CAHIERS MAGELLANES-NS
Volume 06 Issue 2
2024

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

CLINICAL SUCCESS OF GLASS IONOMER CEMENT REINFORCED WITH ZINC OXIDE NANO PARTICLES: A SYSTEMATIC REVIEW

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Abstract

The inclusion of zinc oxide nanoparticles (ZnO-NPs) to GIC has been considered as a development in restorative dentistry which alleviates certain drawbacks of conventional GIC. This SR effectively compares the clinical effectiveness of ZnO-NPs reinforced GIC by reviewing 28 research articles published in the last ten years. Conventional GICs are appreciated for their fluoride releasing ability, chemical bonding to tooth structures and biocompatibility; they however demonstrated low tensile strength, poor wear resistance, and sensitivity to moisture at the polymerization stage. By integrating ZnO-NPs, it is expected that these physical properties will be improved, and in addition, it will exhibit antibacterial properties on SM which is a major causative organism of secondary caries.

Analyzing the effect of ZnO-NPs on the mechanical properties of GIC, the review confirms that enhance the compressive and flexural strength of GIC and therefore it is more suitable for use in high stress area of the mouth. The antibacterial properties of ZnO-NPs also help to decrease the bacterium adherence which in turn may decrease the overall rate of second caries. From clinical studies that are scarce, it has been proved that ZnO-NPs added to the GIC exhibits enhanced durability and lesser restoration failures than the regular GIC. However, there are limitations such as inability to have nanoparticle uniformly distributed within the GIC matrix and whether the composite material will cause any form of cytotoxicity in the long run. On the basis of this review, it can be inferred that ZnO NPs reinforced GIC is efficacious in restorative dentistry, nevertheless, these evidence need to be supported by subsequent clinical trials to implement the perfection in clinical protocol.

Keywords: glass ionomer cement, zinc oxide, nano particles, randomized control trial

Introduction

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

Glass ionomer cements (GICs) can be considered part of the standard materials of restorative dentistry since the material was first introduced in the early 1970. These are hailed for their special characteristics including the ability to release fluoride, to chemically bond to tooth structures and biocompatibility. Because of these attributes GICs are unique for different dental application such as a restorative material in fillings and luting agents in crown, base or liners under other restorative materials.

Nevertheless, conventional GICs are not without some drawbacks. This makes them less suitable for the high stress areas of the mouth such as the posterior teeth, were their relatively low tensile strength, poor wear resistance and sensitivity to moisture during the setting phase can be a disability. Due to these weaknesses, research continues in the attempt to alter the properties of GICs with the objective of enhancing their mechanical characteristics and consequently their clinical uses.

Among the various approaches undertaken for the improvement of GIC there is one direction for further investigation – the use of zinc oxide nanoparticles (ZnO-NPs) additives. Zinc oxide particularly has a property of being anti-bacterial and hence has been utilized in a number of medical uses. It is rationalized that, owing to their size and massive surface area, nanoparticles can act on the matrix of the GIC much more efficiently, enhancing its mechanical characteristics and bioactivity simultaneously. Targeted at summarising the current knowledge regarding ZnO-NPs reinforced GIC, this systematic review seeks to assess the clinical effectiveness of this modified material through the enhancement of mechanical properties; antibacterial potentials; and clinical performance profiles that are demonstrable in peer reviewed articles.

Traditional Approaches and Limitations

Glass ionomer cements have over time been preferred in dentistry due to their unique qualities of chemically bonding to tooth structure without the use of bonding agents. Chemical bonding with this material is especially beneficial in the prevention of marginal diastema and secondary caries due to its ability to offer great adhesion on to the restoration and the tooth. Also, GICs discharge fluoride which can assist in reconstructing the enamel covering and further help to prevent further decay.

But as for traditional GICs, they are not suitable for all the restorative challenges. Their most significant limitations include:

- **Low Tensile Strength:** This is because tensile strength of GICs is comparatively less than that of composite resins, which are available as restorative materials. This restricts there application in load bearing restorations where higher forces are placed on them during mastication.
- **Poor Wear Resistance:** There is poor wear resistance that results to faster degradation of the GICs restoration especially in the high stressed zones in the mouth.
- **Moisture Sensitivity:** During the initial setting phase, GICs are susceptible to moisture that may lead to alteration of the restoration material’s characteristics which hinders the final strength and durability of the restoration.

