Clin Oral Invest (2017) 21:1079–1086
DOI 10.1007/s00784-016-1862-8

ORIGINAL ARTICLE

The effect of resin coating on the shear punch strength of restorative glass ionomer cements

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Received: 16 February 2016 / Accepted: 23 May 2016 / Published online: 4 June 2016

Abstract

Objective The aim of the current study was to examine the shear punch strength (SPS) of high-strength glass ionomer cements (HSGICs) in relation to coating applications and duration of coating.

Materials and methods I—Ninety specimens each of Fuji IX GP Fast (FIX Fast), Ionofil Molar AC (IM), Riva Self Cure (R) and Ketac Molar (KM) were prepared and divided into uncoated and coated groups, sub-divided into three subgroups and incubated for 24 h, 1 week or 8 weeks (distilled water, 37 °C) before SPS.

II—Ninety specimens each of uncoated and coated Fuji IX GP Extra were similarly prepared, divided into six sub-groups and incubated for 2 h, 24 h, 1 week, 1 month, 2 months or 3 months (artificial saliva, 37 °C) before SPS. Another 90 specimens were coated for 2 h, 24 h, 1 week, 1 month or 2 months, after which the coating was removed. Specimens were re-incubated in artificial saliva until the end of the 3-month period and then subjected to SPS.

Results None of the materials gained extra strength when coated. Uncoated KM, IM (at all times) and FIX Fast (at 24 h) were stronger. Fuji IX GP Extra achieved 11.5 MPa after 2 h, which increased to 56.7 MPa after 24 h. The highest strength after 3 months was achieved when the coating was retained for 2 h (71.7 MPa).

Conclusion A resin coating will not positively affect the SPS of HSGICs.

Clinical relevance There is no need to protect HSGICs from water to gain extra strength unless the coating is retained for 2 h.

Keywords Auto-cured glass ionomer · Resin coating · Shear punch strength · Distilled water · Artificial saliva

Introduction

Encapsulated glass ionomer cement (GIC) restoratives outperform their hand-mixed equivalents and are a potential solution to operator-induced variability [1, 2]. Encapsulated, highly viscous GICs, also known as high-strength, auto-cured (HSAC) GICs [3] or the "fast setting" versions [4, 5], have an improved glass particle size and distribution and increased glass surface reactivity, which are intended to extend their use to posterior regions. However, low fracture toughness [6] and flexural strength [7], as well as inadequate early wear characteristics [5], limit HSAC GICs' clinical use to the long-term temporary treatment of classes I and II cavities, restorations of non-occlusion-bearing class II cavities, and deciduous teeth [8] and to atraumatic restorative treatment [9, 10].

A major drawback of all GICs is their susceptibility to early water contamination or dehydration during and after the initial phase of the setting reaction, which leads to the deterioration of the mechanical properties [8]. Therefore, maintaining water balance is critical for GICs to achieve their desired physical properties [11, 12]. Protecting glass ionomer surfaces from the effects of moisture and dehydration immediately after placement has therefore been advocated [13, 14]. Additional benefits of surface protection include reducing wear in occlusal cavities [10] and smoothing glass ionomer material surfaces after polishing.

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Surface coatings have included emollients (coca butter, petroleum jelly), waterproof varnishes (based on nitrocellulose) and resins (methyl methacrylate, amide and preferably filled, light-cured, bonding resins) [8, 10, 15, 16]. It has been demonstrated in vitro that sealing conventional glass ionomers with a surface coating for at least 1 h will result in specimens with optimum compressive strength, likely because of a greater degree of cross-linking and hydration of the gel matrix [12, 17]. Miyazaki et al. tested the effect of surface coatings on the flexural strength and fracture toughness of two resin-modified GICs and one conventional GIC [18]. They found differences between the coated and uncoated cements after 1 h, but no significant differences after the specimens were stored in distilled water for 24 h. They recommended that the cement should be protected from direct water contact for at least 1 h after mixing. However, these studies and others [19, 20] related to earlier conventional GICs and not to encapsulated HSAC GICs, which have a faster setting reaction. Studies on these materials have yielded conflicting results.

