ISSN- 2394-5125 VOL 08, ISSUE 02, 2021

EROSION ON GLASS IONOMER CEMENT AND THEIR ADDITION: A REVIEW

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Abstract
Introduction: Glass ionomer cement (GIC) is a type of tooth-coloured dental restorative material that is commonly used nowadays This restorative material is commonly exposed to an intrinsic and extrinsic erosive oral environment which affects the integrity of the restoration. All along, many modifications have been done to improve the properties of conventional GIC (cGIC) while maintaining its clinical advantages. Several studies have been conducted to compare the effects of erosion on cGICand their modification. Objectives:This literature review aims to analyze the effect of erosion on cGIC, RMGIC, and its modifications.Methods:A literature search was performed using PubMed, Scopus, and Web of Science databases to identify the related articles that are within the research interest using multiple keyword combinations. Searches were limited to articles that were published from the year 1990 to 2019. Seventy-four articles that fit the research criteria were selected.Results:Conventional GIC had been greatly affected when exposed to low pH solutions such as hydrochloric, phosphoric, and citric acid. It showedgreater mean of surface microhardness loss, solubility, and microleakagecompared to RMGIC that was modified with resin addition. The modification with casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) showed no changes in surface microhardness loss when exposed to an acidic medium.Conclusion:Conventional GIC is more affected in an acidic environment compared to after its modification such as RMGIC and CPP-ACP modified cGIC. Patients with high risk exposure to erosive environment should not be restored only by cGIC unless it is used in closed-sandwich technique restoration.
Keywords: acid challenges on dental materials, erosion on GIC modifications, GIC erosion, pH effect on GIC and its modifications, RMGIC erosion effect.

Main text
Introduction

Glass ionomer cement is a type of tooth-coloured dental restorative material whichwere invented in 1969 and reported by Wilson and Kent in the early 1970s[1,2]. Conventional GIC(cGIC) is mainly composed of three essential ingredients, namely polymeric water-soluble acid (polyalkenoic acid), ion-leachable glass (calcium alumino-fluoro-silicate glass powder), and water[3,4]. The components in cGIC undergo an initial setting within 2 to 6 minutes through acid-base reaction[5].The maturation process of the cement takes place after 24 hours of initial setting, so the cement should be prevented from dehydration by the placement of surface protection coatings such as petroleum jelly[5,6,7].

Physical properties of cGICinclude the ability to form a chemical bond with tooth enamel and dentine throughan ion exchange mechanism, able to release fluoride and act as fluoride reservoir by absorbing salivary fluoride from dentifrices, mouthwashes and topical fluorides as well as possesses similar coefficient of thermal expansion as dentine[1,8,9]. These properties make it suitable to be used as temporary restoration, atraumatic restorative treatment (ART) material, cavity liner/base, fissure sealant and luting cement [10]. However, cGIC exhibits low fracture toughness, wear resistance and mechanical strength which limits their usage at high stress-bearingareas[1,8]. Conventional GIC also exhibits an initial slow setting which in turn makes it sensitive to moisture, low early strength as well as progressive loss of cGICwhich will eventually cause the failure of the restoration[11]. To overcome these drawbacks, many modifications have been done on cGIC such as resin-modified glass ionomer cement (RMGIC), bioactive glass reinforced glass ionomer cement, silica-reinforced glass ionomer cement, zinc-based glass ionomer cement, GIC-nanohydroxyapatite-silica-zirconia, casein phosphopeptide–amorphous calcium phosphate (CPP–ACP)and many more[2,12]. The most widely used modified GIC is RMGIC which was introduced in the early 1990s[13]. Resin modified GIC is a hybrid of cGIC and light-curing resin which sets by photo-polymerization[1,13]. The properties of RMGIC were found to have less moisture sensitivity, early cement strength, improved physical and mechanical properties, and better bond strength to the tooth structure as compared to cGIC[1,14].

