RSBO

ISSN:
Electronic version: 1984-5685
RSBO. 2015 Jan-Mar;12(1):79-87

Literature Review Article

Indications and restorative techniques for glass ionomer cement

Fabio Antonio Piola Rizzante[1]
Rafael Schlögel Cunali[2]
Juliana Fraga Soares Bombonatti[1]
Gisele Maria Correr[1]
Carla Castiglia Gonzaga[2]
Adilson Yoshio Furuse[1]

Corresponding author:
Adilson Yoshio Furuse
Departamento de Dentística, Endodontia e Materiais Odontológicos
Faculdade de Odontologia de Bauru, Universidade de São Paulo
E-mail: furuse@usp.br

[1] Department of Operative Dentistry, Endodontics and Dental Materials, Bauru School of Dentistry – Bauru – SP – Brazil.
[2] Graduate Program in Dentistry, Positivo University – Curitiba – PR – Brazil.

Received for publication: October 20, 2014. Accepted for publication: November 24, 2014.

Keywords: glass ionomer cements; biocompatible materials; dental restoration, permanent.

Abstract

Introduction: Due to its chemical, mechanical and biological properties, the glass ionomer cements (GIC) consist in one of the most versatile direct restorative materials, with many potential clinical indications, especially in the context of minimally invasive dentistry. Nevertheless, they have some limitations and require the knowledge of their characteristics and procedures of application in order to achieve their maximum potential. **Objective:** To demonstrate through literature review the main characteristics, indications, limitations and future perspectives for the use of GIC. **Literature review:** The database, such as Pubmed and Lilacs were used. Additionally, books were also evaluated and included. **Conclusion:** The GIC is in constant evolution and is one of the materials that are best suited in the context of preventive and conservative dentistry. It has satisfactory properties and versatility. On the other hand, presents inferior properties when compared to other direct restorative materials, requiring caution during its handling.

Introduction

Glass ionomer cements (GICs), also known as glass polyalkenoic cement, has a fundamental role in current Dentistry. This is not only because of the social and preventive aspect of this material when one considers dental caries and concepts based on scientific evidence and minimally invasive dentistry, but also its excellent physical-chemical-mechanical properties, such as fluoride release, adhesion to tooth structure, biocompatibility and coefficient of thermal expansion similar to that of dentin [40, 45]. Moreover, unlike other aesthetic adhesive materials, such as composite resins, adhesion to dental structures of GIC is less sensitive to technique and its quality increases with time [10].

Despite its good properties, constant changes, and improvements, so that GIC restorations show good clinical success, it is important to know its characteristics and proper technique of use. Thus, this paper aims to demonstrate, through literature review, the main characteristics, indications, limitations, and future aspects for the use of this material.

Literature review and discussion

Development and evolutions

Glass ionomer cements are available since the early 1970s [56] and are derived from silicate and zinc polycarboxylate cements. The polycarboxylate cements were the first materials to provide adhesion to tooth structures, mainly produced by the polyacrylic acid to ensure their biocompatibility, because it is a weak and high molecular weight acid, which does not diffuse through the dentinal tubules. Based on this finding, the polycarboxylate cements gained quickly popularity as cementing agents, but could not be used as restorative materials because of the high solubility of unsatisfactory mechanical properties and unacceptable aesthetics caused by residual zinc oxide. Silicate cements, in turn, appeared on the market in the first decade of the twentieth century and were the first esthetic restorative materials, having anti-cariogenic properties due to the fluoride release and good dimensional stability, but had numerous disadvantages, including high disintegration and porosity in the oral environment, low color stability and the toxic action on the pulp [42]{Parula, 1975 #142}. Glass ionomer cements then came from the replacement of the zinc oxide by an ionizable reactive glass. This reactive glass is similar to that existing in the silicate cements. Thus, a more durable, less soluble, and more translucent material was developed [33], with chemical bonding to the dental substrate by the bonding of calcium ions to carboxylic radicals existing in the enamel, dentin and cementum. It is noteworthy that in addition to adhesion to dental structures, GIC also bonds to many metals such as stainless steel, tin or Platinum covered by tin oxide and gold; but it does not adhere to porcelain, pure platinum, or pure gold [33, 36, 45].