A significant improvement in flexural strength was reported by Zoergiebel et al., in a study that used Riva Self Cure (SDI), ChemFil Rock (Dentsply) and Fuji IX GP Fast and Extra (GC) with their corresponding coatings [8]. By contrast, the micromechanical properties (Vickers hardness and indentation modulus) of these GICs did not benefit from the resin coatings [8, 14]. Bagheri et al. showed significantly lower hardness for coated Fuji IX but an increase in shear punch strength (SPS) [21]. Bonifacio et al. found a significant improvement in flexural strength with Fuji IX GP Extra (GC) but no improvement with Ketac Molar (3M ESPE) and their corresponding coatings [22]. Leirskar et al. showed that uncoated specimens of HSAC glass ionomers (Fuji IX GP) were stronger at all time points [23]. They concluded that early exposure to water positively influences the SPS of Fuji IX GP. Wang et al. examined the effect of early water exposure and surface coating on the SPS of Fuji IX GP Fast (GC), Ketac Molar and Ketac Molar Quick (3M ESPE) [3]. Again, in contrast to current thinking, they found that early exposure to water did not weaken glass ionomer restoratives, and a marginal increase in strength was actually observed for some materials. A recent study by Hankins et al. raised additional concerns about coating [24]. When using a nanofilled, resin-based, light-cured coating on teeth restored with glass ionomers, they found that coated restorations had significantly higher cuspal flexure than did restorations without coating. Their explanation for this finding was that teeth restored with glass ionomers exhibited setting shrinkage that deformed the tooth cusps. Water absorption compensated for the shrinkage. Surface coatings reduce water absorption and slow the shrinkage compensation rate. Surface coatings also severely impede the glass ionomer's fluoride release property [25]. The aforementioned studies [3, 8, 14, 21–23] tested the mechanical properties of coated vs. uncoated HSAC GICs. No studies have tested an intermediate approach of coating the specimens for a predetermined time period and then removing the coating. Such an approach is valid because it not only prevents early water contamination but also enables contact with water afterwards to allow the strength associated with "bound" water and, consequently, hydration to increase [23].

The aim of the current study was to examine changes in the SPS of encapsulated HSAC GICs relative to coating application, storage duration and timing of coating removal.

The null hypotheses that were tested were as follows: (1) early exposure to water will have no influence on the SPS of the encapsulated HSAC GICs, (2) storage duration will have no influence on the SPS and (3) the timing of the coating removal will have no influence on the SPS after a predetermined storage duration.

Materials and methods

Part I

The four HSAC GICs and their respective coatings evaluated in this study are shown in Table 1. The materials were supplied in encapsulated form and activated or mixed according to the manufacturer's instructions using a RotoMix (3M ESPE, St. Paul, MN, USA).

Specimens to evaluate SPS were prepared by injecting the cements into polyvinyl chloride washers (6.0 mm in diameter and 1.5 mm thick), which were placed on a glass slab over a short polyester strip, and care was taken to avoid incorporating air bubbles. The filled washers were immediately covered with another polyester strip and a glass slab that was hand pressed for 1 min. The washers remained covered by the polyester strips for up to 7 min before removal.

Ninety specimens were prepared for each material and randomly divided into two groups. Following removal of the strips, both surfaces of the specimens in group 1 were immediately coated with the appropriate coating (Table 1) using a small, disposable brush and light cured from both sides for 20 s with an ESPE Elipar Highlight QTH curing unit at a light intensity of 500 mW/cm^2 (Demetron, Model 100, curing radiometer Kerr). The specimens in group 2 were left uncoated. Each group was then divided into three sub-groups that were placed in distilled water at 37 °C and stored for periods of 24 h, 1 week or 8 weeks.

After storage, the glass ionomer surfaces were gently polished under water using 400-grit wet carborundum paper in a grinder-polisher machine (Ecomet, Buchler Co, IL, USA). The resulting specimens were free of resin coating and had flat and parallel surfaces and a standard thickness of approximately 1.5 ± 0.1 mm. The exact thickness was measured using a digital micrometer (Mitutoyo, Tokyo, Japan) and recorded prior to testing. Nine specimens with flaws or bubbles were discarded.