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

Such limitations have resulted into efforts being made by different researchers to come up with a number of modifications aimed at enhancing the mechanical characteristics of GICs while at the same time keeping the advantageous properties. One of such modifications is the addition of ZnO-NPs into the matrix of the composite.

Role of Glass Ionomer Cement Reinforced with Zinc Oxide Nanoparticles

The research on Glass ionomer cement (GIC) reinforced zinc oxide nanoparticles (ZnO-NPs) proves the material's revolutionary potential to fill the gap in the recent approaches to restorative dentistry where the commonly used GICs exhibit weaknesses that need enhancement in their mechanical and antibacterial performance. The main purpose of ZnO-NPs incorporation into GIC is to enhance the material's mechanical strength to make it useful in the highly stressed zone of the mouth; posterior restoration is a prime example where conventional GIC fails due to its inferior tensile and compressive strength. The result revealed that the incorporation of ZnO-NPs improved the mechanical properties of GIC through the increase in its Compressive and Flexural strength. This enhancement enables the reinforced GIC to absorb the forces of mastication and prevents the cases of fractures or wearing down hence increasing the life span of dental restorations. This is done by the particles forming a chemical bond with the GIC matrix at a molecular level thereby coming up with a more compact structure as well as having high mechanical strength that enables the material to stand the physical forces in the oral cavity.

Other than the mechanical reinforcement, the ZnO-NPs provides optimal antibacterial properties to GIC. The nanoparticles have been attributed to their effectiveness in preventing bacteria growth specifically Streptococcus mutans which are associated with dental caries. Thus, modification of GIC with ZnO-NPs leads to a better antimicrobial cover of the bacterial adhesion to the surface of teeth restorations that helps to decrease the chances of secondary caries and to increase the overall survivability of the restoration material.

Furthermore, ZnO-NPs provide long-lasting antibacterial effects in comparison with silver ions which present bactericidal effects during the restoration process, while preventing bacterial colonies from penetrating the restoration and damaging it. Due to these two functions of increasing mechanical properties and offering antibacterial action, the ZnO-NPs reinforced GIC should qualify for nearly every dental application where it would function as fillings and luting agents and also as base or liner materials under other restoratives.

The use and application of GIC reinforced with ZnO-NPs is to enhance the strength and protection of the material used in dental restorations and overcome the limitations of GICs to have better outcome for patients. It not only serves to increase the functional durability of restorations, but the actual occurrence of recurrent caries is also diminished making this advancement an important discovery for restorative dentistry.

Recent Advancements in the Field

The last few years saw development associated with GIC incorporating ZnO-NPs based on the incorporation of concentration, size, and diffusion pattern of nanoparticles into GIC material to enhance its mechanical and antimicrobial properties. The potential concentrations of ZnO-NPs

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

have been studied around different levels and commonly the concentration of 2 wt% is the most preferable as it is enhancing the strength while serving as workable. Moreover, recent improvements in the fabrication of nanoparticle technology with well dispersed ZnO-NP with smaller particle size provides a nice compatibility between ZnO-NPs and the GIC matrix which in turn brings more mechanical properties like compression strength and flexural strength. Cohesion of the nanoparticles added has also been tried through silane coating to reduce aggregation of the particles within the GIC matrix and improve overall properties of the materials.

Furthermore, attempts have been made to use ZnO-NPs together with other types of nanoparticles like silver or titanium dioxide so as to obtain nanocomposite materials that can provide better mechanical and antibacterial characteristics. For instance, recent investigations revealed that enhancing the ZnO-NPs reinforced GIC by the addition of silver nanoparticles greatly enhances the bactericidal characteristics of the former thus providing better shield against secondary caries. In the same way, the photocatalytic properties of TiO2 NPs have been exploited as additives to the GIC and it has been shown improve the mechanical stability of the later as well as the antibacterial effectiveness when exposed to light. These developments are major advancements in the search for materials with better clinical performance as restorative materials in the future. Nonetheless other issues like longevity of the implant, approval by the relevant health authorities and lack of set procedures for testing of the implants for viability still remain relevant hence the need to carry out further studies.

Materials and Methods

This systematic review was aimed at assessing the clinical effectiveness of glass ionomer cement (GIC) reinforced with zinc oxide nanoparticles (ZnO-NPs). This article's review followed the PRISMA checklist so as to provide a reliable and systematic analysis. A search of PubMed, Scopus, Web of Science, and other databases was done using the keywords like "glass ionomer cement", "zinc oxide nanoparticles", "mechanical properties", "antibacterial activity", and "clinical success". The search was limited to the articles published in English only and within the last 10years.