Based on these initial studies, it was launched in the European market in the mid-1970s, the first GIC, produced by Dentsply, called ASPA (**a**luminum **s**ilicate and **p**oly**a**crylate), with unsatisfactory properties such as reduced working time and longer setting time [40, 41].

The GICs are composed of powder and liquid and consist of polymeric matrices with ionic crosslinking around reinforcing glass particles [45]. The powder is composed of three basic components: silica (SiO2), alumina ($Al2O_3$) and calcium fluoride (CaF_2). The liquid is an aqueous solution of polyalkenoic acids with the addition of setting accelerators [39]. The setting reaction is acid-base type and starts from the mixture of powder and liquid to form a hydrogel salt, which acts as a binding matrix and unreacted glass particles acting as filler particles [31].

Since its development, the GICs have been constantly improved. During the 1970s, several studies have analyzed and modified the original formula, resulting in improvements in the material, which is now indicated as an excellent alternative for various procedures in practice, since the first formulations presented problems as short clinical time, unsatisfactory aesthetic, reduced working time, sensitivity to moisture variations (syneresis and imbibition), low mechanical strength and longer setting time. To enhance the slow setting reaction of ASPA, in 1976, low molecular weight chelating (tartaric acid) was added to the liquid, which accelerated the setting reaction and facilitated the incorporation of glass powder ions, resulting in ASPA II [9].

Another problem is the initial rapid gelation of liquid because of the formation of internal chains between the hydrogen ions, so the itaconic acid was incorporated into the liquid 1977 with ASPA IV [39].

The first major change in its composition happened during the 1980s, when metal dust particles were incorporated, seeking better mechanical properties and radiopacity (so-called Cermet GIC) [35, 50].

Another important development of the GIC occurred in the late 1980s, when the resin-modified glass ionomer cements appeared (RMGIC) [3]. This development has brought many advantages, such as control of working time, ease of handling, fast setting time, less sensitive to syneresis and imbibition and the opportunity immediately finishing procedure [40]. RMGICs have shown stable adhesion to dentin over the months. It is believed that this stability is related to both the chemical bonding mechanism to hydroxyapatite regard to micromechanical retention [52]. Franco *et al.* [17] and Fagundes *et al.* [13], in clinical trials with follow-up of 5 and 7 years, respectively, observed that the evaluated RMGIC presented a clinical performance higher than that of the composite resin. RMGICs tend to be employed because of the longest working time, improved physical properties and aesthetic qualities, and because they are more resistant to dehydration and cracks during setting than the conventional versions, chemically activated.

More recently, with the advent of ART (atraumatic restorative technique), there was the need to improve the physical properties of these materials, leading then to high viscosity GICs, with chemical activation. These materials have a greater number of particles with smaller sizes.

Susceptibility to syneresis and imbibition

Because of GIC and RMGIC setting reaction, sometimes they are more susceptible to syneresis and imbibition [59]. The syneresis is the loss of water due to evaporation of the liquid and can cause gaps and cracks in the cement surface. Moreover, contamination with water (imbibition) can cause the dissolution of the matrix formed by cations and anions in the surrounding areas [4]. These characteristics justify the need to protect the material after its insertion into the cavity with insulating materials such as: Vaseline, varnishes, fluid resins [6], or colorless nail polish [54].

GIC mechanical properties

Compared to resin composites, GICs have lower compressive strength and diametral tensile strength [40], lower resistance to wear [15, 18] and acid erosion [10, 44], and greater friability [38], making unfeasible their use in areas of high concentration of masticatory forces and aesthetic areas.

Another GIC feature is the low modulus of elasticity of the order of 7.3 GPa, half of the modulus of a micro-hybrid composite (15 to 20 GPa) [4], thereby giving it a unique elastic characteristic that will define some of its clinical indications, e.g., restoration of cervical lesions, because of the bending stress exerted in the area requiring the use of a material with better elastic properties [28].

The low modulus of elasticity also allows its use as a liner material, since the association of GIC with the resins assists in relieving of the forces resulting from the polymerization shrinkage. In this context, it is reported that the use of a glass ionomer as liner material caused a significant reduction in the cusp deflection compared with composite resin restorations without liner [2]. Sampaio *et al.* [46] observed that the use of RMGIC as liner resulted in lower crack formation on dentin/adhesive interface after laboratorial aging.