Dental erosion is the progressive loss of dental hard tissues caused by a chemical process and does not involve bacterial action[14,15]. In current days, high consumption of acidic drinks and beverages due to easier to get can cause restorative materials commonly exposed to the effect of erosion by causing tooth sensitivity,toothache and severe wear. An intrinsic erosive environment includes gastric acid reflux or excessive vomiting while an extrinsic environment includes carbonated drinks or medications. Thus, it is important to know the ability of the dental restorative materials to withstand erosion. Various techniques can be applied to evaluate the loss of dental materials after erosive exposure. The most frequently used techniques are scanning electron microscope (SEM), profilometry, stereomicroscope, microradiography, and iodide permeability test[16]. Hence, this review will be done on literature related to erosion on GIC and its modificationwhich might be able to help operators selecting better options for patient's treatment when there is an acidic mouth environment.

Methodology

Search strategy and study selection

A literature search was performed using electronic databases such as PubMed, Scopus, and Web of Science to identify the related articles that are within the research interest. The inclusion criteria for this review are articles that were published from the year 1990 to 2019 with different combinations of the following keywords: "GIC erosion","pH effect on GIC and its modifications", "acid challenges on dental materials", "RMGIC erosion effect" and "erosion on GIC modifications". The exclusion criteria are articles that were written in a foreign language and have no abstracts available. Articles that fulfilled the criteria for this study were selected, the information was assessed, gathered and a report was written.

Results

Seventy-four articles that follows the criteria were selected which comprise of 30 articles from PubMed, 24 from Scopus and 20 from Web of Science as tabulated in Table 1.

Technique of assessing erosion effect on GIC

From the literature review search, few techniques had been used by researchers in assessing the erosion effect on dental materials, specifically GIC [17]. This includes scanning electron microscope (SEM), profilometer, and stereomicroscope. The SEM is one of the most frequently used devices for assessing erosion due to easily used and availability especially for descriptive assessment as it produces three-dimensional representation that is useful for understanding the surface structure of the sample[17]. The second most common technique used is the profilometer where the technique uses probe tip movementto assess the surface roughness of eroded specimens as it has sufficient sensitivity to investigate early tooth tissue loss produced by limited exposure to acid[18,19]. Some researchers use stereomicroscopedue to its simplicity in measuring the depth of erosion or use code for grading [16]. A clinical photograph is not popularly used because the photographs may not give an accurate result of the extent of erosion and the quality of the outcome depends on the photographer's dexterity and light reflectivity[17]. Other techniques such as polarized light microscopy, Dynamic Secondary Ion Mass Spectometry (DSIMS), Non-Contact Confocal Laser Scanning Microscopy, Scanning Acoustic Microscope (SAM), and etc. had been used but no so popular [17].

Effects of different erosive solutions on GIC and its modifications.

Several studies have been conducted to investigate the effect of erosion on tooth-coloured dental restorative materials especially GIC. Generally,cGIC was significantly degraded with erosion. Different erosive solutions or drinks showeda different level of degradation to GIC and its modification. The effect may be or may not be related to the pH but the type of acid usually plays a role. In one study, both cGIC and RMGIC were significantly eroded by five different acidic drinks but not all in proportionate with the pH of the acidic drinks [20]. Coke® and orange juices show greater erosive effect and pineapple juice caused the least erosion for both cGIC and RMGIC. Different result seen in another study by Aliping-McKenzie *et al.*(2004)where the tooth-coloured dental restorative materials were severely eroded in fruit juices but lesser when compared to Coke[21]. Orange juice containing citric acid and apple juice containing maleic acid showed greater erosive threat compared to Coke thatcontains phosphoric acid.