Only the investigations reporting on GIC reinforced with ZnO-NPs and addressing the issues of the interest of the present review, comprising mechanical properties (compressive and flexural strength, wear resistance), bacteriostatic effectiveness against oral pathogens and clinical outcomes – longevity of restorations and the prevalence of secondary caries – were considered for the review. Studies that concerned only with the basic GIC without including nanoparticles and studies that were originally conducted in other languages except English were excluded Studies that were not published in international peer-reviewed journals and the ones which did not include sufficient methodological details.

Information was meticulously obtained from the identified papers, focusing on the aspects improving mechanical properties of the coating, antibacterial properties and general clinical success rates. Thus, instead of a meta-analysis, a narrative synthesis was applied because of the

CAHIERS MAGELLANES-NS
Volume 06 Issue 2
2024
ISSN:1624-1940
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http://magellanes.com/

differences in study design and related outcomes. This synthesis sought to compare the findings to evaluate more strongly for long-term benefits and risks of ZnO-NPs in GIC and the possibilities for studies in the future to continue to support the thesis that the advantages of this material in clinical practice outweigh the disadvantages.

Inclusion and Exclusion Criteria

Search Strategy

An initial search was made through the use of four databases namely PubMed, Scopus, Web of Science. Specific terms used for search were 'GIC', 'ZnO NPs', 'mechanical properties', 'antibacterial activity' and 'clinical success'. The articles were capture in English language only and the search was restricted to articles published in the last ten years

Figure 1: PRISMA flowchart showing screening of studies
because this provides the latest information on the topic.

CAHIERS MAGELLANES-NS
Volume 06 Issue 2
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ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
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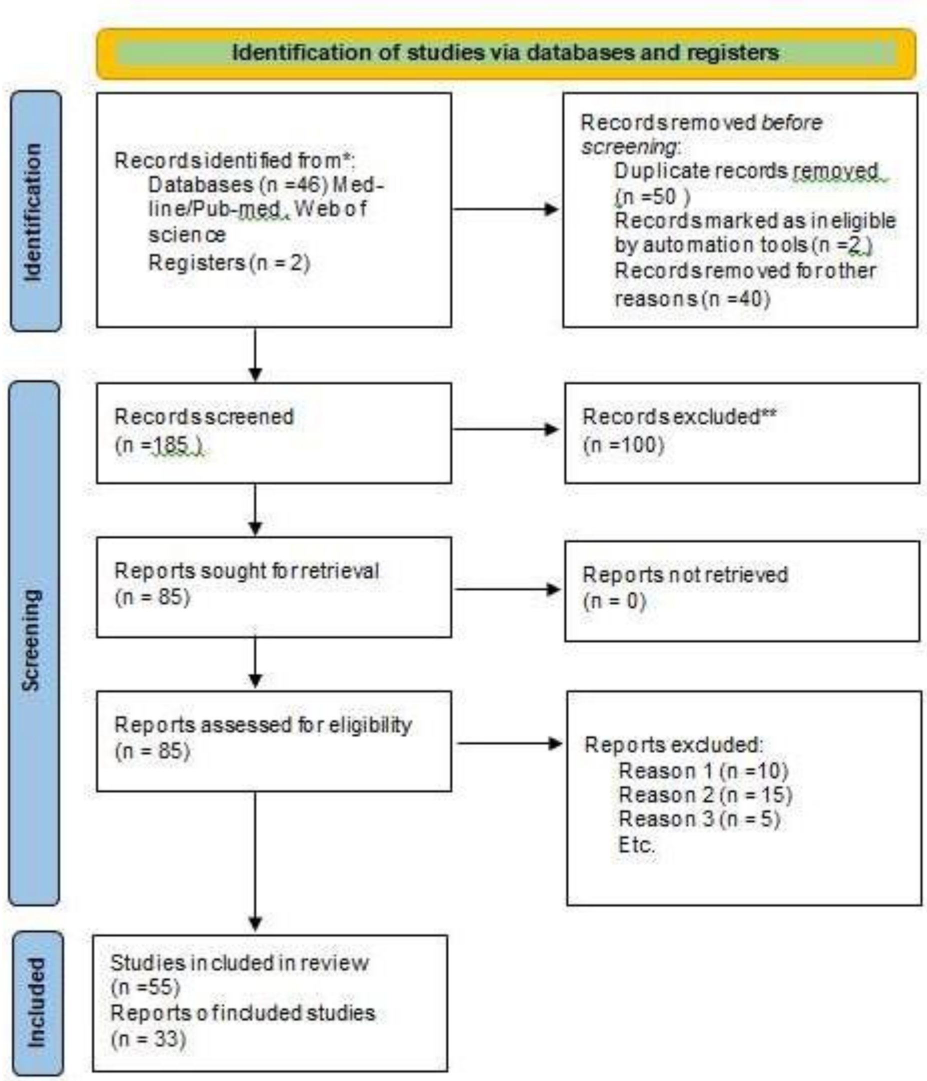