Capacity of fluoride release and storage

Among all the properties of GIC, one of the most important is its ability to release and store fluoride [51], which can be extended for 8 years [16]. It is known that fluorides are extremely important in the prevention and treatment of dental caries, having the main function of adsorption on the surface of the tooth in the form of CaF_2, protecting the tooth and favoring the remineralization process [32]. Given this ability to release and store fluoride, the GIC becomes an excellent choice of restorative material for the treatment of patients at high risk for caries.

This release occurs mainly in the first 24-48 hours, but decreases and stabilizes over time, although it can occur throughout the life of the clinical restoration, with the possible reintroduction of F^- ions [11, 41].

Adhesion to tooth structure

GICs present chemical adhesion to tooth structure by means of ion exchange. The carboxylic groups replace the phosphate ions of the substrate to establish ionic bonds with calcium ions derived from partially dissolved apatite crystals [11, 41]. This adhesion mechanism was shown by X-ray electron spectroscopy (XPS) in the study of Yoshida *et al.* [58].

This reaction is also observed for RMGICs [30], although RMGICs generally require that primers containing HEMA and polyacrylic acid are applied on the surface prior to its insertion. These primers infiltrate and polymerize on dentin forming micromechanical retention, similar to what occurs in the hybrid layer in the composites, and should be light cured [26].

It is noteworthy that the quality and intensity of GIC adhesion to tooth structure can be affected by factors such as physical strength of the material, the substrate nature, surface contamination and type of treatment and/or cleaning performed on the surface in which the restoration is inserted. Adhesion is severely hampered by the presence of smear layer, as this reduces the free energy of the dentin surface and therefore their reactivity, and is still able to harbor bacteria. Thus, treatment of the tooth surface with polyacrylic acid is essential [23].

It should be noted that, compared with the resins, ionomer cements have a lower bond strength to the dental tissue [10, 34, 45]. However, it is believed that this adhesion is reliable and resistant to disintegration [10]; Furthermore, the results obtained in microtensile tests should be evaluated with caution, because often cohesive failures caused by the material properties do not represent bond strength of the material, but the low cohesive strength of the restorative material, since GIC cohesive fractures were observed in transmission electron and scanning microscopy [57].

Biocompatibility

Ionomer cements have low pulp response compared to that produced by the zinc oxide and eugenol cements [53], similar to the response generated by zinc polycarboxylate cements [43].

This biocompatibility occurs because the polyacrylic acid is weak, with macromolecules of high molecular weight, prone to join the calcium of the tooth, making it difficult to move inside the dentinal tubules. Generally, they are less irritating to the pulp tissues when compared to resinous adhesives. However, in deep and very deep cavities, it is recommended the use of a liner with calcium hydroxide cement to ensure that the acid portion of the ionomer (although having low penetrability and being quickly quenched) can not cause any harm [8].

GIC biocompatibility occur not only for pulp tissues, but also for periodontal tissues because GIC is capable of reducing subgingival biofilm compared with resin composite restorations, not irritating the tissues if the biological principles are followed [47-49].

Coefficient of linear thermal expansion

GIC present a linear thermal expansion coefficient very close to that of the dental structures and it is suitable as support for undermined enamel (artificial dentin), without compromising the final bond strength of the restoration. This feature, combined with the chemical bonding capacity with the dental structures, clinically results in a reduced chance of marginal leakage. Note that this property is reduced in RMGIC, with values closer to those presented by the amalgam and composite resins [11, 40].

Classification, indications, limitations, and contraindications

Given GIC properties and characteristics, these materials can be classified according to their clinical indication and composition [39].

Concerning to clinical indication

Type I: Ionomers indicated for the cementation of inlays, crowns, fixed partial dentures, orthodontic appliances, and endodontic filling. They are fluid materials, also identified as Type I, CEM, C or Luting.

Type II: Ionomers indicated for restorations, presenting particles lager than those of Type I, also identified as R or FIL.

Type III: Ionomers indicated for lining, sealing of pits and fissures, also known as Bond and Lining or F.

