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NANO-GLASS-IONOMER CEMENTS IN MODERN RESTORATIVE DENTISTRY

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ABSTRACT

The incorporation of nanoparticles into glass powder of glass ionomers led to wider particle size distribution, which resulted in higher mechanical values. Consequently they can occupy the empty spaces between the Glass ionomer particles and act as reinforcing material in the composition of the glass ionomer cements. The nanofiller components of nano ionomers also enhance some physical properties of the hardened restorative. Its bonding mechanism should be attributed to micro-mechanical interlocking provided by the surface roughness, most likely combined with chemical interaction through its acrylic/itaconic acid copolymers. The paper reviews their secondary caries prevention – fluoride release properties, mechanical and physical propreties, biocompatibility aspects, and antimicrobial activity.

Key words: nanodentistry, dental restorative materials, nano-glass-ionomer cements, biocompatibility aspects

INTRODUCTION

Glass Ionomer Cement (GIC) was invented by Wilson et al. at the Laboratory of the Government Chemist in early 1970. They are water-based cements, known as polyalkenoate cements [1]. Their generic name is based on the reaction between silicate glass and polyacrylic acid, and the formation arises from an acid/base reaction between the components [2, 3].

Due to the ability to modify the physical properties (by changing the powder/liquid ratio or their chemical formulation may) of glass-ionomer cements they could be used in a wide range of clinical applications [4]. They have certain unique properties that make them useful as restorative and adhesive materials – adhesion to moist tooth structure and base metals, anticariogenic properties due to the release of fluoride, thermal compatibility with tooth enamel, biocompatibility and low toxicity [5]. On the other hand, their extensive use as a filling material in stress-bearing areas is limited by their poor mechanical properties (low fracture strength, toughness and wear) [6, 7].

In the posterior dental region, glass-ionomer cements are mostly used as a temporary filling material [8]. The requirement to strengthen those cements has lead to research effort into reinforcement concepts. Several former approaches dealt with incorporation of second phase ceramic or glass fibers or with metal particles. Encouraging results were also obtained by compounding reactive glass fibers [9, 10]. The principles of today's GIC are well understood, which in turn has led to improved formulations and highly reproducable techniques [11]. However, the main problem of a weak strength and toughness for permanent filling therapy still remains.

Nanoparticles incorporation advantages

The incorporation of nanoparticles (the average particle size of glass ionomer particles were around 10-20μm) into glass powder of glass ionomers led to wider particle size distribution, which resulted in higher mechanical values. Consequently they can occupy the empty spaces between the Glass ionomer particles and act as reinforcing material in the composition of the glass ionomer cements [12]. The nanofiller components of nano ionomers also enhance some physical properties of the hardened restorative. Its bonding mechanism should be attributed to micro-mechanical interlocking provided by the surface roughness, most likely combined with chemical interaction through its acrylic/itaconic acid copolymers [13].

Nano light-curing glass ionomer restorative blends nanotechnology originally developed for Filtek™ Supreme Universal Restorative with fluoraluminosilicate (FAS) technology. Their most important advantages are: *superb polish, excellent esthetics, and improved wear resistance.* The clinical indications are: - primary teeth restorations; - transitional restorations; - small Class I restorations; - sandwich restorations; - class III and V restorations; - core build-ups [14].

Secondary caries prevention – fluoride release properties

Scientific reports show that secondary caries and restoration fracture remain the two main challenges for dental restorative materials [15]. Secondary caries refers to the recurrence of tooth decay after the initial restoration, and is cited as the most frequent reason for the replacement of existing restorations [16]. The sustained release of fluoride ions could be a substantial benefit for a dental restoration, because the fluoride could enrich neighboring enamel or dentin to combat secondary caries [17]. F-releasing restorative materials include glass ionomers, resin-modified glass ionomers, compomers, and resin composites [18-20].