Table 1 Glass ionomer cements and respective coatings (batch no.), manufacturer and chemical composition

Glass ionomer cement	Manufacturer	Composition
Ketac Molar (287092)	3M ESPE AG, Seefeld, Germany	Al-Ca-La fluorosilicate glass, 5 % copolymer acrylic and maleic acid
Ketac Glaze (280616)		Ethanediyl ester, dicyclopentyldimethylene diacrylate, aminoethyl ester
Riva Self Cure (B0802192)	SDI, Victoria, Australia	Fluoroaluminosilicate glass, polyacrylic acid + tartaric acid
Riva Coat LC (070123)		Acrylic monomer
Ionofil Molar AC (660526,701878,721166)	VOCO AC, Guxhaven, Germany	Polyacrylic and tartaric acid, fluorosilicate, parabens
Final Varnish LC (591698, 611414)		Bis-GMA, diurethandimethacrylate, BHT
Fuji IX GP Fast (0609011,0604131)	GC Corp, Tokyo, Japan	Fluoroaluminosilicate glass, polyacrylic acid, water
G-Coat Plus (0707131)		Methylmethacrylate, multifunctional methacrylate, camphorquinone

SPS testing was conducted as previously described [3, 23] using a custom-designed shear punch apparatus mounted on a universal testing machine (Instron, model 4502, Buckinghamshire, UK) and operated at a crosshead speed of 0.5 mm/min. The device consisted of a flat-ended steel punch (3.2 mm in diameter) fitted into the hole of a matching die (3.25 mm in diameter) to create a compression cage (Fig. 1). The washers containing the specimens were precisely positioned in the apparatus in a self-locating recess and held with a clamp tightened with a lever (Fig. 1) that exerted a torque of 3 Nm which minimized bending when punched. The force-displacement curve was continuously recorded, and the maximum force required to punch out the specimen—force (N)—was used to calculate the shear strength according to the following equation:

$$\text{shear strength(MPa)} = \frac{\text{force(N)}}{\pi \text{ X punch diameter (mm)X thickness of specimen(mm)}}$$

The Kolmogorov-Smirnov test was used to test for normality of the distribution. Data were analysed using three-way ANOVA. The dependent variable was SPS (MPa). The independent variables were material, time and surface coating. For each of the tested materials, two-way ANOVA and a post hoc Scheffe test were performed. The independent variables were time and surface coating. The level of significance was $p = 0.05$.

Part II

Based on the results of part I, an additional 270 specimens of HSAC glass ionomer (Fuji IX GP Extra) (strontium fluoroaluminosilicate glass, aqueous polyacrylic acid) were fabricated to determine whether retaining the coating for a predetermined length of time would influence the SPS of the material.

The preparation steps were identical to those in part I. Specimens were randomly divided into three groups of 90 specimens each. The specimens in group 1 were left uncoated. The specimens in group 2 were immediately coated on both sides with G-Coat Plus (GC Corp, Tokyo, Japan) and light cured. Each group was then divided into six sub-groups of 15

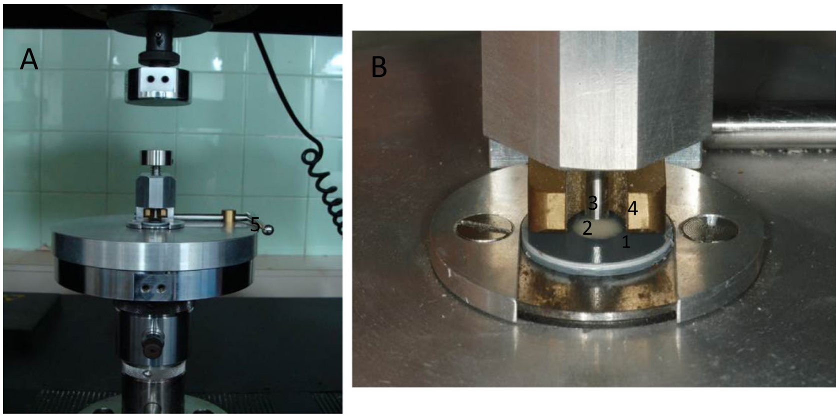

Fig. 1 Shear punch test apparatus assembled into the loading machine (**a**) and with a closer view of the testing chamber (**b**). *1* washer, *2* specimen, *3* punch, *4* clamp, *5* lever

