The development of a tangible nano-composite dental material – A literature review

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Abstract

Nano-composites are fabricated, structurally harnessed, customized nano biomaterials with clinical relevance as dental restorative composites. Various improvisation and optimization of its variables have been pursued to enable commercial production of a tangible material, able to provide and sustain the needed characteristic strength and resilience of human oral mineralized tissues biocompatibility needs. Variable sizes and materials are introduced to these nano-composites to improve performance and wear pattern while close-monitoring of its inert engineered stabilities properties. In this review, a brief historical acknowledgment of the development and evolution of nano-composite materials, optimized applications, and characterization till date will be explored. The various engineering methods to optimize the inert morphological and its mechanical properties will also be highlighted. Finally this paper will also discuss biocompability issue.

KEYWORDS: Hybrid, nano-composites, mechanical properties and dental restorative materials.

Introduction

The development of a tangible dental materials of pertinent in restorative works is a revolving dynamic event and have integrate and introduce various innovative efforts that have span cascade of research and development tedious efforts over a rhetorical historical time period of over four centuries. The existence of commercially available conventional composite have been patented reported with varying degrees of property enhancements and further improvised by a much better optimized structural designed nano-composite material. Nano-composites are thus materials in which certain periodic elements of the material structure exist, or co-exist, at the so-called ‘nano’ level, which can enhance significantly a composite’s properties. Nano-composites are thus a class act nanoscale material, in which at least one dimensions of the filler phase, is smaller than 100 nm. They offer an opportunity to explore new behaviors and functionalities beyond that of conventional composite materials. Extensive experimentation has been undertaken to identify the composition, mechanical properties, and *in vivo* response of these material. This microscopically and engineered technology tested products have been explored and designed much to answer controversies to conventional amalgam usage in clinical scenario on the oral dental mineralized tissues. Dental nano-composites are also characterized by filler-particle sizes of < 100 nm; however these materials offer esthetic and strength advantages over commercially available conventional microfilled and hybrid resin-based composite (RBC) systems, primarily in terms of smoothness, polishability and precision of shade characterization, plus flexural strength and micro hardness similar to those of the better-performing posterior RBCs. The main goal of this review was to collect, all available data of pertinent to nano-composite either in tandem to its development and improvements as an innovative dental biomaterials. Search of papers investigating these issues was performed using PUBMED and focusing publications in English. The various improvement and patent efforts revolve in tandem to development and optimization of hybrid generation with better biocompability to supporting biological tissues and less perpetual on-pouring of possible hazardous compound as its inert feature and better structural flexural strength and loading characteristic. This improvement's thus promote and revolve around filler loading technology that include, filler matrix bonding and modification of its resin monomer.

A historical renaissance.

The development and introduction of various materials and substance for betterness of human kind and health revolve with each community's cultural adaption and believe geographical availability, religious conflicts, and political keenness and the renaissance for a scientific elucidated inquiry. Knowing the history of the development of this composite materials can shred better informative perspective of how, transformed and the innovative state of the art is progressing and optimized. The main question will thus be, "How will this composite perform better than those commercial available today?" As such the rule of thumb is, nano-composite products thus designed must be optimized and structural a buildup around the known scientific evidence-based facts and well meticulous technological optimized observed conclusive results. Thus a product with enhance performance and tested biocompatible properties. Nanohybrid and nanofilled RBCs are generally the two types of composite restorative materials referred to under the term "nanocomposite", usually in a context of particle size. (1,2). An early goal of the dental nanocomposite development was the introduction of materials that possessed the strength to function under the stresses of Class I and Class II occlusal applications, while at least replicating the esthetic standards of hybrids and microfills. Microfilled composites use silicon dioxide filler particles less than 100 nm in diameter in conjunction with prepolymerized organic fillers, aggregated by crushing them into larger filler particles. While this system produces consistently high-quality surface smoothness and has the longest clinical track record, these restorations lack the high strength needed to emulate amalgam (3).

Years	Composition Of Modification
1950's	Glass filled PMMA
1960's	PMMA - Bis GMA
Mid 1970's	Self Cure - UV cure
Late 1970's	UV Cure – Visible Light Cure
Late 1970's	Bis GMA – others Monomers
Late 1970's	Macrofill – Microfill

Early 1980’s	Macrofill – Hybrid
Mid 1980’s	Direct – Indirect
Late 1980’s	Hybrid – Small Particles
Mid 1990’s	Flowables and Packables
Mid 1990’s	Small Particles - Microhybrid
2000	Microfill – Nanofill and Nano hybrid
Mid 2000	Low shrink formulation
2010	Self adhesive flowables restoratives

Table. 1 : The evolution of dental restorative materials. (State of the art: Jack L. Ferracan (15) (Department of Restorative Dentistry, Oregon Health & Science University, Portland, 2011).