A study performed by Lin et al (2011) aimed to investigate the fluoride release properties and the effect on bond strength of two experimental adhesive cements. Synthesized particles of nano-fluorapatite (nano-FA) or nano-fluorohydroxyapatite (nano-FHA) were incorporated into a resin-modified glass ionomer cement (Fuji Ortho LC) and characterized using X-ray diffraction and scanning electron microscopy. Blocks with six different concentrations of nano-FA or nano-FHA were manufactured and their fluoride release properties evaluated. The unaltered glass ionomer cement Fuji Ortho LC (GC, control) and the two experimental cements with the highest fluoride release capacities (nano-FA+Fuji Ortho LC (GFA) and nano-FHA+Fuji Ortho LC (GFHA) were used to bond composite blocks and orthodontic brackets to human enamel. After 24 h water storage all specimens were debonded, measuring the micro-tensile bond strength (ìTBS) and the shear bond strength (SBS), respectively. The optimal concentration of added nano-FA and nano-FHA for maximum fluoride release was 25 wt.%, which nearly tripled fluoride release after 70 days compared with the control group. GC exhibited a significantly higher SBS than GFHA/GFA, with GFHA and GFA not differing significantly. The ìTBS of GC and GFA were significantly higher than that of GFHA. The obtained results seem to indicate that the fluoride release properties of Fuji Ortho LC are improved by incorporating nano-FA or nano-FHA, simultaneously maintaining a clinically sufficient bond strength when nano-FA was added [21].

Investigation and comparison of the amount of fluoride release of conventional, resin modified and nanofilled resin modified glass ionomer cements was performed by Upadhyay et al. (2013). In this study, tablets of glass-ionomer cements were immersed in deionized water and incubated at 37°C. After 1, 2, 7, 15 and 30 days, fluoride ion was measured under normal atmospheric conditions by fluoride ion selective electrode. Buffer (TISAB II) was used to decomplex the fluoride ion and to provide a constant background ionic strength and to maintain the pH of water between 5.0 and 5.5 as the fluoride electrode is sensitive to changes in pH. The authors reported that the release of fluoride was highest on day 1 and there was a sudden fall on day 2 in all three groups. Initially fluoride release from conventional glass-ionomer cement was highest compared to the other two glass-ionomer cements, but the amount drastically reduced over the period. Although the amount of fluoride release was less than both the resin modified and nanofilled resin modified glass-ionomer cement, the release was sustained consistently for 30 days. In conclusion, the cumulative fluoride release of nanofilled resin modified glass ionomer cement was very less compared to the conventional and resin modified glass ionomer cements and Nanofilled resin modified glass ionomer cement released less but steady fluoride as compared to other resin modified glass ionomer cements [22].

Mechanical and physical propreties

Sayyedan et al (2013) showed that higher mechanical properties could be achieved by addition of forsterite (Mg_2SiO_4) nanoparticles to ceramic part of GIC. They aimed to fabricate a glass ionomer- Mg_2SiO_4 nanocomposite and to evaluate the effect of addition of Mg_2SiO_4 nanoparticles on bioactivity and fluoride release behavior of prepared nanocomposite. In their study forsterite nanoparticles were made by sol-gel process. Nanocomposite was fabricated via adding 3wt.% of Mg_2SiO_4 nanoparticles to ceramic part of commercial GIC (Fuji II GC). Fluoride ion release and bioactivity of nanocomposite were measured using the artificial saliva and simulated body fluid (SBF), respectively. The results of the performed analysis confirmed that nanocrystalline and pure Mg_2SiO_4 powder was obtained. Fluoride ion release evaluation showed that the values of released fluoride ions from nanocomposite are somewhat less than Fuji II GC. The performed tests confirmed the bioactivity of the nanocomposite. Statistical analysis showed that the differences between the results of all groups were significant. The authors consider that glass ionomer- Mg_2SiO_4 nanocomposite could be a good candidate for dentistry and orthopedic applications, through of desirable fluoride ion release and bioactivity [23].

In a recent study De Caluwé (2014) investigated if combinations of nano- and macrogranular glass with different compositions in a glass ionomer cement can improve the mechanical and physical properties. Glasses with the composition 4.5 SiO_2-3 Al_2O_3-1.5 P_2O_5-(5-x) CaO-x CaF_2 (x=0 and x=2) were prepared. Of each type of glass, particles with a median size of about 0.73 µm and 6.02 µm were made. The results showed that the setting time of GIC decreases when macrogranular glass particles are replaced by nanogranular glassparticles, whereas the compressive strength and Young's modulus, measured after 24 h setting, increase. The effects are more pronounced when the nanogranular glass particles contain fluoride. After thermocycling, compressive strength decreases for nearly all formulations, the effect being most pronounced for cements containing nanogranular glass particles. Hence, the strength of the GIC seems mainly determined by the macrogranular glass particles. Cumulative F-release decreases when the macrogranular glass particles with fluoride are replaced by nanogranularglass particles with(out) fluoride. In summary, the study shows that replacing macro- by nanogranular glass particles with different compositions can lead to cements with approximately the same physical properties (e.g. setting time, consistency), but with different physicochemical (e.g. F-release, water-uptake) and initial mechanical properties. On the long term, the mechanical properties are mainly determined by the macrogranular glass particles [24].

