Compressive Strength of New Glass Ionomer Cement Technology based Restorative Materials after Thermocycling and Cyclic Loading

Kompresijska čvrstoća restaurativnih materijala temeljenih na novoj tehnologiji stakleno-ionomernih cemenata nakon termocikliranja i cikličkog opterećenja

Abstract

Objective: The objective of the study was to compare compressive strengths of two glass ionomer-based materials, with and without a light-cured, nano-filled coating, after cyclic loading and thermocycling. Materials and methods: To determine compressive strength of new restorative materials over a longer period of time, materials were analysed under simulated conditions where cyclic loading replicated masticatory loading and thermocycling simulated thermal oscillations in the oral cavity. Four groups of samples (n=7)—(1) Equia Fil (GC, Tokyo, Japan) uncoated; (2) Equia Fil coated with Equia Coat (GC, Tokyo, Japan); (3) Equia Forte Fil (GC, Tokyo, Japan) uncoated; and (4) Equia Forte Fil coated with Equia Forte coat (GC, Tokyo, Japan)—were subjected to cyclic loading (240,000 cycles) using a chewing simulator (MOD, Esetron Smart Robotechnologies, Ankara, Turkey). Results: Compressive strength measurements were performed according to ISO 9917-1:2007, using the universal mechanical testing machine (Instron, Lloyd, UK). Scanning electron microscope (SEM) analysis was performed after thermocycling. There were no statistically significant differences between Equia Fil and Equia Forte Fil irrespective of the coating (p<0.05), but a trend of increasing compressive strength in the coated samples was observed. Conclusions: Coating increases the compressive strength of Equia Fil and Equia Forte Fil, but not significantly.

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Introduction

Glass ionomer cements (GICs) are widely used in dentistry due to their biocompatibility, chemical adhesion to dental tissues, and anticariogenic potential (1-3). Their relatively weak mechanical properties, however, have prompted numerous research efforts focused on improving their overall hardness and clinical performance as long-term fillings in posterior teeth (4-7).

For example, water balance has been shown to play an important role in achieving optimal physical properties in glass ionomer materials. In the initial setting phase, which includes the neutralization reaction between metal cations released from the glass and polymeric acid, glass ionomer materials are sensitive to water and the cement sets within 3-6 minutes (2,8). Dissolution of metal cations during the setting process can be avoided by protecting the cement from additional water. Once the cement has set, the maturation process

Uvod

Stakleno-ionomerni cementi u širokoj su uporabi u dentalnoj medicini zbog biokompatibilnosti, kemijske veze sa zubnim tkivima i anti-kariogenog potencijala (1-3). Njihova relativno slaba mehanička svojstva, međutim, su uzrokovala brojnu istraživacku aktivnost namijenjenu poboljšanju njihove ukupne trudnosti i kliničke performanse u dugotrajnim uvođenjima u zubu (4-7).

Na primjer, vodna balansa je pokazala se važnom u postizanju optimalnih fizičkih svojstava u stakleno-ionomernim materijalima. U početnom etapi formiranja, koja obuhvaća neutralizacijsku reakciju medu metalnim kationima i polikarbonskim kiselinama, stakleno-ionomerne materijale su nagnute prema rastućoj vodnosti. Nakon što se cement postavlja, proces maturacije događa se slijedeća 24 sata te čak do godinu dana (2). Tijekom maturacije
occurs during the next 24 hours and up to a year afterward (2). During maturation, care must be taken to avoid the cement becoming dehydrated, which leads to surface cracking and a chalky appearance (9).

For this reason, there are several surface protection coatings commonly used in clinical practice that are applied in order to prevent the early loss of ions participating in the setting reaction, and also to prevent water loss later on (10). Mechanical properties of the glass ionomer—in particular, the surface hardness—were shown to improve after a coating was applied (11). The coat is responsible for the glaze effect that enhances the aesthetics of the set material; it also provides effective protection during the water-sensitive initial setting phase and has been shown to increase the glass ionomer’s compressive strength after fatigue strength and reduce abrasive wear of the filling (12,13).

