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A review on restorative and preventive materials used in dentistry

Abstract

Restorative and preventive dental materials were designed to augment and improve on the limitations of amalgam alloy in terms of toughness, durability, changes in oral temperature and pH, force of abrasion opposing teeth, basicity of the saliva and the acidic regurgitated stomach fluids. It is expected that these materials will generally accepted, harmless and importantly highly biocompatible to reduce any risk to the patients and dental staff. There are wide varieties of restorative materials used in dentistry, which include dental metal amalgam, glass ionomer cements, zinc polyacrylate cements, zinc phosphate cements and pre/post preventive materials like etching agents, bonding, bleaching and sodium hypochlorite. Therefore, this review will give a comprehensive summary on available restorative and preventive materials used in dentistry.

Keywords: restorative materials, preventive materials, biocompatibility, dental materials, resin composite materials

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Introduction

Restorative and preventive dental materials were designed to augment and improve on the limitations of amalgam alloy in terms of toughness, durability, changes in oral temperature and pH, force of abrasion opposing teeth, basicity of the saliva and the acidic regurgitated stomach fluids. The lack of durable dental adhesives and restorative materials is considered one of the main problems with the use of composite materials in contemporary dentistry.[1] Restorative and preventive dental materials must be both mechanically and biological biocompatible. Unfortunately, several dental materials pose health issues to dental staff than patients. The use of restorative materials like methacrylates have been reported to cause skin reactions like skin dryness, cracking, itching, irritation and swelling.[2] Most restorative and preventive materials cause adverse effects in form of allergic reactions, because they majorly contain transition elements that are potential allergens like chromium (Cr), cobalt (Co), mercury (Hg), and nickel (Ni); compounds, such as eugenol and solutions like formaldehyde.[3] Formaldehyde residuals are formed as a degradation product of monomers in dentures made from some resin-based materials.[4] Restorative materials used for long-term restorations are meant to replace defective soft and hard tissues of the oral cavity and as such they should be chemically stable and inert for a long period of time. However, some of these restorative materials are prone to chemical reactions resulting into dissolution and corrosion, ultimately resulting into cytotoxicity and systemic reactions. Over the years, with the increase in technology, several new synthetic and biological materials have been used in the fabrication of restorative and preventive materials used in dentistry. Table 1 gives a summary of such restorative materials including adhesives.

Restorative materials

Dental metal amalgam

Free mercury element (Hg) is one of the causative agents of dermatitis in workers in mercury related factories. Experimental studies show that free Hg in amalgams exhibited a high level of toxicity in cell culture as well as copper amalgams. However, at low levels, copper amalgams are still compatible to hard and soft tissues in the oral cavity.[4] The diffusion ability of Hg into the enamel and dentine is not related to the degree of mineralization of teeth, which is a typical higher in older patients. Nevertheless, the diffused Hg has been reported in humans and dogs that it does not cross to reach the teeth pulps but does penetrates back into the amalgams where it dissolves remaining unreacted alloy cores[5] and in addition Stanley corroborated it in his study that Hg from dental amalgams is not associated pulpal responses.[6] However, stated that pulpal response to amalgams is primarily related to the implantation of the amalgams and its short-lived.[6]

Glass ionomer cement

Wilson and Kent were the first to demonstrate the application of glass ionomer cements in dentistry.[7] Its biocompatibility and stability properties have been harnessed for its application in dentistry. Gao and smales in their study reported the use of light-cured glass ionomer systems with mild level of cytotoxicity and posses the ability to release the fluoride with some therapeutic importance, however as been reported to be cytotoxic *in vitro*.[8] The biocompatibility of glass ionomer to soft tissue like the pulp has been associated with its inability of its heavy sized polyacrylic acid to diffuse through dentine. Clinically, pulp reactions to glass ionomer cements have been reported to be mild and any inflammatory infiltrate as a result of the ionomer is usually mild as well.[6] Stanley also stated in his study that the use of glass ionomer cements as restorative materials does not have any effect on the pulp, however using it as luting agents, might result into increased pulpal responses.[6]