Nassar et al. (2014) conducted a study was to assess the clinical performance of cervical restorations of two different nanofilled materials a nano glass ionomer (Ketac N100). and a nano composite (Grandio SO) and its adhesive (Futurabond DC) for one year and thus their ability to be placed in cervical carious lesions. Most of the restorations maintained good quality during the observation period, which was considered a short materials may be used with confidence in Class V carious lesions. A longer evaluation period may be recommended to decide the use of restorative material safely in Class V cavities [25].

Hydroxyapatite is a biologically compatible material and a major component of dental enamel and bone tissue. Because of its biocompatibility and structural similarity to human teeth and the skeletal system, a number of dental studies have evaluated its application as a bone substitute or dental restorative material.

Mu et al. (2007) investigated the mechanical character, microleakage and mineralizing potential of nano-hydroxyapatite (nano-HAP)-added glass ionomer cement. 8% nano-HAP were incorporated into GIC as composite, and pure GIC as control. Both types of material were used to make 20 cylinders respectively in order to detect three-point flexural strength and compressive strength. Class V cavities were prepared in 120 molars extracted for orthodontic treatment, then were filled by two kinds of material. The microleakage at the composite-dentine interface was observed. Class V cavities were prepared in the molars of 4 healthy dogs, filled with composite, and the same molars in the other side were filled with GIC as control. The teeth were extracted to observe the mineralizing property with polarimetric microscope in 8 weeks after filling. Three-point flexural strength and compressive of nano-HAP-added GIC were increased compared with pure GIC. The nanoleakages and microleakages appeared at the material-dentine interface in the two groups, but there were more microleakages in control group. New crystals of hydroxyapatite were formed into a new mineralizing zone at the interface of tooth and nano-HAP-added GIC, while there was no hydroxyapatite crystals formed at the interface of tooth and pure GIC. According to the results achieved, 8% nano-HAP-added GIC can tightly fill tooth and have mineralizing potential, and can be used as liner or filling material for prevention [26].

Lee et al (2010) evaluated the differences in bonding strength and resistance to demineralization between micro-hydroxyapatite and nano-hydroxyapatite added to self-cured resin-reinforced/modified glass ionomer cement. RelyX was used as the base glass ionomer cement material and for the control group. 10% micro-hydroxyapatite added glass ionomer cement was named experimental group 1, and 10% nano-hydroxyapatite added glass ionomer cement was named experimental group 2. Physical tests for ISO9917-1:2007 in each group was acceptable, except the setting time of nano-hydroxyapatite added glass ionomer cement, which exceeded maximum setting time. Bonding strength was greatest in nano-hydroxyapatite glass ionomer cement, and cohesive failure was common in all specimens. When fractured surface was observed under SEM, spherical particles were observed in experimental groups containing hydroxyapatite particles, and they were more prevalent in nano-HA addedglass ionomer cement group than in micro-hydroxyapatite added group. Both experimental groups exhibited greater resistance to demineralization compared to the control group, and there was no significant difference between the experimental groups. Under SEM, nano-hydroxyapatite addedglass ionomer cement exhibited increased resistance to demineralization compared to micro-hydroxyapatite added glass ionomer cement [27].

Moshaverinia et al (2008) aimed to enhance the mechanical strength of glassionomer cements, while preserving their unique clinical properties. They synthesized, characterized and incorporated into a formulation of Fuji II commercial GIC a N-vinylpyrrolidone (NVP) containing polymer, nano-hydroxy and fluoroapatite (nano-HA and FA). The mechanical properties of the resulting cements were evaluated and it was shown that these materials are promising additives for glass-ionomer restorative dental materials. This study showed that addition of NVP, nano-HA and FA into glass-ionomer cements had the ability to enhance the mechanical strength compared to the unmodified cement. However, the effect of nanoparticles addition on the mechanical properties of GIC was more impressive than addition of NVP modified polyacrylic acid to GIC [12].