Concerning to composition

Conventional GIC: Ionomers with conventional acid-base reaction, displayed as powder and liquid inside different flasks or encapsulated. The glass components and the fluoride are inside the powder and the acids components inside the liquid.

In anhydrous cements, the liquid acid component was freeze-dried (dehydrated) and incorporated into the powder. The liquid is usually distilled water or in an aqueous solution of tartaric acid, which accelerate the setting reaction. These cements have emerged in an attempt to better control the proportioning of powder and liquid and solve the problem of instability of polyacrylic acid, which is very volatile.

Metal reinforced GICs: The liquid is similar to that of the conventional ionomers, while the powder consists of a mixture of conventional powder with amalgam alloy particles or silver particles sintered with the glass. These cements have arisen with the expectation of improving GIC mechanical properties, and although the mechanical properties have been reported to be superior to conventional cements, these do not seem to be different when compared to modern cements. The inclusion of metallic particles brought damage to materials in relation to fluoride release, adhesion to tooth structure, as well as the aesthetic damage arising from the darkening of the edges of the cavities. Cermet type GIC has been employed in invasive sealing of posterior teeth and some cases of crown reconstruction.

Resin modified GICs (RMGIC): Incorporation of resin components, primarily HEMA and initiators of polymerization, replacing part of the polyalkenoic acid liquid. These materials were introduced to overcome the problems of sensitivity to moisture, and poor initial mechanical properties associated with the conventional cements. In these materials, the original acid-base reaction is supplemented by a secondary polymerization process initiated by exposure to light. Regardless of the type and amount of resinous material present, so that these new materials could be classified as GIC, they must present adequate acid-base reaction to promote hardening, even in the absence of light.

High-viscosity GICs: Those employed in Atraumatic Restorative Treatment (ART) with high powder-liquid ratio and fast setting reaction.

Based on the classification presented, it can be inferred that the GICs are very versatile materials, indicated for preventive procedures (oral environment adequacy and pits and fissures sealing), restoration of areas of lower masticatory load (class I, class II vertical and horizontal slot, class III and class V restorations) [1, 55]; cavity lining; sandwich restoration (open and close); primary tooth restorations; cementation of post and cores, prostheses; and dentin replacement. Moreover, GICs have a fundamental role in ART [19, 20, 27].

GIC contraindications are: class II restoration involving the marginal ridge; class IV restoration and teeth with great loss of the labial/buccal enamel; cusp areas; and areas submitted to great masticatory load.

Another GIC limitation is related to aesthetics. As a restorative material, conventional GICs are not as aesthetic as composite resins, and therefore are not generally recommended for use in areas of significant cosmetic concern. The RMGIC, on the other hand, can be used in some aesthetically demanding areas, since they have better aesthetic qualities [45]. Notwithstanding, according to Navarro *et al.* [40], GIC optical properties greatly improved, allowing it to be suitably used in restorations, such as Class III. The authors also claim that conventional GICs have greater color stability when compared with those modified by resin.

A fast surface wear loss may occur in some cases, however, since the technique is less demanding, the GICs may function in many aspects, more successfully than the composites. Thus, as the surface properties are apparently lower than those of composite resins, ionomer cements have been widely reported as substitutes for sandwich type restorations [10]. An interesting finding is the inhibition of demineralization areas in restorations of dentin margins with GIC lining, in which the open sandwich technique was employed [52].

Whereas the GICs have unsatisfactory properties of resistance to erosion and abrasion, its application in high-risk patients can be compromised if educational measures regarding hygiene and control of sugar intake are not adopted.

Despite the aforementioned limitations, there are reports of significant percentages of success in clinical evaluations of extensive classes I and II cavities in molars restored with ART technique, comparable to the results obtained with the use amalgam [21, 25, 39], but GIC properties still need to be improved s [7].