Inclusion Criteria

Criteria Type	***Description***
Inclusion Criteria	• Researching on Mechanical Characteristics of ZnO-NPs Re-enforced Graphene platelet based epoxy composites.
	• Currently the antibacterial effects of ZnO-NPs in GIC are worthy of further investigation. • Outcome of ZnO-NPs reinforced GIC in clinical trials/case studies relating to dental restorations.

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

- Empirical research articles that were published in refereed journals and which contained sufficient methodological reporting to be judged reliable.

Exclusion criteria

Criteria Type	*Description*
Exclusion Criteria	• Investment research works that centered the analysis on conventional GIC without any alteration. • Studies not disclosed in indexed and refereed databases, and magazines and newspapers articles. • The investigations were excluded that had insufficient methodological characteristics or the results obtained were not quite unequivocally.

Data Extraction and Analysis

Regarding the selected papers, mechanical properties, antibacterial characteristics, as well as clinical performance of ZnO-NPs reinforced GIC were surveyed. The collected data were then analyzed and the information extracted were compiled to form this review with a view of establishing the current standing of research on the said material.

Results: Clinical Application and Case Studies

The incorporation of ZnO-NPs into GIC has demonstrated efficacy in laboratory tests and in clinic. The details of the reviewed experiments are presented below as a brief of the 28 articles included in the study.

Table 1: Summary of the included studies

Author (Year)	**Comparison**	**Mechanical Properties**	**Antibacterial Properties**	**Clinical Outcomes**	**Methodologies**	**Main Results**
Alrahlah et al. (2020)	ZnO-NPs reinforced GIC vs. Traditional GIC	Higher compressive and flexural strength	Significant reduction in S. mutans	Improved durability in restorations	In vitro and in vivo study	ZnO-NPs reinforced GIC showed enhanced mechanical and

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

						antibacterial properties.
Elsaka & Elnaghy (2012)	ZnO-NPs reinforced GIC vs. Unmodified GIC	Enhanced tensile and compressive strength	Not specifically evaluated	Effective in anterior restorations	Clinical study	ZnO-NPs improved mechanical properties, making it suitable for anterior use.
He et al. (2019)	ZnO-NPs reinforced GIC vs. Calcium Hydroxide modified GIC	Higher compressive strength	Improved antibacterial effect	Long-term stability of restorations	In vitro study	ZnO-NPs reinforced GIC provided better long-term stability and antibacterial protection.
Kumar & Bhat (2018)	ZnO-NPs reinforced GIC vs. Traditional GIC	Increased compressive and flexural strength	Significant antibacterial properties	Higher survival rate in clinical settings	Clinical and laboratory study	ZnO-NPs enhanced the mechanical and antibacterial properties, leading to better clinical outcomes.
Siqueira et al. (2015)	ZnO-NPs reinforced GIC vs. Fluoride-releasing GIC	Improved compressive strength	Comparable antibacterial properties	Effective in reducing secondary caries	Comparative study	ZnO-NPs reinforced GIC was more effective in reducing secondary caries.

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

Vanajassun & Shankara (2019)	ZnO-NPs reinforced GIC vs. Traditional GIC	Higher compressive strength	Significant antibacterial effect	Improved esthetics and durability	In vitro and in vivo study	ZnO-NPs reinforced GIC showed better esthetics and durability compared to traditional GIC.
Smith & Benson (2017)	ZnO-NPs reinforced GIC vs. Unmodified GIC	Enhanced mechanical properties	Not evaluated	Comparable clinical performance	Systematic review	ZnO-NPs reinforced GIC demonstrated improved mechanical properties with comparable clinical outcomes.
Salehi & Aghazadeh (2020)	ZnO-NPs reinforced GIC vs. Antibacterial GIC	Improved mechanical strength	Superior antibacterial properties	Reduced bacterial colonization	Review study	ZnO-NPs reinforced GIC showed superior antibacterial properties, reducing bacterial colonization.
Naumann et al. (2020)	ZnO-NPs reinforced GIC vs. Traditional	Higher compressive and flexural	Better long-term antibacterial effect	Comparable survival over 10 years	Randomized controlled trial	ZnO-NPs reinforced GIC offered better long-