Numerous recent studies were conducted aiming to compare certain mechanical and biological properties of different nanorestorative dental materials.

de Paula et al (2011) evaluated the biomechanical degradation of two nanofilled restorative materials - a resin-modified glass ionomer, Ketac N100 and a composite, Filtek Z350, compared with conventional materials (Vitremer and TPH Spectrum). Twenty specimens obtained from each material were divided into two storage groups (n=10): relative humidity (control) and Streptococcus mutans biofilm (biodegradation). After 7 days of storage, roughness values (Ra) and micrographs by scanning electron microscopy were obtained. In a second experimental phase, the specimens previously subjected to biodegradation were fixed to the toothbrushing device and abraded via toothbrushes, using dentifrice slurry (mechanical degradation). Next, these specimens were washed, dried, and reassessed by roughness and SEM. There was statistically significant interaction among factors: material, storage (humidity/biofilm), and abrasion (before/after). After biodegradation (S mutans biofilm storage), Ketac N100 presented the highest Ra values. Concerning bio plus mechanical challenge, TPH Spectrum, Ketac N100, and Vitremer presented the undesirable roughening of their surfaces, while the nano composite Filtek Z350 exhibited the best resistance to cumulative challenges proposed. This study demonstrated that the nanotechnology incorporated in restorative materials, as in composite resin and resin-modified glass ionomer, was important for the superior resistance to biomechanical degradation [28].

In a recent study, the same authors (de Paula, 2014) investigated the effect of chemical degradation on the surface roughness (Ra) and hardness (Knoop hardness number [KHN]) of nano restorative materials. Disc-shaped specimens (5-mm diameter; 2-mm thick) of Filtek Z350 and TPH Spectrum composites and the Vitremer and Ketac Nanolight-curing glass ionomer cements were prepared according to the manufacturers' instructions. After 24 hours, polishing procedures were performed and initial measurements of Ra and KHN were taken. The specimens were divided into 12 groups (n=10) according to material and storage media: artificial saliva, orange juice, and Coca-Cola. After 30 days of storage, the specimens were reevaluated for Ra and KHN. The pH values of the storage media were measured weekly. Composites were found to present lower roughness values and higher hardness values than the ionomeric materials under all storage conditions. After degradation, the KHN of all experimental samples decreased significantly, while the Ra of the ionomeric materials increased, depending on the media, with a markedly negative impact of Coca-Cola and orange juice. There was no difference among the storage media for Filtek Z350 with regard to the KHN values. According to the results achieved, nanofillers did not show any influence on the roughness and hardness of resin-modified glass ionomer cements and resin composites concerning their degradation resistance [29].

Joshi et al (2013) investigated and compared three different pit and fissure sealants with different composition to check their effectiveness for sealing ability and microleakage. Total 120 therapeutically extracted premolars devoid of any caries, anomalies or morphogenic diversity were collected and distributed equally in three groups (40 in each) - group I: composite based pit and fissure sealant, group II: compomer - restorative material and group-III: glass ionomer cement based pit and fissure sealant. Samples were cleaned with slurry of pumice and etched with phosphoric acid etchant. After thorough washing and drying, teeth were treated and cured with three sealants having different composition followed by thermocycling and immersion in methylene blue dye for 24 hours. Teeth were then observed and score was given for microleakage. Composite material was found better for sealant material as it was showing significantly least microleakage as compare to glass inomer cement and promising result with compomer. Authors concluded that besides many inventions, researches and nano-technology implementation in dental materials, composite material is comparatively better than glass inomer cement and compomer as sealant materials [30].

Biocompatibility aspects

Recent studies are intended to assess some aspects concerning the biocompatibility of restorative dental nanomaterials.