specimens each that were placed in artificial saliva (NaCl, KCl, $CaCl_2 \cdot H_2O$, $NaH_2PO_4 \cdot H_2O$, KSCN, $Na_2S \cdot H_2O$, urea) at 37 °C and stored for 2 h, 24 h, 1 week, 1 month, 2 months or 3 months before testing. The artificial saliva was replaced every 2 weeks. After storage, the glass ionomer surfaces were gently polished under water using a 400-grit wet carborundum paper in a grinder-polisher machine (Ecomet, Buehler Co, IL, USA), and SPS testing was conducted as described in part I.

As in group 2, the specimens in group 3 were immediately coated on both sides with G-Coat Plus and incubated in artificial saliva. The specimens were then divided into six sub-groups of 15 specimens each. The coating was left in place for predetermined time intervals *only* (2 h, 24 h, 1 week, 1 month, 2 months or 3 months). After the designated time period, the coating was removed using the same grit wet carborundum paper. The specimens were then returned to the artificial saliva medium at 37 °C until the end of the 3-month post-fabrication period. The artificial saliva was replaced every 2 weeks. SPS testing was conducted as described in part I.

Groups 1 and 2 data were analysed using two-way ANOVA. The dependent variable was SPS (MPa). The independent variables were time and surface coating. Group 3 data were combined with the values of the uncoated group 1 specimens tested after 3 months and analysed using one-way ANOVA and a post hoc Tukey's test. The dependent variable was SPS (MPa). The independent variable was duration of coating. The level of significance was $p = 0.05$.

Results

Part I

Three-way ANOVA (SPS—within-subject factor; material, time and coating—between-subject factors) revealed significant differences amongst the materials, times and coatings ($p < 0.001$) as well as significant interactions of material-time and material-coating ($p < 0.001$). The time-coating interaction ($p = 0.837$) and the material-time-coating interaction ($p = 0.494$) were not significant. Therefore, for each tested material, a separate two-way ANOVA was conducted (independent variables: time, coating) as well as a post hoc Scheffe test for the different times.

Ketac Molar (KM) Uncoated specimens were stronger at all time points ($p < 0.05$). The mean strength of both the coated and uncoated specimens increased significantly ($p < 0.05$) after ageing in distilled water at 37 °C from 24 h to 1 week and from 1 to 8 weeks (Table 2).

Riva Self Cure (R) There was no significant difference in the SPS between the coated and uncoated specimens ($p = 0.744$). The mean strength increased significantly ($p < 0.05$) after ageing in distilled water at 37 °C from 24 h to 1 week, and there was no further significant change over the remainder of the test period (Table 2).

Table 2 Mean (±SD) shear punch strength (MPa) of uncoated and coated HSAC GIC's after different incubation periods

Materials	Coating	24 h	1 week	8 weeks
Ketac Molar	−	59.2 (3.4)^{aA}	71.3 (6.7)^{aB}	78.8 (7.6)^{aC}
	+	50.8 (3.5)^{bA}	60.2 (6.9)^{bB}	67.3 (5.6)^{bC}
Riva Self Cure	−	44.2 (4.1)^{cA}	51.7 (5.2)^{cB}	51.8 (4.2)^{cB}
	+	43.9 (2.6)^{cA}	52.7 (5.3)^{cB}	52.1 (4.6)^{cB}
Ionofil Molar AC	−	53.2 (3.9)^{dA}	72.2 (7.7)^{dB}	68.6 (6.9)^{dB}
	+	47.6 (5.6)^{eA}	65.9 (6.5)^{eB}	59.1 (6.9)^{eB}
Fuji IX GP Fast	−	56.0 (3.1)^{fA}	62.9(4.3)^{fB}	61.9 (4.5)^{fB}
	+	49.7 (3.7)^{gA}	60.6 (4.7)^{fB}	60.2 (2.3)^{fB}

For each material separately, means with the same upper case letter in each row or the same lowercase letter in each column are not significantly different ($p > 0.05$)

Ionofil Molar AC (IM) Uncoated specimens were stronger at all time points ($p < 0.05$). The mean strength of both the coated and uncoated specimens increased significantly ($p < 0.05$) after ageing in distilled water at 37 °C from 24 h to 1 week, and there was no further significant change over the remainder of the test period (Table 2).