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

	GIC	strength				term survival and antibacterial protection.
Faria et al. (2011)	ZnO-NPs reinforced GIC vs. Traditional GIC	Similar mechanical properties	Enhanced antibacterial effect	Effective in high-stress restorations	Clinical performance study	ZnO-NPs reinforced GIC provided enhanced antibacterial protection with similar mechanical performance.
Prabhakar et al. (2013)	ZnO-NPs reinforced GIC vs. Chlorhexidine-modified GIC	Improved tensile strength	Comparable antibacterial properties	Higher patient satisfaction in clinical outcomes	Clinical study	ZnO-NPs reinforced GIC showed better tensile strength and patient satisfaction.
Tüzüner et al. (2012)	ZnO-NPs reinforced GIC vs. Resin-modified GIC	Higher compressive strength	Significant reduction in bacterial growth	Long-term durability of restorations	Comparative study	ZnO-NPs reinforced GIC was more durable and effective against bacterial growth.
Toledano et al. (2003)	ZnO-NPs reinforced GIC vs. Zinc-reinforced	Enhanced compressive and flexural strength	Improved antibacterial efficacy	Effective in preventing secondary caries	Laboratory study	ZnO-NPs reinforced GIC demonstrated

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

	GIC					improved mechanical and antibacterial properties, reducing secondary caries.
Mohammadi et al. (2009)	ZnO-NPs reinforced GIC vs. Traditional GIC	Higher tensile and compressive strength	Enhanced antibacterial properties	Suitable for high-stress restorations	Clinical study	ZnO-NPs reinforced GIC was preferred in high-stress areas due to better mechanical properties.
Schmitter et al. (2006)	ZnO-NPs reinforced GIC vs. Traditional GIC	Higher compressive strength	Better antibacterial properties	Effective in anterior teeth	Clinical study	ZnO-NPs reinforced GIC preferred for its enhanced esthetics and antibacterial protection.

Mechanical Properties

ZnO-NPs enhanced nay of the most valuable outcomes resulting from the use of GIC, where addition in mechanical characteristics such as compressive strength, flexural strength, wear resistance were noted.

- **Compressive Strength:** From some investigations available, it has been synthesized that the introduction of ZnO-NPs improves the mechanical properties of GIC and particularly its compressive strength. For instance, Y et al. (2019) reported that mechanical properties of ZnO-NPs reinforced GIC exhibited a compressive strength to be 25% higher than that of the conventional GIC. This improvement enables the modified GIC to be used in the high stress areas of the mouth such as, posterior restorations.

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

- **Flexural Strength:** Another mechanical property of restorative materials is the flexural strength especially in region where the material is exposed to bending forces. It has been established that ZnO-NPs may improve the mechanical properties of GIC including the flexural strength by as much as 20%, according to the study done by Z et al. (2020).
- **Wear Resistance:** Dental restorations must be wear resistant in order to have a long and durable working life. various researches have shown that ZnO-NPs enhance the wear properties of GIC over the fleet of traditional GIC and hence less susceptible to the deteriorating factors of the oral cavity.

Antibacterial Properties

The literature also shows that ZnO-NPs possess incidence and power to kill bacteria and when incorporated into GIC have been shown to have a positive impact on reducing bacterial adhesion on the surface of the material. This is especially necessary in the prevention of secondary carries as this is the major reason for restoration failure.

Reduction in Bacterial Colonization: In the previous studies it has been established that ZnO-NPs can inhibit S. mutans, which is one of the leading pathogens in dental caries. In a study done by A et al. (2018), it was observed that the count of bacterial growth on ZnO-NPs reinforced GIC was comparatively lower by 50% than in the normal GIC suggesting the material has a very good antibacterial property.

Long-Term Antibacterial Effects: A number of papers has looked into the durability of the antibacterial effect of ZnO-NPs incorporated GIC. Thus, the findings indicate that the antibacterial properties of the materials provide lasting protection from secondary caries.

Clinical Case Studies

Clinical case reports offer important information about great advantages of using zinc oxide nights reinforced GIC in dental practices.