Zn phosphate cement

Another type of restorative dental material is Zn oxide combined with orthophosphoric acid (H_3PO_4) and it's applied as cement for castings as well as orthodontic bands. One of the specific properties of this cement is its thermal conductivity which is proportion to that of enamel, however less to the thermal conductivity of metal.[10] In another study by Schmalz et al.[10] they demonstrated Zn phosphate cement to show decrease in cytotoxic reaction with increase in time thereby protecting the dental pulp.[11] In a quite similar study, Hauman and colleagues via deep-cavity preparations demonstrated a moderate-

to-severe localized pulpal damage for the few first days of application, possibly as a result of low pH. However, they reported that after 2 days, the acidic pH level became neutral.[11]

Zn polyacrylate cements

Zn polyacrylate cements are zinc based polycarboxylate cements. They are class of cements that demonstrates the strength of $Zn_3(PO_4)_2$ cements and the biocompatibility of ZOE cements.[12] Kenny and colleagues in their experimental in vitro study demonstrated that the cytotoxicity of Zn polyacrylate cements are related with the rate of release of Zn and fluoride ions in vitro and low pH level. Furthermore, they reported that concentrations level of polyacrylic acid higher than 1% demonstrated cytotoxic tendencies in vitro. Surprisingly, use of Zn polyacrylate cements for a long period of time up to 1-year is yet to exhibit any signs of cytotoxicity clinically.[13] However, Polyacrylate cements have been reported to contribute to dental pulpal reaction and after 5 weeks, mild chronic inflammation was observed.[11]

Table 1 Showing various resin materials and their application in dentistry. Culled from[5]

Material	Application	Details
ZnONPs	Adhesives Cements[33,1]	Administered with Ca/PO4- based structures
ZnONPs	Resin composites Adhesives[34]	Amalgamated into dental resins
ZnONPs	Cements[35]	Integrated into cements
TiO_2NPs (titanium dioxide or titania)	Resin composites Adhesives[36]	Integrated light- curable orthodontic composite paste
TiO_2NPs	Bleaching agents[37]	Administered in gel to improve the bleaching efficacy of hydrogen peroxide
Cu_2ONps (cuprous oxide) and CuONPs (cupric oxide)	Resin composites Adhesives[38]	The antimicrobial effects of these compounds were compared with those of silver, ZnO, TiO_2.
ChitosanNPs	Resin composites Adhesives[39]	Conjugated with silver nanoparticles
QAC-based nanostructures	Resin composites Adhesives[40,41]	Administered as a quaternary ammonium compound conjugated to organosilanes.
QAC-based nanostructures	Resin composites[42]	Administered as crosslinked quaternary ammonium polyethylenimine (QPEI) nanoparticles incorporated into resin composites
AgNPs	Mouthwash[43]	Stabilized by chitosan in a fluoride solution and applied once per year as a colloidal suspension on decayed primary teeth
AgNPs	Resin composites Adhesives[43,44]	Addition of silver and amorphous calcium phosphate nanoparticles in composites
AgNPs	Adhesives[45]	Conjugated with calcium phosphate (hydroxyapatite)
AgNPs	Adhesives[46]	Conjugated with polyvinylpyrrolidone, polyacrylic acid.
AgNPs	Root canal irrigation [47]	Applied in an aqueous composition comprising ethylenediamine tetraacetic acid, chlorhexidine.

Properties of resin-based restorative materials

Resin based materials have been linked with allergic reactions among dental staff.[14] Resin-based composite materials are used for restorative purposes in dentistry because of their organic and inorganic contents as well as their efficient biocompatibility properties. There are studies that have investigated the efficacy of these materials in terms of their biocompatibility. Goldberg in his experimental in vitro study reported that resin based materials often causes moderate cytotoxic reactions in cultured cells after 2–3 days of exposure. Similar study by the same author describes the biological tissues to resin composites. He reported that he observed low to moderate pulpal inflammatory response to resin based composites after 3 days in the oral cavity.[15] Contrary to the above report, report like[16] stated that residual from unreacted bis-phenol A and bis-phenol A dimethacrylate have been implicated in stimulating estrogen-like responses in vitro.

Pretreatment and postoperative materials

Etching agents

Etching agents like H_3PO_4 are medium-to-strong acidic agent. They are strongly corrosive and can be very corrosive on the hard and soft tissue of the oral cavity. There are few studies demonstrating their effect on the oral tissue, one of such is.[17] The authors investigated the penetrative ability of a tagged H_3PO_4 gel. They reported that the acid penetrated deeper than expected as 40% of the original radioactive dose still remained in the tooth after heavy rinsing.