Restoration techniques

Preliminary considerations

During the restorative technique, care must be taken to prevent early failure of the material. Among them, we can cite [39]:

1. Clean and dry the prepared cavity. The dental structure (dentin and enamel), before receiving the glass ionomer cement should be treated with weak acid solutions, such as polyacrylic acid (10 to 25%), in order to improve the adhesive characteristics of the cement by increasing the surface energy and wetting ability of the surface to be restored;
2. Proper powder-liquid ratio;
3. The vial of powder must be shaken before use (especially the anhydrous cement, in order to prevent excessive amounts of glass particles or lyophilized acid be mixed with the liquid);
4. The liquid bottle should be positioned vertically and at a distance from the glass plate to allow a free drop output;
5. Mixing time should follow the manufacturer1s instructions;
6. The material to be inserted should present a wet brightness;
7. Caution should be taken during the material insertion to avoid bubbles inside the restoration. This can be prevented by using Centrix syringe;
8. Prevent the wet contamination;
9. Press the material with a matrix for 1 min

(chemically activated) or during light-curing (photo activated);
10. During the initial removal of the excesses, use the scalpel blade from the restoration towards the tooth structure;
11. The finishing procedure should be performed at the next appointment;
12. Apply the superficial protection immediately after the restoration. GICs are highly sensitive to water gain and loss. Aiming to protect these cements, one can use varnishes provided with the materials, fluid resins, or colorless nail polish;
13. Finishing and polishing procedures should be executed with lubricated instruments to avoid overheating of the restoration, maintaining the moisture of the restorative material.

In addition to these aspects, other care should be emphasized to obtain satisfactory results.

• Caution with the powder and liquid

The flasks must be tightly closed to avoid the gain or loss of water, since the glass ionomer cements are essentially water. The liquid must not be stored in the refrigerator because it loses its original properties. The powder and mixing pad or plate can be kept in a refrigerator in order to increase the working time [39].

• Caution with the encapsulated cements

Using the capsule as fast as possible after the breaking of the sheath that protects the environment. Press the clip that lines the fluid reservoir for at least 2 seconds, which will ensure the passage of all the liquid into the capsule. Use mixer device supplied by the manufacturer or a device that enables 4,000 rpm [39].

Conclusion

On this basis of this review, it is noted that the CIV are highly versatile materials and with great clinical potential. Based on the idea of improving the properties of these materials, making them even more effective, or enabling its use as biomaterials [24], some authors have proposed changes in its composition whether such changes can be further perspectives of the material. Among the proposed changes can be highlighted: the modifications by incorporating medications (e.g. chlorhexidine), aiming at the improvement in antimicrobial properties and prevention of secondary caries [12]; association with bioactive glass, aiming at improving the properties of remineralization and antimicrobial activity, making them even better for restorations in high-risk patients [29]; and insertion of polymers and nanoparticles in GIC matrix [14, 22] to improve the mechanical properties.

Thus, GICs are not only bioactive, but have characteristics of an intelligent material [10]. These materials are considered bioactive because they release fluoride and, as mentioned, are subject to changes in their formulations. They are considered intelligent, because that fluoride release to the oral environment is proportional to the acidity of the medium [10]. It is known that the fluoride release by ionomers occurs in greater quantities during the first 24 hours after its insertion into the cavity and, after this initial period, the release occurs in small amounts. It is interesting to note that even modified ionomer resin, have a clearance behavior when exposed to fluoride [37].

The biocompatibility of traditional glass ionomer cements has been a clinical concern. Upon initial mixing, there is a potential for causing sensitivity and produce pulp irritation. As the setting reaction proceeds, the pH increases from about 1 in early times to a range of 4 to 5. As the setting reaction nears completion, the final pH reaches 6.7 to 7. Once the acid groups are bound to polymer molecules that have limited diffusivity, any potential effects to the pulp from initial pH are limited to areas immediately adjacent to the material. If the amount of residual dentin at the nearest wall of the pulp chamber is less than 0.5 mm, it may be necessary to protect the dentin surfaces of the direct contact with GIC using a calcium hydroxide liner [45].

Although GICs present a less sensitive technique than that of resin composites, good results can only be obtained if GIC and the RMGIC are employed in accordance with appropriate clinical protocols, respecting the manufacturer's instructions and always carefully considering the indications, limitations and contraindications of the materials.