Equia Coat is a hydrophilic, low-viscosity nano-filled coating agent that consists of 50% methyl methacrylate and 0.09% camphorquinone. It is a component of a restorative system based on GIC technology that also consists of Equia Fil. In 2015, Equia Forte (GC, Tokyo, Japan) was released as a new restorative material based on glass hybrid technology where a glass filler matrix combines fillers of different sizes. It consists of microlaminated Equia Forte Fil with a nano-filled coat (Equia Forte Coat, GC, Tokyo, Japan) (14). Similarly as in the Equia Coat, in the Equia Forte Coat, nanofiller particles are dispersed in the liquid. Additionally, the Equia Forte Coat contains a multifunctional monomer that, as the manufacturer claims, improves surface hardness and wears resistance.

The standard techniques for assessing the strength of dental materials include determining compressive strength (CS) (15, 16). To determine compressive strength, the mechanical properties of tested materials are analyzed over a longer period of time and under simulated conditions where cyclic loading replicates masticatory loading and thermocycling simulates thermal oscillations in the oral cavity (17). The purpose of this in vitro study was to assess CS values for the two new restorative materials, with and without coating after cyclic loading and thermocycling, and to determine whether the nano-filled coating influences CS values after the initial setting and before moisture contamination. The hypothesis of the study was that the compressive strength of the tested materials would be higher after cyclic loading and thermocycling if they had been treated initially with a nano-filled coating.

Materials and methods

This in vitro study was approved by the Ethics Committee of the School of Dental Medicine, University of Zagreb, approval number 05-PA-15-12/2017.

Sample preparation

The two restorative materials used in this study were Equia Fil GC (Tokyo, Japan) and Equia Forte Fil GC (Tokyo, Japan). The samples were divided into uncoated groups and groups coated with either Equia Coat or Equia Forte Coat (GC, Tokyo, Japan).

Cylindrical aluminum molds (6 mm diameter x 3 mm height) were used to prepare the samples. The materials were

valja paziti da se ne dogodi dehidracija cementa jer rezultira površinskim pucanjem i kredastim izgledom (9).

Zbog toga postoji nekoliko površinskih zaštitnih premaza koji se obično upotrebljavaju u kliničkoj praksi za sprječavanje ranog gubitka iona koji sudjeluju u procesu stvrdnjavanja te kasnijeg gubitka vode iz materijala (10). Pokazalo se da su mehanička svojstva staklenih ionomerova, posebno površinska tvrdoća, boljši nakon aplikacije premaza (11). Premaz je također odgovoran za sjaj koji poboljšava estetiku stvrdnutog materijala i pruža učinkovitu zaštitu tijekom početne fazе stvrdnjavanja osjetljive na prisutnost vode, a pokazalo se da povećava i kompresijsku čvrstoću staklenih ionomerova nakon cikličkog opterećenja te smanjuje abrazivno trošenje ispunu (12, 13).

Equia Coat je hidrofilni niskoviskozni nanopunjeni premaz koji se sastoji od 50% metil-metakrilata i 0,09% kamforikona. On je komponenta u restaurativnom sustavu temeljenom na GIC tehnologiji koji uključuje i Equia Fil. Godine 2015. pojavio se na tržištu novi restaurativni materijal Equia Forte (GC, Tokio, Japan) proizveden na temelju staklo-hibridne tehnologije u kojem je matrica staklenog punila kombinacija čestica punila različitih veličina. Sastoji se od Equia Forte Fila mikrolaminiranog nanopunjenog premazom (Equia Forte Coat, GC, Tokio, Japan) (14). Slično kao u Equia Coatu, i u Equia Forte Coatu čestice nanopunila raspršene su u tekućinu. Uz to, Equia Forte Coat sadržava multi-funkcionalni monomer za koji proizvođač tvrdi da poboljšava površinsku tvrdoću i otpornoć na trošenje.

Standardni postupak za procjenu čvrstoće dentalnih materijala uključuje određivanje kompresijske čvrstoće (CS-a) (15, 16). Kako bi se odredilo mehaničko svojstvo kompresijske čvrstoće ispitivanih materijala tijekom duljeg razdoblja, simulirani su uvjeti mastikatornog opterećenja cikličkim opterećenjem i termičke oscilacije u usnoj šupljini termocikliranjem (17). Svrha ovog istraživanja in vitro bila je procijeniti vrijednosti CS-a dvaju novih restaurativnih materijala, s premazom ili bez njega, nakon cikličkog opterećenja i termocikliranja, te odrediti utjecaje li nanopunjeni premaz, apliciran nakon inicijalnog stvrdnjavanja prije kontaminacije vlagom, na kompresijsku čvrstoću. Hipoteza ovog istraživanja bila je da će vrijednosti CS-a ispitivanih materijala nakon cikličkog opterećenja i termocikliranja biti veće ako su inicijalno bili premazani zaštitnim nanopunjenim premazom.