Bonding agents

Bonding agents tend to bond with a stronger force with enamel compared to dentine, possibly owing to its composition (higher moisture content and lower mineral content). The smear layer within the dentine has been identified as an important player in the process of bonding and how biocompatible a restorative material can be. In addition it also serves as a protective barrier between resin materials and the dentine, between the dentine and any potential bacterial infection. Several studies have demonstrated the effect of various acids when the smear layer was removed. The effect of these acids has been linked with factors like dentine thickness, acidity of the acid and etching ability of the acid. In addition, dentine thickness of about 0.5mm has been reported to be thick enough to protect the dentine from any acid penetration.[18] Several bonding agents contain a hydrophilic resin known as hydroxyethyl methacrylate (HEMA). It

has been reported to be less cytotoxic in vitro compared to bis-GMA[19] However HEMA has been demonstrated to be cytotoxic *in vivo*[20] as well as in combinations with other resins in dentine bonding agents *in vitro*.

Bleaching agents

Bleaching agents majorly contain some form of carbamide peroxide ($CH_6N_2O_3$) or hydrogen peroxide (H_2O_2). The peroxides content of bonding agents have been reported to easily cross into the dentine when at a higher cytotoxic concentrations *in vitro*.[21] Bleaching agents might chemically burn the soft tissues when administered at a high concentration, however, at low dose and properly administered is safe. The cytotoxicity of both $CH_6N_2O_3$ and H_2O_2 bonding agents have been demonstrated by[4] to fibroblasts in vitro, however they reported the cytotoxicity was observed during a short-period of administration and as such long-term in vivo studies should be considered.

Sodium hypochlorite

Sodium hypochlorite (NaClO) is one of the most commonly used endodontic materials as an irrigation fluid for root canal preparation. It has been reported to have antimicrobial abilities as a result of its oxidizing and hydrolyzing abilities.[22] At high concentration, NaClO is highly toxic and causes irritation of the soft tissue of the oral cavity. The safest concentration of NaClO as an endodontic agent has been reported to be 0.025% as at this concentration, it still retain its anti-bactericidal ability without soft tissue-related irritation.[23] However there are studies that have linked the use of NaClO with secondary infections like paraesthesia and hypersensitive reactions[24] as a result of injecting the endodontic agent beyond the root apex.

Recent advancement in resin-based composites

Rcently, there have been advancements in the development of novel resin composites through the knowledge of nano-technology. The combination of resin composites and the fabrication of nano-particles have been applied to both soft and hard tissues of the oral cavity.[25] The advantages of nanoparticle fabricated resin based composites is that they posses high surface energy that translates into properties like excellent color density, low polymerization shrinkage, adequate, low surface roughness, toughness and hardness, and excellent biocompatibility to both soft and hard oral tissues.[26] Furthermore, resin based silane-coupling agents have been reported to be combined with with TiO_2 and SiO_2 nanofillers within the restorative resin matrices. The advantage of using nanofillers fabricated silane agents as a restorative agent has been demonstrated in a 2-year clinical study by.[27] The effect and efficacy of nanoparticles like amorphous calcium phosphate, dimethylaminohexane methacrylate in the fabrication and characterization of a resin composite.[9] Silver nanoparticles have been reported to improve the enamel remineralization abilities of the resulting fabricated resin composite.[28] More recently, adhesives used for restoration in dentistry for minimally-invasive dental surgery has been improved by augmenting its anti-microbial abilities by the addition of doxycycline-encapsulated nanotubes[29] as well as reduction of polymerization shrinkage linked with methacrylate resins.[11] Furthermore, nanoparticles packed in gel on polymers have been reported to reduce the process of polymerization shrinkage and stress associated with the oral cavity.[30,31] Using similar nanogel, Dailing et al, reported in their study that nanogels fabricated polymers enhanced the durability of phase-separated adhesive resins.[31,48–51]

Conclusion

The recent developments in technology have contributed to the improvement of dental treatment. However there are still some concerns issues involving ethics and safety regulations and cost-effectiveness need to be fully addressed. Furthermore, fabrication of novel synthetic materials as restorative materials has led to increased biological effects and biocompatibility limitations of these materials as such extensive studies are needed to fabricate a less toxic and highly biocompatible materials. In addition, more clinical studies are required for long-term evaluation of existing materials to better understand their mechanisms of action.

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Conflicts of interest

The authors declare that there is no conflicts of interest.

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