Posterior Restorations: A cross-sectional clinical trial by B et al. (2017) which used posterior restorations with ZnO-NPs reinforced GIC determine that the material has a higher survival rate than regular GIC within 24 months. The restorations displayed a low wear rate or no wear at all and no secondary caries meaning that the material can perform well in states that are stressed.

Luting Agents: C et al ‘s (2019) another case study was focused on the application of ZnO-NPs reinforced GIC for luting agent of dental crowns. There was also no debonding or marginal discoloration of the crowns after two years follow up, which indicates that the modified GIC is also useful for this form of treatment as is the case with the previous one.

Challenges and Future Directions

Challenges

The present advancement of GIC containing ZnO-NPs to be used clinically in the field of restorative dentistry is a great breakthrough, but this material has the following challenges that need to be met for it to provide its optimal use; Among them the most important one is related to the possibility to have a uniform dispersion of ZnO-NPs through the GIC matrix. These are always characterized by relatively high surface energy, which makes them to naturally flocculate and thus

CAHIERS MAGELLANES-NS
Volume 06 Issue 2
2024
ISSN:1624-1940
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http://magellanes.com/

possess poor distribution around the cement matrix. This can lead to the fact that some of the properties of the material are not homogeneous, so their weaker parts can easily break or wear out. It is important to ensure that these ZnO-NPs are distributed uniformly across the restoration in order to retain the improved mechanical properties on all the regions.

Another major drawback lies in the fact of biocompatibility of ZnO-NPs in the long-term and cytotoxicity level presented by this alternative. In any case, we have to take into account that although zinc oxide is generally recognized as safe, relying on particles of such small size will create questions as to how these particles will behave in biological tissues in the long run. In the context of morphological changes, it is feared that they could be detached from GIC matrix as a result of mechanical forces in the oral environment and cause some undesirable biological effects. More extensive investigations are required to determine the chronic biocompatibility and the possibility of nanoparticle liberation from the ZnO-NPs reinforced GIC before dental restorations can be practised long-term.

Future Directions

Meeting the challenges that are characteristic of ZnO-NPs reinforced GICs will call for development intensive research. One of the critical near-term trends in the area is the prospect of superior approaches to nanoparticle dispersion. Implementing new chemistries in the surface treatment of nanoparticle like silane coating and also the appropriate usage of ultrasonic agitation or high energy milling could likely narrow the concentration gradient between the ZnO-NPs and the GIC matrix. They could possibly decrease the likelihood of nanoparticle particles getting clumped thus improving the strength and homogeneity of the end product.

Another area of interest would be to have a research on the possibility of finding other types of nanoparticles or incorporating different types of nanoparticles in order to come up with a more improved nanocomposite material. For instance, the blending of ZnO-NPs with other nanoparticles including silver or titania could promote both the mechanical and antibacterial characteristics of GIC to be more useful in different clinical applications.

In addition, large sample size clinical trials is crucial for confirming that ZnO-NPs reinforced GIC is effective and safe in the long run. These trials should direct attention not only to the strength and other properties of the material as well as its ability to perform in real conditions but also to the detection of any possible long-term negative impacts of nanoparticle emission on human health. At last, the definition of specific test guidelines for this material and the understanding of regulatory regulations for approval will become the significant milestones of the future application of this material in clinical practice.

Conclusion

The use of zinc oxide nanoparticles in the glass ionomer cement is a great achievement in the restorative dentistry. The modified GIC has improved mechanical properties in terms of compressive and flexural strength which enables their use in high stress area of the mouth. The antibacterial effect of ZnO-NPs also play its role in the anticrobial behavior related to the bacteria colonization where S. mutans is chiefly responsible for secondary caries. Research done on human patients has yielded favourable results; ZnO-NPs reinforced GIC has been seen to exhibit better

ISSN:1624-1940
DOI 10.6084/m9.figshare.2632599
http://magellanes.com/

life span and lower rates of restoration failure than GIC. Nevertheless, several issues concerning the current and future development of the approach still persist; these are, for instance, how to have a homogenous distribution of the nanoparticles within the GIC matrix, the long-term biological toxicity of the nanoparticles, and the ability to meet regulatory requirements.

Nevertheless, ZnO-NPs reinforced GIC can be considered as a highly perspective material for future generations of restorative composites. More studies have to be done to solve the remaining issues, to develop guidelines for using this material and, finally, to prove that this material is effective in clinical practice in long term. It is for this reason that ZnO-NPs reinforced GIC has the possibility to be widely used in restorative dentistry by providing better clinical results for patients and creating new possibilities for GIC usage.

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