Materijali i metode

Ovu studiju in vitro odobrilo je Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu (broj odobrenja 05-PA-15-12/2017).

Priprema uzoraka

U ovom istraživanju korištena su dva restaurativna materijala – Equia Fil GC (Tokio, Japan) i Equia Forte Fil GC (Tokio, Japan). Uzorci su podijeljeni u nepremazane skupine i skupine premazane Equia Coatom ili Equia Forte Coatom (GC, Tokio, Japan).

Cilindrični aluminijski kalupi (6 mm u promjeru x 3 mm u visini) korišteni su za pripremu uzoraka. Materijali su pri-
prepared according to the manufacturer's instructions and packed into the molds at room temperature. The top surface of each specimen was covered with a celluloid strip and a glass slide, and the specimen was allowed to set in a moist environment in an incubator for 10 min. The specimens were then removed from the molds by applying pressure at one side of the samples. Equia Coat was applied on every second Equia Fil sample, and Equia Forte Coat was applied on every second Equia Forte Fil sample; both types of the coated samples were light-cured from each side for 20 s using a Bluephase C8® Light Unit (Vivadent, Schaan, Liechtenstein). There were four experimental groups, each containing seven samples: (1) Equia Fil coated, (2) Equia Fil uncoated, (3) Equia Forte Fil coated, and (4) Equia Forte Fil uncoated. After coating, the samples were stored in a moist environment at 37°C for 24 h. The compositions of the samples used in the study are shown in Table 1.

### Compressive strength measurements and SEM evaluation of the samples

The specimens were subjected to thermocycling (10,000 cycles of 5°C and 55°C, 100 s per cycle, and a 5 s interval to remove water from the chambers). After thermocycling, wear simulation was performed using a chewing simulator (MOD, Esetron Smart Robotechnologies, Ankara, Turkey). A mass of 5 kg, comparable to 49 N of chewing force, was exerted (18). According to previous studies, 240,000–250,000 load cycles to clinically simulate the one-year chewing condition, the wear test included 240,000–250,000 load cycles in a chewing simulator equivalent to approximately one year of chewing (19,20). The wear test included 240,000 load cycles to clinically simulate the one-year chewing condition. After cycle loading, the specimens were stored in distilled water at room temperature for one week prior to compressive strength measurements.

The compressive strength measurements for the tested materials were performed at room temperature (23±1°C) according to ISO 9917-1:2007. The compressive strength was determined by loading at a crosshead speed of 1 mm/min until specimen failure. A universal mechanical testing machine was used (Instron, Lloyd, UK). The fracture load was recorded for each sample, and compressive strength was calculated using the equation \( CS = \frac{4F}{\pi D^2} \), wherein \( CS \) stands for compressive strength, \( F \) is the maximum applied load in Newtons (N), and \( D \) is the diameter of the specimen in mm (app. 4 mm).

### Mjerenje kompresijske čvrstoće i SEM evaluacija uzoraka

Uzorci su podvrgnuti termocikliranju (10 000 ciklusa na 5 °C i 55 °C, 100 sekunda po ciklusu, interval od 5 sekunda, interval za uklanjanje vode iz komora). Poslije termocikliranja, mastikatorno trošenje simulirano je s pomoću simulatora žvakanja (MOD, Esetron Smart Robotechnologies, Ankara, Turska). Primijenjena je masa od 5 kilograma, ekvivalentna zvačnoj sili od 49 N (18). Prema dosadašnjim istraživanjima, od 240 000 do 250 000 opterećujućih ciklusa u žvačnom simulatoru ekvivalentno je otprilike jednoj godini žvakanja (19,20). Test trošenja sastojao se od 240 000 cikličkih opterećenja kako bi se simuliralo kliničko stanje nakon jedne godine žvakanja. Nakon cikličkog opterećenja uzorci su bili jedan tjedan pohranjeni u destiliranoj vodi na sobnoj temperaturi.