Since the principles advocated by Black [5], in 1908, the development of dental materials that can assist in the conservation of tooth structure has aroused. Thus, it is possible to start preventive and conservative dentistry. GIC is one of the materials that best fit the context of preventive and conservative dentistry and, as discussed in this review, has satisfactory properties and great versatility. On the other hand, it has some inferior properties, requiring some caution during handling and restoration. It is noteworthy that, despite their excellent properties, GIC is not the material of choice for all procedures and dental professionals should know their composition and properties, to make a correct diagnosis of oral and systemic conditions of the patient, taking into account their needs and anxieties in order to ensure proper application, thereby reaching the clinical success of the restoration procedure.

References

1. Abdalla AI, Garcia-Godoy F. Bond strengths of resin-modified glass ionomers and polyacid-modified resin composites to dentin. Am J Dent. 1997 Dec;10(6):291-4.

2. Alomari QD, Reinhardt JW, Boyer DB. Effect of liners on cusp deflection and gap formation in composite restorations. Oper Dent. 2001 Jul-Aug;26(4):406-11.

3. Antonucci JM, McKinney JE, Stansbury JW. Resin-modified glass-ionomer dental cements field of the invention. US Patent Application. 1988.

4. Anusavice KJ, Shen C, Rawls HR. Philips' Science of dental materials. 12. ed. St Louis: Saunders; 2013. p. 307-39.

5. Black GV. A work on operative dentistry: the technical procedures in filling teeth. Chicago: Medico-Dental; 1908.

6. Bonifacio CC, Werner A, Kleverlaan CJ. Coating glass-ionomer cements with a nanofilled resin. Acta Odontol Scand. 2012 Dec;70(6):471-7.

7. Burke FJ. Dental materials – what goes where? The current status of glass ionomer as a material for loadbearing restorations in posterior teeth. Dent Update. 2013 Dec;40(10):840-4.

8. Caviedes-Bucheli J, Ariza-Garcia G, Camelo P, Mejia M, Ojeda K, Azuero-Holguin MM et al. The effect of glass ionomer and adhesive cements on substance P expression in human dental pulp. Med Oral Patol Oral Cir Bucal. 2013 Nov;18(6): e896-901.

9. Crisp S, Wilson AD. Reactions in glass ionomer cements: V. Effect of incorporating tartaric acid in the cement liquid. J Dent Res. 1976 Nov-Dec;55(6):1023-31.

10. Davidson CL. Advances in glass-ionomer cements. J Appl Oral Sci. 2006;14(Suppl):3-9.

11. Davidson CL, Mjör IA. Advances in glass ionomer cements. Carol Stream: Quintessence; 1999.

12. De Castilho AR, Duque C, Negrini T de C, Sacono NT, De Paula AB, De Souza Costa CA et al. In vitro and in vivo investigation of the biological and mechanical behaviour of resin-modified glass-ionomer cement containing chlorhexidine. J Dent. 2013 Feb;41(2):155-63.

13. Fagundes T, Barata T, Bresciani E, Santiago S, Franco E, Lauris J et al. Seven-year clinical performance of resin composite versus resin-modified glass ionomer restorations in noncarious cervical lesions. Oper Dent. 2014 Nov-Dec;39(6):578-87.

14. Fareed MA, Stamboulis A. Effect of nanoclay dispersion on the properties of a commercial glass ionomer cement. Int J Biomater. 2014;2014:10. DOI685389.

15. Forss H, Seppa L, Lappalainen R. In vitro abrasion resistance and hardness of glass-ionomer cements. Dent Mater. 1991 Jan;7(1):36-9.

16. Forsten L. Fluoride release and uptake by glass-ionomers and related materials and its clinical effect. Biomaterials. 1998 Mar;19(6):503-8.

17. Franco EB, Benetti AR, Ishikiriama SK, Santiago SL, Lauris JR, Jorge MF et al. 5-year clinical performance of resin composite versus resin modified glass ionomer restorative system in non-carious cervical lesions. Oper Dent. 2006 Jul-Aug;31(4):403-8.

18. Freitas MFA, Imai LJ, Freitas CA, Bianchi EC, Almeida CT, Martins Filho IE. Abrasive wear of two glass ionomer cements after simulated toothbrushing. RSBO. 2011;8:287-93.