The erosion effectalso shows different features in different areas where erosion at the body might be different from the margin of restoration. A study found that Coke® with lower pH (pH 2.58) showed greater erosion at the body of restoration whereas marginal erosion depth was greater in orange juices (pH 3.41) [20]. The study also found that margins of the cGICrestoration had greater dissolution compared to the body of the restoration especially when immersed in citric acid solution. Different types of materials being affected differently by erosion. Resin-modified GIC showed only minimal damage when compared to cGIC while composite resin (CR) and porcelain have no changes[22]. Thus, the authors stated that cGIC is not suitable for patients having strong citric acid or gastric acid-induced erosion but closed sandwich restorations may be performed [22].Different combinations of acids also give different erosive results such as Coke containing carbonic and phosphoric acid (pH 2.5) has a greater effect on the surface microhardness of cGIC compared to another Coke containing carbonic and citric acid (pH 2.98) [23].

A study was done for the Malaysian population concerning few popularly consumed tropical juices by assessing at the surface roughness of the CR, cGIC, and RMGICwhich found that tamarind juice (pH 3.00) had the greatest erosive effecton the materials compared to mango juice (pH 3.11) and pineapple juice (pH 3.18) after being immersed for a day [24].Minimal change in pH gives the differences. Another study's finding was orange juice (pH 2.85) greatly affects the surface roughness and solubility of cGIC[25]. In this study, the cGIC was severely eroded by hydrochloric and citric acid solutions while minimally eroded by phosphoric acid following two hours of exposure.Another study showed an identical result whereby the newer and the older generation of GIC which are GC Fuji® VII, GC Fuji® Bulk, GC Fuji® IX Fast, Fuji® IX Extra, and GC Equia® Forte Fil completely dissolved in citric acid (pH 3.5-4.0) after 7 days followed by phosphoric acid (pH 2-3) and lactic acid (pH 4-4.5) [26].Assessment on the erosionin post-radiation xerostomic patients revealed that cGIC had the greatest failure related to the marginal adaptation and anatomical form after 24 months regardless of the use of neutral pH sodium fluoride gel compared to RMGIC and composite resin[27]. This result is similar to a study conducted by Viana *et al.*in 2020 [28]. Conventional GIC had significantly higher surface loss values compared to RMGIC, CR, and compomer which shows a similar result as a study done by Babita*et al* whereby GIC shows the highest value for the mean of change in average surface roughness when immersed in Coke (pH 1.87) compared to CR and compomer [18,29].

Scarce of studies were found on the erosion of modified GIC else than RMGIC. Casein phosphopeptide–amorphous calcium phosphate (CPP–ACP) modified GIC were found to have the ability to release fluoride, calcium, and phosphate ions under acidic solutions compared to cGIC that only releases fluoride in response to an acidic environment [30]. The CPP-ACP acts to repair by remineralizing the acid-eroded enamel surface to produce a higher nanoindentation hardness of the remineralized enamel [31]. However, a study found that the CPP-ACP modified GIC is ineffective in preventing erosive effect and remineralization of enamel that subjected to extrinsic erosion [32,33].

Discussion

Classification of GIC

Glass ionomer cement can be classifiedbased on its clinical use into Type I, Type II, and Type III[11]. The type of GIC used is important as it influences the outcome of clinical procedure and the satisfaction of the patient. Type I GIC is a radiopaque cement that is used as luting and bonding in cementation of crowns, bridges, inlays, onlays, and orthodonticbands [1,11]. This type of cement has moderate strength with a relatively low powder:liquid ratio (1.5:1 to 3.8:1). Besides, it has fast-setting properties that provide an early resistance to water[11]. Type II GIC is used as restorative cement and could be further divided into 2 types depending on the importance of the appearance.Type II GIC (1) is used for anterior repairs whereby the aesthetics are the priority as it has a good colour match and translucency[11,13]. This type of GIC is usually radiopaque and has a high powder:liquid ratio (3:1 to 6.8:1). However, this type of GIC needs protection from moisture for at least 24 hours with petroleum jelly or varnish[11,13]. Type II GIC (2) is usually radiopaque and being used for posterior restorations or repairs whereby the aesthetics are not the priority[11,13]. This type of GIC has a high powder:liquid ratio (3:1 to 4:1) with fast setting properties that make it having early resistance to water uptake[11]. Type III GIC is a radiopaque cement used as a lining or base cement. For liners, the powder:liquid ratio is low (1.5:1) to allow good adaptation of the cement to the cavity walls. For bases, the powder:liquid ratio is high (3:1 to 6.8:1) as the base acts as dentine replacement[11,13].Due to many weaknesses, the cGIChad been modified by the addition ofa few materials or powder.