Mjerenja kompresijske čvrstoće provedena su na sobnoj temperaturi (23 ± 1 °C) prema ISO 9917-1:2007. Kompresijska čvrstoća određena je opterećenjem pri brzini klipa od 1 mm/min. do pucanja uzorka. Korišten je univerzalni uređaj za mjerenja mehaničkih svojstava (Instron, Lloyd, UK). Opterećenje pri pucanju zabilježeno je za svaki uzorak, a kompresijska čvrstoća izračunata je prema formuli \( CS = \frac{4F}{\pi D^2} \), u kojoj je \( CS \) kompresijska čvrstoća, \( F \) maksimalna aplikirana sila u njutnima (N), a \( D \) promjer uzorka u milimetrima (otprilike 4 mm).
SEM evaluation of the samples

The specimens were analysed using SEM after thermocycling. They were placed into an electrically conductive polymer mass; grinded at 300 rpm using water cooling and sandpaper (P320, P500, P1000, P2400, P4000); and polished at 150 rpm with 30 N force applied using diamond pastes (3 µm and 1 µm) and lubricant. Subsequently, they were gold sputter-coated and observed under SEM (JSM-6400 SEM, JEOL, Tokyo, Japan) at 20, 200, and 1,000 times magnification.

Statistical analysis

Statistical analysis was performed using the SAS statistical package. The Shapiro–Wilk test was used to analyze the normality of distribution. The Kruskal–Wallis test and factorial ANOVA were used to compare the differences between the sample groups at the level of significance p=0.05.

Results

The distribution of compressive strength measurements for all groups of samples was normal (the Shapiro–Wilk test). The Kruskal–Wallis test and factorial ANOVA analysis showed that there were no statistically significant differences between Equia Fil and Equia Forte Fil irrespective of the coating (Table 2), but a trend of increasing compressive strength in the coated samples was observed (Figure 1).

The SEM evaluation showed that when the samples were not coated prior to thermocycling, Equia Fil and Equia Forte Fil specimens were abraded with surface microcracks present (Figure 2).

Discussion

The results of this study showed that the compressive strength of Equia Fil and Equia Forte Fil after cyclic loading and thermocycling was higher when the samples were coated after initial setting with Equia Coat and Equia Forte Coat, respectively, but the differences were not statistically significant. These results are in agreement with some previous studies that also reported that applying a low-viscosity coating agent after initial setting enhanced the mechanical properties of the material (11). A recent report claims that there has been improvement in mechanical properties of the fast-setting GICs with simplified application procedures, i.e., in the absence of a protective varnish (21). However, this finding

| Stress at maximum load (MPa) | Factorial ANOVA | Kruskal-Wallis |
|-----------------------------|-----------------|----------------|
| Mean                       | St.dev.         | p               | p               |
| EQUIA Forte Coating (+)    | 198.02          | (37.68)         | 0.126           |
| EQUIA Forte Coating (-)    | 175.57          | (36.22)         |                 |
| EQUIA Coating (+)          | 172.80          | (25.37)         |                 |
| EQUIA Coating (-)          | 163.81          | (19.67)         |                 |

| Factor         |                   |                |
|----------------|-------------------|----------------|
| Material       |                   | 0.1185          |
| Coating        |                   | 0.1815          |

Table 2. There were no statistically significant differences between coated and uncoated Equia Fil and Equia Forte Fil groups.
ing cannot be interpreted as inconsistent with the results of this research since nano-filled coating agents were used instead of varnish.

Furthermore, in this study, Equia Forte Fil exhibited higher compressive strength than Equia Fil. This can be explained by the fact that the glass-hybrid concept of the Equia Forte restorative system, where the filler particles of approximately 25 µm are combined with highly reactive smaller particles (4 µm), contributes to the increase in the material’s strength (22). Furthermore, the nano-multifunctional monomer within the Equia Forte Coat improves the physical properties of the overall restorative system. This monomer used in Equia Forte Coat is functionalized with more functional groups to promote crosslinking, flexibility or adhesion. Although we did not evaluate clinical performance, we can assume that the improved physical properties should contribute to enhanced clinical performance (14). We can therefore correlate our findings with the results of some clinical studies that reported that the coating did not significantly improve clinical performance of the GIC materials in terms of reduced occlusal wear and increased survival rates (23,24).

