alkaline particles neutralize the remaining acid groups, and the presence of calcium hydroxide seems to accelerate the neutralization.\textsuperscript{32,33} TheraCem cements tested in this study have calcium-fluoride and MDP in their composition.

In the present study, TheraCem shows a higher bonding performance regardless of the bonding substrate. The interaction between resin cement and dentin creates a micromechanical interlocking that is considered the fundamental principle of adhesion to the tooth substrate, based on an exchange process where inorganic tooth material is exchanged for synthetic resin.\textsuperscript{29}

This process involves two phases. One phase consists of the removal of calcium phosphates, by which micro-irregularities are exposed at the dentin surface. The subsequent so-called hybridization phase involves infiltration and in situ polymerization of resin within the produced micro-irregularities. Micromechanical interlocking is believed to be a prerequisite in achieving good bonding within clinical circumstances, and the potential benefit of additional chemical interactions between functional monomers and tooth-substrate components has recently regained attention.

According to the adhesion-decalcification concept, specific active ingredients (calcium and fluoride) within TheraCem resin cement can ionically interact with hydroxyapatite.\textsuperscript{34} Such molecules are able to etch/infiltrate the dentin and react with hydroxyapatite, generating calcium ions with a reduced binding energy. These ions act as an electron acceptor, enabling chemical interaction with the composite. This way, the micromechanical interlocking and chemical binding with hydroxyapatite are thought to synergistically provide the ultimate adhesion of the material.

In addition to the functional monomers, there are other components in TheraCem that are key to its bonding performance. For example, rheologic modifiers were incorporated in TheraCem to increase the flowability of the cement, which is thought to improve the wettability of the cement to the substrate.\textsuperscript{28} In fact, the mean bond strength of TheraCem to dentin is significantly higher than that of RelyX. This result is supposed to be directly related to the amount of calcium ions (Ca\textsuperscript{2+}) available for bonding, which varies significantly according to tooth region (enamel or dentin).\textsuperscript{25} However, the difference in bond strength was explained again by failure mode and morphologic changes of debonded surfaces, demonstrated by the SEM (Figs 2 and 3).

The second part of the study deals with micro-shear bond strength of zirconia to different cements. It was concluded that zirconia shows significantly higher micro-shear bond strength (Fig 1) with the TheraCem group (MDP-containing) than with the RelyX group (non-MDP-containing). This was also supported by failure mode analysis using SEM (Fig 4), where TheraCem showed more cohesive failure than RelyX. The null second hypothesis was accepted. These were in agreement with results in the literature, demonstrating that 10-MDP can improve the bonding effectiveness of conventional resin cement to zirconia restorations.\textsuperscript{13,16} Also, many studies reported no significant difference in shear bond strength for 10-MDP cemented zirconia before and after thermocycling.\textsuperscript{9–11} It was reported that MDP is a key molecule in bonding (with great affinity) to the oxide layer on a zirconia surface (like ZrO\textsubscript{2}), causing an improved bond strength with adhesive resin substrate. The adhesive potential to zirconia may be determined by other factors, such as the particle size of fillers and viscosity. The active parts of MDP react with the surface of zirconia.\textsuperscript{10}

Therefore, the bond strength may have been influenced by the resin wettability on the zirconia surface, which reduces the contact angle between zirconia and adhesive resin and results in an intimate interaction between both.\textsuperscript{15} In 2011, Kim et al\textsuperscript{35} mentioned that the surface energy of adhesive resins and the contact angle with the bonded surface have a great effect on bond strength.

Furthermore, the new rheologic modifiers added to the TheraCem composition resulted in a decrease in its viscosity compared to RelyX Unicem, where gaps were clearly seen at the zirconia/cement interface. These gaps indicate a higher viscosity of cement and lack of intimacy with the zirconia surface.\textsuperscript{10}
Nagaoka et al.\textsuperscript{13} in 2017 proposed three possible models of interaction mechanisms of 10-MDP with zirconia surfaces (Fig 5). The first model (Fig 5a) indicates adsorption of the 10-MDP monomer onto the surface by hydrogen bonding between the P=O (oxo group) and Zr-OH group. The second model (Fig 5b) indicates ionic bonding of the 10-MDP monomer with zirconia. The third model (Fig 5c) mentioned that, in addition to ionic bonding between 10-MDP and zirconia, the adsorbed 10-MDP monomers have hydrogen-bonding interactions with zirconia via P=O (oxo group).

Many researchers mentioned that the bonding capacities of resins are related to their ability to infiltrate into a substrate’s surface irregularities and that their mechanical properties are greatly affected by the percentage of filler content. According to the manufacturer documents, the amount of silanized fillers in RelyX Unicem is 72 wt%, while their amount in TheraCem was lower, at 61 wt%. Moreover, the presence of silanized fillers in the resin matrix decreases the viscosity.\textsuperscript{36,37}

According to the mentioned facts, the novel cement (TheraCem) could be mechanically stronger than RelyX due to its higher substrate content, less viscosity, and higher penetrating ability. Bonding performance is more related to the organic matrix than to the inorganic fillers. The latter is more responsible for mechanical properties.\textsuperscript{36,37}

**Conclusions**

Within the limitations of the present study, the following can be determined:

- MDP-containing resin cements can positively affect microshear bond strength with all tested substrates, and the bond strength is not affected by thermocycling.
- Addition of calcium and fluoride to the new generation of cements containing MDP (TheraCem) can modify the bond strength with dentin.
- Clinical significance: TheraCem self-adhesive resin cement can be considered a promising cement for many clinicians.

Further studies, especially clinical trials, are required to study the unique properties of this cement and compare it with more types of self-adhesive resin cement.

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**References**