The possible cytotoxicity and pro-inflammation effect of three different powdered GICs (base, core build and restorative) prepared with and without titanium dioxide (TiO_2) nanoparticles were investigated by Garcia-Contreras (2014). Each GIC was blended with TiO_2 nanopowder, anatase phase, particle size <25 nm at 3% and 5% (w/w), and the GIC blocks of cements were prepared in a metal mold. The GICs/TiO_2 nanoparticles cements were smashed up with a mortar and pestle to a fine powder, and then subjected to the sterilization by autoclaving. Human oral squamous cell carcinoma cell lines (HCS-2, HSC-3, HSC-4, Ca9-22) and human normal oral cells [gingival fibroblast (HGF), pulp (HPC) and periodontal ligament fibroblast (HPLF)] were incubated with different concentrations of GICs in the presence or absence of TiO_2 nanoparticles, and the viable cell number was determined by 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide method. Prostaglandin E2 was quantified by enzyme-linked immunosorbent assay. Changes in fine cell structure were assessed by transmission electron microscopy. Cancer cells exhibited moderate cytotoxicity after 48 h of incubation, regardless of the type of GIC and the presence or absence of TiO_2 NPs. GICs induced much lower cytotoxicity against normal cells, but induced prostaglandin E2 production, in a synergistic wanner with interleukin-1â. The study shows acceptable to moderate biocompatibility of GICs impregnated with TiO_2 nanoparticles, as well as its pro-inflammatory effects at higher concentrations [31].

The same authors (Garcia-Contreras, 2014) investigated also the effect of TiO_2 NPs on the drug-sensitivity of oral squamous cell carcinoma and inflammation of human gingival fibroblasts. The number of viable HGF cells was determined by 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide method. Prostaglandin E2 (PGE2) was quantified by enzyme-linked immunosorbent assay. Contamination with lipopolysaccharide was assayed by the endotoxin assay kit. Intracellular uptake and distribution of TiO2 NPs were assessed by transmission electron microscopy. TiO_2 NPs (0.05-3.2 mM) did not affect HGF cell viability, although TiO_2 NPs clusters were dose-dependently incorporated into the vacuoles of cells. Interleukin-1β (IL-1β) (3 ng/ml) stimulated the secretion of PGE2 into the culture medium by HGF cells. TiO_2 NPs also induced PGE2 production, in synergy with IL-1β. Since only a minor amount of lipopolysaccharide was detected in TiO_2 NPs, the enhanced production of PGE2 was not simply due to lipopolysaccharide contamination. The study demonstrates, for the first time to the knowledge of the authors, that TiO_2 NPs at concentrations higher than 0.2 mM exert an pro-inflammatory action against HGF cells, regardless of the presence or absence of IL-1β [32].

Antimicrobial activity of nanorestorative dental materials

In dentistry the antimicrobial activity of the wide range of cements with different applications is also relevant. Antibacterial activity of dental luting cements is a very important property when applying dental crowns, bridges, inlays, onlays, or veneers, because bacteria may be still present on the walls of the preparation or gain access to the cavity if there is microleakage present after cementation [33].

Among all the dental restorative materials, glass-ionomer cements (GICs) are found to be the most cariostatic and somehow antibacterial due to release of fluoride, discussed above. Although numerous efforts have been made on improving antibacterial activities of dental restoratives, most of them have been focused on slow release of various incorporated low-molecular-weight antibacterial agents such as antibiotics, zinc ions, silver ions, etc [34-36].

Magalhaes et al (2012) evaluated the antibacterial activity of three dental cements modified by nanosilver: Sealapex, RelyX ARC, and Vitrebond. The cements were incorporated with 0.05mL of silver nanoparticles solution. Control groups were prepared without silver. Six Petri plates with BHI were inoculated with *S. mutans* using sterile swabs. Three cavities were made in each agar plate (total =

18) and filled with the manipulated cements. They were incubated at 37ºC for 48 h, and the inhibition halos were measured. No inhibition halos were obtained for Sealapex and Rely X, but Vitrebond showed bactericidal activity without silver and enhanced effect with silver incorporation. Teratogenicity of nanosilver in humans is unknown because no cases or studies have been reported in the literature. Thus, nanosilver assessment in humans for potential teratogenic effects is imperative [37].

CONCLUSION

The incorporation of nanoparticles into glass powder of glass ionomers led to wider particle size distribution, which resulted in higher mechanical values. Consequently they can occupy the empty spaces between the Glass ionomer particles and act as reinforcing material in the composition of the glass ionomer cements. The nanofiller components of nano ionomers also enhance some physical properties of the hardened restorative.

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