The observed increase of CS in the coated samples, although not statistically significant, could be explained by the reduction of undesirable early water exchange (25). The application of a coating on the newly placed GIC was, therefore, recommended to prevent the water escape before it became strongly bound by hydration of the cations released from the glass or siloxane groups on the surface of glass particles (26,27). In the present study the specimens were stored in distilled water before the compressive strength measurement.

Figure 1 A tendency of increasing compressive strength in the coated samples was noticed for both Equia Fil and Equia Forte Fil, but the increase was not statistically significant.

Figure 2 SEM images show rough surfaces with microcracks in the samples that were not coated, while the surfaces of the coated samples were smooth and free of microcracks.

Slika 1. Tendencija povećanja kompresijske čvrstoće u uzoraku premazanih coatom zabilježena je za Equia Fil i Equia Forte Fil, ali to povećanje nije bilo statistički značajno

Slika 2. SEM slike pokazuju grubu površinu s mikropukotinama u nepremazanim uzorcima, a površine premazanih uzoraka gлатke su i bez mikropukotina

resultat ne može se smatrati proturječnim rezultatima u ovom istraživanju jer je u ovom istraživanju upotrijebljen nanopu- njeni svjetlosno-polimerizirajući premaz (coat), a ne jedno- stavni premaz (varnish).

Nadalje, ovo je istraživanje pokazalo da je kompresijska čvrstoća Equia Forte Fila veća od one Equia Fila. To se mo- že objasniti staklohibridnim konceptom restaurativnog susta- va Equia Forte, u kojem su čestice punila veličine od 25 µm kombinirane s visokoreaktivnim manjim česticama (4 µm), što pridonosi povećanju čvrstoće materijala (22). Osim toga, nanomultifunkcionalni monomer u Equia Forte Coa- tu poboljšava fizikalna svojstva cijelog restaurativnog susta- va. Monomer u Equia Forte Coatu funkcionaliziran je s vi- še funkcionalnih skupina koje promiču kržno povezivanje, fleksibilnost i adheziju.

Premda u ovom radu nije istraživano kliničko ponašanje, može se pretpostaviti da poboljšana fizikalna svojstva prido- nose kliničkom poboljšanju (14). Zato se naši rezultati mo- gu usporediti s rezultatima nekih kliničkih studija u kojima je istaknuto da premazivanje coatom nije značajno poboljša- lo kliničku izvedbu GIC-a kad je riječ o smanjenom okluza- nom trošenju i produktnom trajanju ispuno (23, 24).

Uočeno povećanje CS-a u premazanim uzorcima, prem- da nije bilo statistički značajno, može se objasniti smanje- njem nepoželjne rane izmjene vode (25). Primjena coat na novopostavljeni GIC stoga se preporučuje kako bi se sprije- čila dehidracija prije čvrstog vezanja vode hidracijom katio- na otpuštenih iz stakla ili siloksanskih skupina na površini staklenih čestica (26, 27). U ovom su istraživanju uzorci pri- je mjerenja kompresijske čvrstoće bili pohranjeni u destilira-
ments were taken, but it was not expected that the storage in water would influence the water sorption in the uncoated groups since the escape of loosely bound water was shown to be critical at this stage, as mentioned earlier (27).

After the acid-base reaction, clinically described as the initial setting, the maturation process takes place within the material until complete setting occurs (28). The water absorbed in the maturation phase occupies coordination sites around metal cations or hydration regions around the polyanion chain within the set cement (9). This enables shrinkage compensation, and the proportion of loosely bound water decreases relative to the proportion of tightly bound water as the cement matures (9, 29). The maturation results in altered mechanical properties for GICs, and compressive strength increases asymptotically to a stable value higher than the one found at 24 hours (28,30).

The increase in compressive strength during the initial period of a few weeks after placement was established for conventional glass ionomers decades ago, and it seems to occur faster in modern, highly viscous glass ionomers, where the increase in CS is significant during the first day and rises further until one week after placement (31,32,28). In this study, the compressive strength of the tested GIC materials was not determined after the initial setting or after 24 h, hence we cannot draw any conclusions about how the CS values changed over time within one group of samples. However, when comparing compressive strength values exhibited by the materials used in this study with the compressive strength values of other fast-setting glass ionomers, we can observe that the values obtained after aging simulations are similar to those obtained after 24 hours in a previous study (33). This might imply that thermocycling does not reduce compressive strength in GIC materials, as already reported (34).

