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EVOLVING TRENDS IN GLASS IONOMER CEMENT: FROM HISTORICAL INSIGHTS TO NANO-ENHANCED MATERIALS IN RESTORATIVE DENTISTRY

Dentistry

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ABSTRACT

Glass ionomer materials were introduced in the 1970s by Wilson and Kent as dental fillings, available in powder and liquid forms, functioning through an acid-base reaction. These materials offer valuable properties that have led to their widespread adoption in dentistry, serving various purposes such as dental fillings, luting cement, atraumatic restorative procedures, and the sandwich technique. Despite their benefits, challenges such as poor aesthetics, extended setting times, and compromised mechanical properties have necessitated innovations in conventional glass ionomers. This article presents a historical perspective on the evolution of glass ionomers, highlighting recent advancements. Notably, nanotechnology has found application in both conventional and resin-modified glass ionomers since 2007. Nanoparticles, referred to as nanomers, and nanoclusters have been incorporated into FAS glass, leading to enhanced properties in conventional glass ionomers.

KEYWORDS

GIC, nanomer, nanoparticles, dental cements

INTRODUCTION

The historical evolution of dental fillings traces back over 13,000 years to Northern Italy, where evidence of this practice has been discovered in the remains of ancient inhabitants. Through the centuries, the choice of filling materials has evolved significantly, transitioning from the use of beeswax to the introduction of amalgam in the 1700s. However, a pivotal turning point in dental materials occurred at the dawn of the 19th century when Charles Allen penned the first written work on dentistry, titled "Operator of Teeth".

The 20th century ushered in refinements and innovations in filling materials, propelling researchers to embark on a quest to create a substance that not only restored but could potentially replace enamel and dentin. This pursuit culminated in the discovery of Glass Ionomer Cement (GIC) in 1969, as reported by Wilson and Kent in 1970.[1] GIC has revolutionized the restorative approaches, particularly in minimally invasive dentistry.

The utilization of GICs in dentistry has become widespread, primarily owing to their high fluoride release and white coloration. Their versatility is evident in dental applications, encompassing the restoration of deciduous teeth, anterior class III and V restorations, cementation (luting) of crowns, bridges, and orthodontic appliances, restorations of non-carious teeth with minimal preparation, temporary cementation of crowns and other indirect restorations, application in the sandwich technique, atraumatic restorative therapy, fast-setting liners and bases, binding composites to tooth structures, fissure sealants, and metal-reinforced core build-up materials.[2-4] However, despite their manifold advantages, clinical usage of GICs remains constrained by their comparatively inferior mechanical properties, susceptibility to initial desiccation and moisture, and suboptimal surface finish.

Evolution of GIC

Extensive modifications in the composition of GICs have been pursued, with particular focus on the glass powder component. Innovations have explored the incorporation of metal powders, reactive glass fibres, and other nonreactive fillers as potential reinforcement phases, aiming to bolster the mechanical and physical attributes of GICs without compromising their adhesive and fluoride release properties. The sequence of developmental changes in GICs is described in Figure 1.

Fundamentally GICs consist of two main components: powder and liquid.[1,5] The powder is composed of fluoro-aluminosilicate glass (FAS), while the liquid contains polyalkenoic acids, which are carboxylic acids (Figure 2).

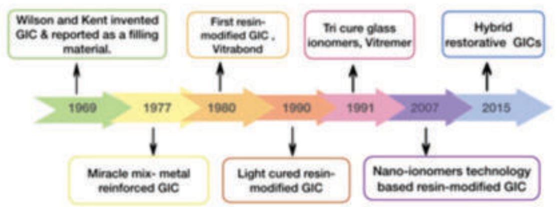

Figure 1- Evolution of GIC through ages

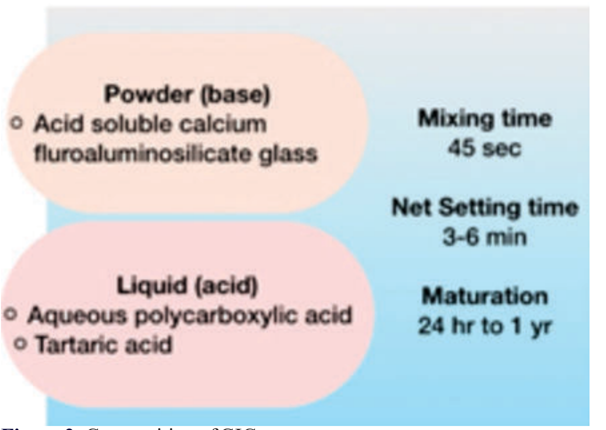

Figure 2- Composition of GIC

Notably, polyacrylic acid predominates as the primary constituent of the liquid component. To enhance manipulation ease, less viscous polyacids such as maleic and itaconic acids may also be present. Additionally, additives like barium and strontium salts may be introduced into the powder to increase radiopacity. The setting of conventional GICs occurs through an acid-base reaction between polyacrylic acid and FAS particles, commencing with an initial gelation reaction followed by the binding of unreacted glass particles, serving as fillers within the silica gel matrix.