Fuji IX GP Fast (FIX Fast) Uncoated specimens were stronger at all time points, but the difference was only significant at 24 h ($p < 0.05$). The mean strength of both the coated and uncoated specimens increased significantly ($p < 0.05$) after ageing in distilled water at 37 °C from 24 h to 1 week, and there was no further significant change in strength over the remainder of the test period (Table 2).

Ketac Molar achieved the highest SPS (64.6 ± 4 MPa). Ionofil Molar AC and Fuji IX GP Fast achieved 58.7 ± 4 MPa and 58.5 ± 2.2 MPa, respectively, whilst Riva Self Cure yielded the lowest value at 49.4 ± 2.2 MPa.

Part II

Table 3 shows the SPS of Fuji IX GP Extra as a function of incubation time in artificial saliva with and without coating. Two-way ANOVA (time, coating) revealed a significant difference only amongst the times ($p = 0.002$), indicating that there was no significant difference in strength between the coated and uncoated specimens. A post hoc Tukey's test of the differences between times revealed that the mean strength increased significantly ($p < 0.05$) to almost its maximal value for both the coated and uncoated specimens only after ageing for 24 h (56.5 MPa), and the increase thereafter was insignificant.

Table 3 Means (±SD) shear punch strength (MPa) of uncoated and coated Fuji IX GP Extra after different incubation periods

Coating	2 h	24 h	1 week	1 month	2 months	3 months
−	11.6(0.4)^{aA}	57(8.9)^{aB}	55.9(4.5)^{aB}	57.1(5.8)^{aB}	56.1(7.3)^{aB}	59.1(7.2)^{aB}
+	11.4(0.4)^{aA}	56.5(5.4)^{aB}	56.4(3.9)^{aB}	57.7(4.7)^{aB}	60.9(5.4)^{aB}	62.2(4.3)^{aB}

Means with the same uppercase letter in each row or the same lowercase letter in each column are not significantly different ($p > 0.05$)

One-way ANOVA showed a significant difference in the SPS after 3 months in relation to the coating duration ($p < 0.001$). A post hoc Tukey's test (Table 4) showed that the highest SPS was achieved when the coating was removed after 2 h (71.7 MPa). There were no significant differences in strength amongst materials coated for 0 h, 24 h, 2 months and 3 months or amongst materials coated for 0 h, 24 h, 1 week, 1 month and 2 months (Table 4).

Discussion

The results of the first part of the current study do not support our first null hypothesis because early exposure to water positively influenced the SPS of three encapsulated HSAC GICs (KM, IM and FIX Fast), whilst resin coating had a negative influence. Early exposure to water had no influence on the SPS of either the Riva Self Cure or the Fuji IX GP Extra.

The first part of this study, which was an extension of the work of Leirskar et al. [23] and Wang et al. [3] with other HSAC GICs, fully supported their finding that early exposure to water does not weaken the mechanical properties of GICs. The SPS test was used because it has been shown that during mastication, occlusal forces induce shear stresses within both teeth and restorations [26, 27]. The advantages of the SPS test have been reported by Mount et al. [28] and later by Nomoto et al. [29]. The only prerequisites are flat parallel surfaces that are evenly supported and a method to restrain the specimens to avoid bending when punched [29]. The reliability of the test is reflected by a low coefficient of variation of approximately of 8.5 %. A second variable that contributes to this low coefficient of variation is the use of encapsulated HSAC GICs, which reduces any potential variation in the powder-to-liquid ratio and the number of porous elements or voids [6].