Our results further suggest that coating Equa Fil and Equa Forte Fil rendered their surface free of microcracks, possibly due to more favorable water balances during the first 24 hours that enabled complete maturation. The SEM pictures taken after thermocycling show smooth and microcrack-free surfaces of glass ionomer samples coated with Equa Coat (Figure 2). This also shows that the nano-filled coat does not readily wear off. In this research, we did not focus on occlusal wear or volumetric loss of the loaded material based on GIC technology, but we can assert that the coat visualized on SEM images after thermocycling is consistent with the previously reported reduced occlusal wear of a GIC-based material protected by a surface resinous coating (12).

**Conclusion**

The clinically important mechanical property of compressive strength after thermocycling and cyclic loading was not found to be significantly improved by coating glass ionomer based restorative materials with nano-filled resinous coats, although a trend toward increased was recorded in the coated samples.
GIC Compressive Strength after Fatigue

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Conflict of Interest

None declared.

Zahvala

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Sukob interesa

Autori nisu bili u sukobu interesa.

References

1. Yip HK, Tay FR, Ngo H, Smale RS, Pashley DH. Bonding of con-
temporary glass ionomer cements to dentin. Dent Mater. 2001
Sep;17(5):456-70.
2. Lohbauer U. Dental Glass Ionomer Cements as Permanent Filling
Materials? Properties, Limitations and Future Trends. Materials
(Basel). 2010;3(1):76–96.
3. Brzovic Rajic V, Miletić I, Gurgan S, Peroš K, Verzak Ž, Ivanović
Malčić A. Fluoride Release from Glass Ionomer with Nano Filled
Coatom and Varnish. Acta Stomatol Croat. 2019 Jun;53(2):132-140.
4. Xia D, Brantley WA, Cubertson BM, Wang G. Mechanical proper-
ties and microstructures of glass-ionomer cements. Dent Mater.
2000 Mar;16(2):129-38.
5. Gu YW, Yap AU, Cheang P, Khor KA. Effects of incorporation of
HA/ZrO2 into glass ionomer cement (GIC). Biomaterials. 2005
Mar;26(7):713-20.
6. Tjandrawinita R, Irie M, Yoshida Y, Suzuki K. Effect of adding spher-
ical silica filler on physico-mechanical properties of resin modified glass-
ionomer cement. Dent Mater. J 2004 Jun;23(2):146-54.
7. Spajić J, Par M, Milat O, Demoli N, Brzović Rajić V. Mechanical
Properties of High Viscosity Glass Ionomer and Glass Hybrid Restorative Materials. Acta Stomatol Croat. 2019 May;53(3):37-46.
8. Nicholson JW. Chemistry of glass ionomer cement (GIC). Biomateri-
als. 2005 Mar;26(7):713-20.
9. Nicholson JW, Wilson AD. The effect of storage in aqueous solu-
tions on glass-ionomer and zinc polycarboxylate dental cements.
J Mater Sci Mater Med. 2000;11(6):357–60.
10. Brito OR, Velasco LG, Bonini GA, Imparato JC, Raggio DP. Glass Ionomer
cement hardness after different materials for surface protection. J
Biomed Mater Res A. 2010 Apr;91(3):243-6.
11. Faraji F, Heshmat H, Banava S. Effect of protective coating on micro-
hardness of a new glass ionomer cement: Nanofilled coating versus
unfilled resin. J Conserv Dent. 2017 Jul-Aug;20(4):260-63.
12. Dierck VT, Tuys MS, Hien CN, Phuong LH, Khanh NG. The effect of a
nano-filled resin coating on the 3-year clinical performance of a con-
temporary high-viscosity glass-ionomer cement. Clin Oral Invest.
2014 Apr;18(3):753-9.
13. Kanik D, Turkun LS, Dasch W. In vitro abrasion of resin-coated highly
viscous glass ionomer cements: A confocal laser scanning microscopy
study. Clin Oral Investig. 2017 Apr;21(3):821-829.