Methods of assessing erosion on dental materials especially GIC

Several techniques could be used to evaluate the effect of erosion on the dental materials. For *in-vitro* techniques, Scanning Electron Microscope (SEM) was one of the first techniques to determine the *in-vitro* resorption of dental hard tissues[34]. It reveals the effects of superficially deposited precipitates resulted from mineral dissolution by various agents[35,36]. It can also evaluate the efficacy of salivary pellicle and dental plaque in protecting underlying the enamel surfaces from acidic dissolution[34,35]. Besides, SEM readings are highly reproducible and can be performed on both polished and unpolished native surfaces after gold-sputtering, which mimics conditions at the tooth surface [17].

Surface profilometry is also an *in-vitro* technique that quantifies the dental tissue loss using non-treated area as a reference[35]. It also gives information on the surface roughness where the surface of the sample can be scanned to produce a 2D or 3D profile using a contact or non-contact measuring device[39]. Erosive lesions with $0.5\mu m$ depth can be constantly detected and also measured using non-contact profilometry[40]. Stereomicroscope is another device which is used to measure the depth of erosion and a 3-dimensional images can be produced for better view of the sample [34].The data for measurement depth of erosion could be tabulated in micrometer or using code as classification [22]. Polarized light microscopy is another*in-vitro* technique used to measure the depth of lesion by observing the crystal birefringence changes in cross-sections of dental erosion specimens[41]. This technique can be used to observe organic and inorganic rigid and repeatable structures. For eroded dentine, this technique discriminates between the partly or fully demineralized tissues in the form of the pore volume.

Non-Contact Confocal Laser Scanning Microscopy (CLSM) is an *in-vitro* technique that produces high-resolution 3D optical images with depth selectivity from sample[17]. This technique does not require sample preparation while visualizing the surfaces[17]. It has high resolution and fast recording of surface topography and can be used for quantifying erosive tissue loss and softening depth[42]. Scanning Acoustic Microscope (SAM) is another*in-vitro* technique that can be used for the evaluation of local physicomechanical properties of tooth microstructure[43]. This technique has more advantages if compared to other conventional devices as it does not require any preparation for tooth tissue study as it uses focused sound to investigate, measure or produce the image of an object[44]. This is a sensitive technique, however, isless specific as it could not differentiate between erosion, abrasion, and abfraction[44].Besides, Dynamic Secondary Ion Mass Spectrometry (DSIMS) allows semi-quantitative analysis of the elemental and molecular composition of specimen surfaces[16]. Secondary ion mass spectroscopy studies the enamel erosion and fluoride uptake by early erosive lesions[45]. This technique has excellent sensitivity and allows the visualization of 2D and 3D images[46].

Clinical examination and use of photographs is an *in-vivo* technique used in measuring the enamel defect and dental erosion by taking radiographs[17]. Clinical photographs are very useful in monitoring erosive wear in patients[47] and they have the potential in comparing erosion measurements[48].Quantitative Light-Induced Fluorescence (QLF) is an *in-vitro/in-vivo* technique based upon the auto-fluorescence of enamel whereby the decrease in mineral content will decrease its fluorescence[17]. This technique could be used to detect any early mineral changes in enamel and can be used for longitudinal assessment[49]. The demineralized areas will appear darker which could help in measuring the amount of erosion[50]. However, this technique is expensive and could cause problematic probe positioning[17]. Optical Coherence Tomography (OCT) is a high-resolution and non-invasive technique that assesses the degree of mineral loss in enamel[35]. This technique is limited to *in-vivo* accessibility and the presence of enamel erosion will result in a change in optical properties[51].Atomic Absorption Spectrophotometry (AAS) is an *in-vitro/in-vivo* technique that uses optical light absorption to quantify the erosion on enamel and dentine[17]. They are expensive but the measurements are possible and non-destructive longitudinal. It has been used to check the enamel dissolution by measuring the calcium in acid etch solutions[52].