Surface protection of HSAC GICs in the form of a resin coating did not have the expected effect of significantly improving the micromechanical properties of Vickers hardness and indentation modulus [8, 14, 21]. A benefit of resin coating has only been reported in studies in which HSAC GICs were tested for flexural strength [8, 22, 30] or fracture toughness [31]. In those contexts, the resin coating seals visible surface defects, such as crazing and voids, particularly on the tension site where failure initiates or fills porosities and therefore provides internal protection against crack initiation [31]. It does not preserve the water balance [8]. However, other indications for advocating the use of protective coatings, such as G-Coat Plus, that provide a clear, glossy surface; prevent potential aesthetic changes; or increase the wear resistance of restorations were out of the scope of the current research. Diem et al. [10] reported that colour matching with the tooth over a 3-year period was the same with Fuji IX GP Extra regardless of whether it was coated with G-Coat Plus.

The present methodology of SPS testing requires restraining the washers that contain the specimens through precise positioning in the self-locating recess and holding them with a clamp tightened with a lever that exerts a torque of 3 Nm, which minimizes bending when punched. Assuming that negligible flexion exists during testing, no beneficial effect of the resin coating was anticipated.

The postulated explanation put forth by Leirskar et al., who found that early access to water increased the strength of HSAC GICs, was that the increased strength of these materials is associated with an increase in "bound" water and, consequently, hydration [23]. Resin coating limits the hydration process and therefore interferes with the steady increase in strength. Okada and others have also shown a significant increase in the hardness of the HSAC cements following storage in both distilled water and human saliva [32]. However, it is doubtful whether this mechanism is the only valid explanation based on more recent findings indicating that the mechanical properties of HSAC GICs have a strong dependence on the type of material and its chemical composition regardless of conditions such as ageing and coating [14].

The materials tested in the current study included some that gained extra strength (11.9–17.3 %) from early exposure to water (KM, IM in total, FIX Fast after 24 h) and some that

Table 4 Post hoc Tukey's test for Fuji IX GP Extra shear punch strength according to coating duration

0 h	2 h	24 h	1 week	1 month	2 months	3 months
59.1 (7.2)^{a}	71.7 (5.2)^{c}	61.7 (9.1)^{ab}	65.7 (5.1)^{b}	65.8 (3.2)^{b}	64.5 (6.1)^{ab}	62.2 (4.3)^{ab}

Shear punch strength of all groups were tested after 3 months incubation in artificial saliva. Means with the same lowercase letter are not significantly different ($p > 0.05$)

did not (Riva Self Cure, Fuji IX GP Extra). Two of the current materials (KM, FIX Fast) were also tested by Wang et al. using the same methodology, and they reported no difference between coated and uncoated specimens after 4 weeks [3]. We found a noticeable difference for FIX Fast only after 24 h (12.7 %) and negligible effects after 1 and 8 weeks (~2–4 %); therefore, our results are not contradictory to those of Wang et al. [3]. The setting time of Fuji IX GP Fast is approximately 50 % shorter than that of Fuji IX GP, making it less vulnerable to water. This might explain the difference between our findings and those of Leirskar et al., who reported a significantly higher SPS in uncoated Fuji IX GP specimens after 24 h and after 2 to 8 weeks [23]. Interestingly, Riva Self Cure in saliva and water was not reported to be consistently influenced by early exposure to water or resin coating in terms of flexural strength [8].

In the second part of the current study, Fuji IX GP Extra also did not show a significant difference in strength between the coated and uncoated specimens. According to the manufacturer's recommendations, the setting time for GC Fuji IX GP Fast is 3 min, whilst that of GC Fuji IX GP Extra is 2.5 min, which enables final finishing after that time. This shortened setting time might explain why Fuji IX GP Fast gained some extra strength from early exposure to water after 24 h, whilst Fuji IX GP Extra did not benefit from early exposure. The second part of the study used an intermediate approach between coated and uncoated materials by coating the specimens for a predetermined period and then removing the coating and exposing the specimens to artificial saliva. This intermediate approach both prevents early water contamination and enables contact with water afterwards. Hydration of GICs might be necessary to enable the increase in strength over time [23].