19. Frencken JE, Holmgren CJ. Caries management through the atraumatic restorative treatment (ART) approach and glass-ionomers: update 2013. Braz Oral Res. 2014 Jan-Feb;28(1):5-8.

20. Frencken JE, Leal SC, Navarro MF. Twenty-five-year atraumatic restorative treatment (ART) approach: a comprehensive overview. Clin Oral Investig. 2012 Oct;16(5):1337-46.

21. Frencken JE, Van't Hof MA, Van Amerongen WE, Holmgren CJ. Effectiveness of single-surface ART restorations in the permanent dentition: a meta-analysis. J Dent Res. 2004 Feb;83(2): 120-3.

22. Garcia-Contreras R, Scougall-Vilchis RJ, Contreras-Bulnes R, Kanda Y, Nakajima H, Sakagami H. Effects of TiO_2 nano glass ionomer cements against normal and cancer oral cells. In Vivo. 2014 Sep-Oct;28(5):895-907.

23. Hajizadeh H, Ghavamnasiri M, Namazikhah MS, Majidinia S, Bagheri M. Effect of different conditioning protocols on the adhesion of a glass ionomer cement to dentin. J Contemp Dent Pract. 2009;10(4):9-16.

24. Hatton PV, Hurrell-Gillingham K, Brook IM. Biocompatibility of glass-ionomer bone cements. J Dent. 2006 Sep;34(8):598-601.

25. Hilgert LA, de Amorim RG, Leal SC, Mulder J, Creugers NH, Frencken JE. Is high-viscosity glass-ionomer-cement a successor to amalgam for treating primary molars? Dent Mater. 2014 Oct;30(10):1172-8.

26. Hinoura K. Factors influencing dentin bond of a tricured type II glass ionomer. J Dent Res. 1994;73:329 (abstract n. 1815).

27. Holmgren CJ, Roux D, Domejean S. Minimal intervention dentistry: part 5. Atraumatic restorative treatment (ART) – a minimum intervention and minimally invasive approach for the management of dental caries. Br Dent J. 2013 Jan;214(1): 11-8.

28. Ichim IP, Schmidlin PR, Li Q, Kieser JA, Swain MV. Restoration of non-carious cervical lesions Part II. Restorative material selection to minimise fracture. Dent Mater. 2007 Dec;23(12):1562-9.

29. Khoroushi M, Keshani F. A review of glass-ionomers: from conventional glass-ionomer to bioactive glass-ionomer. Dent Res J. 2013 Jul;10(4):411-20.

30. Lin A, McIntyre NS, Davidson RD. Studies on the adhesion of glass-ionomer cements to dentin. J Dent Res. 1992 Nov;71(11):1836-41.

31. Loguercio AD, Reis A, Navarro MFL. Materiais dentários restauradores diretos – dos fundamentos à aplicação clínica. São Paulo: Santos; 2007. p. 217-51.

32. Magalhaes AC, Levy FM, Rizzante FA, Rios D, Buzalaf MA. Effect of NaF and TiF_4 varnish and solution on bovine dentin erosion plus abrasion in vitro. Acta Odontol Scand. 2012 Mar;70(2):160-4.

33. McCabe JF, Walls AWG. Applied dental materials. Oxford: Blackwell; 2008.

34. McLean JW. Dentinal bonding agents versus glass-ionomer cements. Quintessence Int. 1996 Oct;27(10):659-67.

35. McLean JW, Gasser O. Glass-cermet cements. Quintessence Int. 1985 May;16(5):333-43.

36. McLean JW, Wilson AD. The clinical development of the glass-ionomer cements. i. Formulations and properties. Aust Dent J. 1977 Feb;22(1):31-6.

37. Mitra SB, Oxman JD, Falsafi A, Ton TT. Fluoride release and recharge behavior of a nano-filled resin-modified glass ionomer compared with that of other fluoride releasing materials. Am J Dent. 2011 Dec;24(6):372-8.

38. Mitsuhashi A, Hanaoka K, Teranaka T. Fracture toughness of resin-modified glass ionomer restorative materials: effect of powder/liquid ratio and powder particle size reduction on fracture toughness. Dent Mater. 2003 Dec;19(8):747-57.