In contemporary times, the chemical composition of GIC powder has undergone substantial modifications to enhance handling characteristics and mechanical properties. This transformation rests on the hypothesis that greater poly-salt bridges can be formed in the GIC matrix as a result of increasing the chemical affinity between the filler particles and GIC matrix, ultimately surmounting existing hurdles and elevating the material's mechanical properties.

With the culmination of nanoengineering and the principles of nanoscience, scientists have embarked on an endeavour to manipulate dental materials, fortifying their properties. Recent studies have spotlighted the integration of nano-sized particles, often termed "nanoclusters," into dental restorative materials like resin composites, with demonstrable improvements in mechanical properties.[6-8] The latest developments of Glass Ionomers have similarly leveraged these approaches to enhance the physical and mechanical characteristics of GICs, ushering in the era of nano-modified GICs.[9]

Nanotechnology offers various techniques for generating nanoparticles.[10-12] Two principles methods employed in formation of nanoparticles are:

- Top down approach
- Bottom up approach

The former is based on solid-state processing of materials while the later one entangles the fabrication of materials by harvesting atomic elements. Bottom-up processing involves meticulously organised chemical synthesis and material growth, while top-down processes encompass techniques such as milling, machining, and lithography. Top-down approaches, such as chemical vapor deposition (CVD), monolithic processing, and wet and plasma etching, are employed for the creation of functional structures at both micro and nanoscales.

Powder Modified Nano Glass Ionomers

In the year 2014, De Caluwé et al. showed that by modifying conventional GICs with nano-sized glass particles can decrease the setting time and enhance the compression strength and elastic modulus.[13] This enhanced the ease of handling and manipulation and thus decrease the treatment time, benefitting both the clinician as well as the patient. Enhanced mechanical properties withstand the masticatory forces and increase the longevity of restoration.

Nano-silver (nano-Ag) particles were synthesized and added to conventional GIC by Paiva et al. It was reported that the higher concentration of nano-Ag particles (0.50% wt) improved handling characteristics of the modified cement and increased the compressive strength (CS) by 32% of nano-Ag-added GIC along with significant inhibition of microbial growth.[14]

Rehman and collaborators modified the GIC (Fuji II, GC International, Tokyo, Japan) with N-vinylpyrrolidone (NVP) containing polyacids, as well as with nano-hydroxy and fluoroapatite [15]. The synthesized copolymers used in cement formulation were based on acrylic acid and N-vinylpyrrolidone with side chains containing itaconic acid. The nanoceramic particles (nano-hydroxy or nano-fluoroapatite) were synthesized using the ethanol-based sol-gel technique. These nanoparticles were also incorporated in commercial glass ionomer. The addition of NVP, nano-hydrohyapatite, and nanofluoroapatite into GIC led to an increase of the mechanical strength compared to commercial GIC. Also, the effect of modification by using some other particles such as Titanium dioxide and Zirconium oxide is under study. Various modifications in the powder composition of GIC along with their mechanical properties are summarized in the Table 1.

Table 1- Properties Of Various Modifications Of GIC

GIC composition			Mechanical properties			References
Liquid	Powder	Nano-filler particle size	Compressive strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)	
Polyacrylic acid copolymer	FAS + HA	100-200 nm	177–179	19-20	26-28	9
Polyacrylic acid copolymer	FAS + FA	100-200 nm	179	23	33	9
Polymer of AA, NVP 1A (8:1:1)	FAS + FA	100-200 nm	183-8	23.5	36	16
Polyacrylic acid copolymer	FAS + TiO2	Variable size	176.27	-	23.17	17
Polyacrylic acid copolymer	FAS + HA/ZrO2	Dimension 20*200	176.30	12.67	-	18

FAS- Flouro-aluminosilicate HA- Hydroxyapatite FA- Fluoroapatite

Nano-Filled Resin-Modified Glass Ionomer Cements

The incorporation of nanoparticles into RMGICs by the 3M ESPE Company led to the preparation of a new category of restorative materials, called nanoionomers.[19] These nanoionomers contain copolymers of acrylic and itaconic acid, alumino-silicate glass, bisphenol A-glycidyl methacrylate, triethyleneglycol dimethacrylate, hydroxyethyl methacrylate and nanofillers.

A randomized clinical trial examining the effectiveness of nano-RMGIC in comparison to conventional GIC and resin composites demonstrated no distinction in the one-year survival rates of these restoration types.[20] However, these nano-RMGIC has been found to possess inferior marginal integrity compared to conventional RMGIC. This can be stated due to the inferior bonding performance of nano-RMGIC when applied onto enamel rather than dentine.[21] Studies have shown that these nanofillers provide better wear and polish as compared to some commercial cements.[22]

CONCLUSION

The field of dental nano-biomaterials is rapidly advancing, with promising. However, not all modifications, such as nano-Reinforced GIC (nano-RMGIC), have shown clear advantages without long-term clinical data. Further research, encompassing mechanical, biological, and clinical studies, is essential to establish the practical value of nano-modified GICs in dentistry. As we progress, the integration of nano-engineering holds immense potential. Nevertheless, a more extensive body of research, encompassing mechanical and biological studies, coupled with rigorous clinical trials, is indispensable. These are vital to ascertain the practical applicability and efficacy of nano-modified GICs in clinical dentistry. The journey toward the optimal dental restorative material continues, driven by innovation, research, and the pursuit of excellence in patient care.

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