The results of the second part of the current study do not support our third null hypothesis because the timing of coating removal significantly influenced the SPS in the Fuji IX GP Extra after 3 months ($p < 0.001$). There were no significant differences in strength between the uncoated material and the material coated for 24 h, 2 months and 3 months or between materials coated for 24 h, 1 week, 1 month, 2 months and 3 months. The only significant difference was when the coating was kept in place for 2 h and then removed. It is proposed that at the very beginning of the setting process, which is characterized by an interaction between the polyacid liquid and the strontium fluoroaluminosilicate glass of Fuji IX GP Extra with an initial build-up of calcium/strontium polyalkenoate and subsequent initial formation of aluminium polyalkenoate, resin protection from environmental water might have some benefit. The cement strengthened by approximately 14 % compared to both coatings removed at other time points and uncoated material after 3 months. Although a clinical implication might be to protect a restoration made from the abovementioned materials for 2 h during the initial setting and subsequently to expose it to an aqueous environment, it is doubtful whether this would be clinically worthwhile.

The incubating media were distilled water in the first part of the study and artificial saliva in the second part. Okada and his colleagues found that surface hardness increased significantly following storage in both distilled water and human saliva [32]. An important observation in their study was that there was a greater increase in specimens stored in saliva than in those stored in distilled water. Their analysis (X-ray photoelectron spectroscopy and electron probe microanalysis) revealed that hardening was very likely the result of salivary components, including calcium and phosphate, diffusing into the cement structure. In the current study as well as in a study by Zoergiebel et al. [8], the storage agent had no influence; Fuji IX GP Fast in water and Fuji IX GP Extra in artificial saliva had similar strengths of 58.8 and 61.1, respectively.

The results of the current study also do not support the second null hypothesis because storage duration influenced the SPS. The SPS reached a maximum value within 1 week for both coated and uncoated specimens in most of the HSAC GICs (Fuji IX GP Fast, R and IM) that were tested. In Fuji IX GP Fast and R, there were no further significant changes in strength over the test period, whilst in IM, there was a 10 % decrease in strength from 1 to 8 weeks. In the KM group, the SPS increased from 24 h to 1 week and from 1 to 8 weeks, reaching its maximal strength after 8 weeks. Fuji IX GP Extra reached its maximal value after 24 h for both the coated and uncoated specimens. The current results are in agreement with those of Leirskar et al. [23], who reported maximal SPS within 1 and 2 weeks for coated and uncoated specimens, respectively. Zoergiebel et al. [8] reported insignificant increases in the modulus of elasticity in flexural tests as well as in Vickers hardness and the indentation modulus from 1 week to 1 month for Riva Self Cure, Fuji IX GP Fast and Fuji IX GP Extra. Similar results for those materials have indicated that the indentation modulus remains constant for up to 12 months [14].

An interesting finding was the low strength of the Fuji IX GP Extra sample after 2 h, when it had gained only approximately 20 % of the strength it achieved after 24 h. However, no clinical conclusions can be drawn due to a lack of measurements between 2 and 24 h. Our results are in accordance with the findings of Irie at al. [33] who reported that 30 min after being set, conventional GICs (dentin or lining cements) exhibited approximately 20 % of the flexural strength they would achieve after 24 h. However, the current results are quite surprising because HSAC GICs, which have increased glass surface reactivity, were expected to exhibit fast-setting kinetics and improved mechanical properties over a shorter time period. Most studies that have described the mechanical properties of HSAC GICs monitored them for only 24 h or more after mixing and not on the very first day [5, 6, 8, 9, 14, 32]. Peez et al. [34] reported that Ketac Molar Easymix, Fuji IX and Ionofil Molar had a 63–100 % increase in compressive strength after a setting time of 24 h compared to their values after 1 h, but they retained the same flexural strength levels. Munhoz et al. [35] reported that in Fuji IX cements, the conversion of aluminium is a diffusion-controlled process at the early stage and is largely complete after only 6 h; however, no correlation with mechanical properties has been reported. The kinetics of the setting of HSAC GICs and their correlation to different mechanical properties on the first day merits further investigation.

Conclusions

1. Early exposure to water will not adversely affect and resin coating will not positively affect the SPS of HSAC GICs.
2. Resin coating might have a positive affect if kept in place for only 2 h and then removed.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Funding The work was supported by the Department of Oral Rehabilitation of Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Israel.

Ethical approval This article does not contain any studies with human participants or animals that were performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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