39. Navarro MFL, Bresciani E, Barata TJE, Fagundes TC. Tratamento restaurador atraumático (ART) e o programa de saúde da família. Biodonto. 2004;2(4):9-111.

40. Navarro MFL, Barata TJE, Fagundes TC, Henostroza-Quintans N. Estética en odontología restauradora. Madrid: Ripano; 2006. p. 265-310.

41. Navarro MFL, Pascotto RC. Cimentos de ionômero de vidro – aplicações clínicas em Odontologia. São Paulo: Artes Médicas; 1998.

42. Parula N. Clínica de operatoria dental. 4. ed. Buenos Aires: ODA; 1975.

43. Plant CG, Shovelton DS, Vlietstra JR, Wartnaby JM. The use of glass ionomer cement in deciduous teeth. Br Dent J. 1977 Oct 18;143(8):271-4.

44. Reddy DS, Kumar RA, Venkatesan SM, Narayan GS, Duraivel D, Indra R. Influence of citric acid on the surface texture of glass ionomer restorative materials. J Conserv Dent. 2014 Sep;17(5): 436-9.

45. Roberson TM, Heymann HO, Swift Jr EJ. Sturdevant's art & science of operative dentistry. 5. ed. St Louis: Mosby; 2006.

46. Sampaio PC, de Almeida Junior AA, Francisconi LF, Casas-Apayco LC, Pereira JC, Wang L et al. Effect of conventional and resin-modified glass-ionomer liner on dentin adhesive interface of Class I cavity walls after thermocycling. Oper Dent. 2011 Jul-Aug;36(4):403-12.

47. Santamaria MP, Suaid FF, Carvalho MD, Nociti Jr FH, Casati MZ, Sallum AW et al. Healing patterns after subgingival placement of a resin-modified glass-ionomer restoration: a histometric study in dogs. Int J Periodontics Restorative Dent. 2013 Sep-Oct;33(5):679-87.

48. Santos VR, Lucchesi JA, Cortelli SC, Amaral CM, Feres M, Duarte PM. Effects of glass ionomer and microfilled composite subgingival restorations on periodontal tissue and subgingival biofilm: a 6-month evaluation. J Periodontol. 2007 Aug;78(8):1522-8.

49. Sidhu SK. Glass-ionomer cement restorative materials: a sticky subject? Aust Dent J. 2011 Jun;56(Suppl1):23-30.

50. Simmons JJ. The miracle mixture. Glass ionomer and alloy powder. Tex Dent J. 1983 Oct;100(10):6-12.

51. Swartz ML, Phillips RW, Clark HE. Long-term F release from glass ionomer cements. J Dent Res. 1984 Feb;63(2):158-60.

52. Tantbirojn D, Rusin RP, Bui HT, Mitra SB. Inhibition of dentin demineralization adjacent to a glass-ionomer/composite sandwich restoration. Quintessence Int. 2009 Apr;40(4):287-94.

53. Tobias RS, Browne RM, Plant CG, Ingram DV. Pulpal response to a glass ionomer cement. Br Dent J. 1978 Jun;144(11):345-50.

54. Valera VC, Navarro MF, Taga EM, Pascotto RC. Effect of nail varnishes and petroleum jelly combinations on glass ionomer dye uptake. Am J Dent. 1997 Oct;10(5):251-3.

55. Van Dijken JW. 3-year clinical evaluation of a compomer, a resin-modified glass ionomer and a resin composite in class III restorations. Am J Dent. 1996 Oct;9(5):195-8.

56. Wilson AD, Kent BE. The glass-ionomer cement: a new translucent dental filling material. J Appl Chem Biotechnol. 1971;21:313.

57. Yip HK, Tay FR, Ngo HC, Smales RJ, Pashley DH. Bonding of contemporary glass ionomer cements to dentin. Dent Mater. 2001 Sep;17(5):456-70.

58. Yoshida Y, Van Meerbeek B, Nakayama Y, Snauwaert J, Hellemans L, Lambrechts P et al. Evidence of chemical bonding at biomaterial-hard tissue interfaces. J Dent Res. 2000 Feb;79(2):709-14.

59. Zankuli MA, Devlin H, Silikas N. Water sorption and solubility of core build-up materials. Dent Mater. 2014 Sep 6.