A digital pH meter is used to determine the pH of food and drinks by measuring the number of hydrogen ions. The pH of beverages is considered acidic if the pH value is low which shows there is a high concentration of hydrogen ions[17]. It was also used to measure salivary pH before and after consumption ofsoft drink or the pH of beverages with erosive potential [53].Another technique for assessing erosion is by microindentation and nanoindentation technique whichassess the surface hardness by measuring the resistance of a substance to indentation[17]. Microindentation is measured using Knoop or Vicker's diamond indenter while nanoindentation is measured using Berkovich diamond indenter. Both microindentation and nanoindentation techniques requires less cost and are less destructive. These techniques may be inaccurate in measuring the erosion at highly eroded areas. Ultrasonication and chemical analysis is a non-destructive technique that can be used for the early diagnosis of dental erosion and longitudinal measurement of progressive enamel loss[54]. This technique however could cause poor probe positioning and poor reliability in the measurement of enamel thickness changes of less than 300μm[55].

In general, many techniqueswere available in evaluatingthe erosion effect; whereby each technique has its advantages and disadvantages[17]. It shows that *in-vivo* technique achieve greater sensitivity, specificity, and accuracy in measuring tooth loss compared to *in-vitro*technique which mainly could mimic an oral conditions[34].

Addition for modificationsof cGIC

Conventional GIC has few weaknesses in physical and mechanical properties. Due to many weaknesses, various types of phase reinforcements and modifications with the addition of materials or powders were done forcGIC composition by researchers to improve its properties. Nano-silver modified GIC has been synthesized to impart antibacterial activity and improving mechanical properties [56]. This modification has been reported to have an improved handling characteristic, increased compressive strength, and significant antimicrobial activity with increasing concentration of the nano-silver particles [56]. Nano titanium oxide-modified GIC showed an increase in compressive strength and flexural strength compared to cGIC[57]. Reinforcement of bioactive glass powder (BAG) to cGIC showed a stable bond to the tooth through the peptide layer and had antimicrobial properties depending on the composition of the BAG[58]. Another study was done on BAG-GIC hybrid by mixing 10% or 30% of BAG particles with cGIC and RMGIC. The compressive strength of the BAG-GIC hybrid decreased with the increasing amount of BAG[59]. This study also showed that the cGIC-BAG material on average had 55% higher surface microhardness compared to RMGIC-BAG.

ISSN- 2394-5125 VOL 08, ISSUE 02, 2021

Another modification of GIC includes reactive glass fiber reinforced glass ionomer cement. A study was conducted to evaluate the fracture toughness and total amount of energy released from this enhanced GIC[60]. There was an increase in fracture toughness of 140% and the total amount of energy released was 440% compared to cGIC. Another similar study reported that the reinforcement of the hollow and solid discontinuous fiber fillers with 2 different loading fractions resulted in increased fracture toughness and flexural strength of cGIC and RMGIC[61]. Glass ionomer cement was also reinforced by hydroxyapatite to enhance the mechanical properties. A study was conducted on this hybrid showed that the addition of nano-hydroxyapatite and fluorapatite into cement resulted in higher compressive strength, diametral tensile strength, and biaxial flexural strength compared to the cGIC[62]. The bonding of the tooth-ionomer interface has been enhanced by decreasing the size of apatite from micrometer to nanometre scale[63].In another study, cGIC has been reinforced with hydroxyapatite andsilica nanocomposite which showed an increase in the hardness[64]. This silica reinforced glass ionomer was synthesized in an attempt to improve cGIC translucency and increase the number of polysalt bridges in the glass matrix. The hardness, compressive strength, and flexural strength of 35% $SiO_2$is higher compared to 11% and 21% of SiO_2[64].