14. Kielbassa AM, Gloeckner G, Wolgin M, Gloeckner K. Systematic review
on highly viscous glass ionomer cement/resin coating restorations (Part
II): Do they merge Minamata Convention and minimum intervention den-
tistry? Quintessence Int. 2017;48(1):9-18.
15. International Organization for Standardization (ISO). Standard for
water-based dental cements. 2007;9911-9917.
16. Salvičić I, Stojan M, Schauberl P, Zverak Z, Ivanović Malčić A, Brzović Rajić V. Mechanical Properties of High Viscosity Glass Ionomer
and Glass Hybrid Restorative Materials. Acta Stomatol Croat. 2019 Jun;53(3):125-131.
17. Braem M, Lambrechts P, Vanherle G. Clinical relevance of labora-
tory fatigue studies. J Dent. 1994;22(2):97–102.
18. Krejci I, Mueller E, Lutz F. Effects of thermocycling and occlusal
force on adhesive composite crowns. J Dent Res. 1994
Jul-Aug;73(6):1228-32.
19. DeLong R, Sakaguchi RL, Douglas WH, Pintado MR. The wear of
dental amalgam in an artificial mouth: a clinical correlation. Dent
Mater. 1985 Dec;1(6):238-42.
20. Jung YS, Lee JW, Choi YJ, Ahn JS, Shin SW, Huh JB. A study on the in-
vitro wear of the natural tooth structure by opposing zirconia or dental
porcelain. J Adv Prosthodont. 2010 Sep;2(3):111-5.
21. Ilie N. Maturation of restorative glass ionomers with simplified
application procedure. J Dent. 2018 Dec;79:46-52.
22. Miletic I. Modern solutions for direct posterior restorations. GC
Get Connected. 2015;4:32–36.
23. Basso M, Brambilla E, Benites MG, Giovannardi M, Ionescu AC.
Glassionomer cement for permanent dental restorations: a 48-months,
multi-centre, prospective clinical trial. Stoma Edu J. 2015;2(1):25–35.
24. Hesse D, Bonifácio CC, Böecker M, Guglielmi Cde A, da Franca
C, van Amerongen WE et al. Survival rate of atrumatic restorative
treatment (art) restorations using a glass ionomer bilayer technique with
a nanofilled coating: a bi-centered randomized clinical trial. Pediatr Dent.
2016 Jan-Feb;38(1):18-24.
25. Hume WR, Mount GJ. Effect of varnishes and other surface treat-
ments on water movement across the glass-ionomer cement sur-
face. Aust Dent J. 1985 Aug;30(4):298-301.
26. Czarneczka B, Klos J, Nicholson JW. The effect of ionic solutions on
the uptake and water-binding behaviour of glass-ionomer dental
cements. Ceram Sicilky. 2015;59(4):102–8.
27. Berg MC, Jacobsen J, Momsen NCR, Benetti AR, Telling MTF, Seydel T, et al. Water dynamics in glass ionomer dental cements. The Eur Phys J Spec Topics. 2016;225(4):773–7.
28. Nicholson JW. Maturation processes in glass-ionomer dental cements. Acta Biomater Odontol Scand. 2018 Jul 31;4(1):63-71.
29. Hankins AD, Hatch RH, Benson HJ, Blen BJ, Tantbiroj D, Versluis A. The effect of a nanofilled resin-based coating on water absorption by teeth restored with glass ionomer. J Am Dent Assoc. 2014 Apr;145(4):363-70.
30. Mount, GJ. An atlas of glass-ionomer cements: a clinician’s guide. 2nd ed. London: Martin Dunitz; 2002.
31. Bresciai E, Barata Tde J, Fagundes TC, Adachi A, Tenin MM, Navarro MF. Compressive and diametral tensile strength of glass ionomer cements. J Appl Oral Sci 2004;12(4):344–8.
32. Crisp S, Lewis BG, Wilson AD. Characterisation of glass-ionomer cements. 1. Long-term hardness and compressive strength. J Dent. 1976 Jul;4(4):162-6.
33. Bonifácio CC, Kleverlaan CJ, Raggio DP, Werner A, Carvalho RC, van Amerongen WE. Physical-mechanical properties of glass ionomer cements indicated for atraumatic restorative treatment. Aust Dent J. 2009 Sep;54(3):233-7.
34. Lohbauer U, Frankenberger R, Krämer N, Petschelt A. Time-dependent strength and fatigue resistance of dental direct restorative materials. J Mater Sci Mater Med. 2003 Dec;14(12):1047-53.