Zinc-based glass ionomer cement contains zinc oxide which can act as network modifying oxide and an intermediate oxide[65]. A lower concentration of Ca increases the susceptibility of the glass to attack which causes it to be more bioactive[66].A study using niobium pentoxide that was incorporated into GIC to enhance the mechanical properties and exhibits good biocompatibility and bioactivity[67].It showed that the setting time of the cement increased with the increasing amount of Nb in GIC but the mechanical properties are adversely affected[65].Another recent modification, cGIC has been reinforced with hydroxyapatite, silicaand zirconia nanocomposite under a controlled grinding process and it showed an increase in the hardness, Young's modulus, and bioactivity compared to cGIC[68]. This GIC-nanohydroxyapatite-silica-zirconia has shown significant improvement in mechanical, physical, chemical and biological properties. The hardness increased with an increase in the nano-zirconia content up to 5%.This make it possible to be used for wider scope such as higher stress bearing area, for restoration of permanent dentition andstronger ART material [67,68].Casein Phosphopeptide-Amorphous Calcium Phosphate (CPP-ACP) hasbeen shown to promote the remineralization of enamel as well as prevents demineralization [69,70].

Erosion effect of GIC and its modification

Not many studies were found in the literature for the erosion of GIC and its modification.The erosion of dental materials was found to be influenced by the hydrogen ion concentration, titratable acidity, acid strength, buffering capacity and chelating function of the acid [18,24]. The amount of the actual hydrogen ions (titrable acid) significantly influence the erosive effect on dental materials [20,21]. Low pH beverages could adversely affect the properties of the tooth-coloured dental restorative materials [25]. As the pH of the solutions decreased, the hardness of the material decreases while the surface roughness and the solubility of the material increase [25]. The frequency of immersion significantly affects the surface roughness of RMGIC due to the replacement of the hydrogen ion in the GIC with the metal cations in the matrix which will eventually cause more dissolution [71].

Many studies accept that pH is an important factor that contributes to the erosion effects of tooth-coloured dental restorative materials but many other studies suggest that the composition is more important factor [21,71].In a case where citric acid has a higher pH value compared to phosphoric acid, citric acid has a greater effect on cGIC as it has a larger equilibrium constant which allows increased protons exchange for the dissolution of GIC in its solution [26]. Also, the presence of phosphoric acid suppresses the dissolution rate of calcium and phosphate from the tooth [72]. Thus, the composition of the fruit juices has a greater influence on the dental restorative materials compared to the pH of a drink [21,73].

Many other factors influence the roughness of the material such as the shape difference, distribution, number of particles, and the interfacial bonding between particles and matrix [29]. Conventional GIC having more erosion compared to RMGIC which might be due to the formation of a leachable layer that can inhibit degradation of the material and ability to reduce the acidity of the acidic solutions [74]. The presence of resin would reduce the acid challenge intensity making RMGIC have lower susceptibility to erosion compared to cGIC[28,69,70,71].Hence, beverages containing lower pH has more erosive effect but the type, concentration, acid amount, calcium chelating properties, exposure time and temperature, and buffering capacity of the saliva also affects the dissolution in the oral cavity [18].

Conclusion

From this review, it was shown that cGIC ismore affected in an acidic environment compared to RMGIC and other modified cGICs. Erosive environment affects cGIC physical properties whereby its surface microhardness loss, solubility, and microleakage is greater than RMGIC and CPP-ACP modified cGIC. Therefore, patients with a high risk of being exposed to an erosive environment should avoid cGIC restoration to maintain the integrity of the restoration and quality of life unless cGIC is used in closed-sandwich technique restoration.

ISSN- 2394-5125 VOL 08, ISSUE 02, 2021

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Table 1: Articles sources

Electronic databases	Number of articles
PubMed	30
Scopus	24
Web of Science	20
Total	**74**