In this era of evidence base progression toward nanoscale, current laboratory-bench dental research is exploring designs for restorative systems that biomimetically approximate the very processes by which dental enamel is formed (4,5). Deepen an effort in developing of this dental restorative materials is intended for fulfill each of demand in the era of dentistry. Compared to the amalgam the composites have been choosen possess better properties in mechanical and physical essential. At present various studies are focuessed to developed novel nanocomposite material that not only can be used not only as filling material for dental cavities, but that will also eliminate any remaining bacteria flora within the tooth structure and regenerate the actual mineralized structure lost to pathogenic decay activities. To address this problem, the Biomaterials and Tissue Engineering Division at the Department of Endodontics, Prosthodontics and Operative Dentistry of the University of Maryland School of Dentistry has been developing novel nanocomposite. The nanocomposite possesses antibacterial and remineralizing capabilities. Such a combination of capabilities is highly beneficial to inhibit caries, but is unavailable in any current known restorative materials. Nanocomposite-containing nanoparticles of amorphous calcium phosphate, nanoparticles of silver, and quaternary ammonium dimethacrylate had strong antibacterial capabilities that were maintained in a 180-day water-aging experiment. Mechanical strength and elastic modulus of this nanocomposite after a 180-day water-immersion matched those of commercial available control composites but without the said antibacterial properties. Incorporation of quaternary ammonium dimethacrylate into NACP nanocomposite greatly reduced biofilm viability, metabolic activity, colony-forming unit counts, and lactic acid production. The antibacterial results were not significantly different after water-aging for 1, 30, 90, and 180 days. The durable antibacterial properties, plus the calcium and phosphate ion release and acid neutralization properties, indicate that the novel nanocomposite may be useful in restorations to inhibit secondary caries. However, despite the rhethoric rich history associated with the dental restorative development (Table 1) and their prominent position in the restorative and rehabilitation dentistry, much is still found wanting.

Properties which have been shown to undergo substantial improvements include:
• Mechanicals e.g. strength, modulus and dimensional stability
• Decreased permeability to gases, water and hydrocarbons
• Thermal stability and heat distortion temperature

• Chemical resistance
• Surface appearance
• Electrical conductivity
• Optical clarity

Characterization of Morphology and Properties

Characterization of the nano-composite materials is necessary to understand/ analyze various inert properties of nano-composites, as such to ascertain the application potential of these nano-composites. A number of different nano-composite characterization methods are available include thermo-gravimetric analysis, differential scanning calorimetry, transmission electron microscopy, scanning electron microscopy, X - ray diffraction, nuclear magnetic resonance, IR spectroscopy, Raman spectroscopy, X – ray photoelectron spectroscopy, dielectric relaxation spectroscopy, atomic force microscopy, electron spin resonance, continuous - wave and pulsed ESR spectroscopy. A few of them are listed as follows: Nanofill composites are formulated with both nanomer and nanocluster filler particles, whereas nanohybrid composites (Figure 2) are hybrid resin composites containing finely ground glass filler and nanofiller in a prepolymerized filler form (6). Nanofillers at present have been touted as commercially formulation. To boost the greater stiffness, higher elastic , better fracture resistance and improved wear characteristics depend critically on the fillers level within the formulations (7). Some speculation said materials with the nano size do have very special properties. In 2010 China Paper reported, adherence of the pulp cells was revealed to be good. Spiller (8) reported the nanohydrib have superior aesthetic, wear characteristics, high polishability and superior handling characterictics.

Extensive studies have been undertaken to improve dental nano-composites with advances in its filler compositions and resin chemistry. The property enhancements have enabled these nano-composites to be increasingly used as esthetic filling materials. In the development of the dental nano-composites, the three main components can be modified: the inorganic fillers, the organic matrix, and the silane coupling agents. In conjuction for the development of a hybrid dental nano-composite restorative materials, the said nanocomposite must possess acceptable mechanical properties to withstand chewing force, as such the flexural strength test is very important. Other important parameters affecting the physico-mechanical properties of dental composite are solubility (SL) and water sorption (WS).

The role of microscopy in nano-composite development

Various aspects of nano-composite technology, including the use of microscopic techniques for their structural characterization, have been the object of many recent studies (9-14). Microscopy is commonly used to complement the findings from X - ray diffraction. As such electron microscopy (EM), complemented by other techniques, has played a very important role in the elucidation of morphology and structure-property correlations of composite materials. The unparalleled contribution of the microscopic techniques (especially of electron microscopy and scanning force microscopy, SFM) in the development of nano-composite science and technology can be realized by the fact that almost all of the scientific literatures published or communicated, make a direct or an indirect reference to the use of these techniques. Thus, these techniques play a crucial role especially in the optimization of composite properties through structural characterization, which provide direct clues not only about the structure of the filler itself but also about the filler-matrix adhesion, filler distribution, and the impact of the filler on the morphology and properties of the embedding polymer matrix (15-3). Recently, with the help of different electron microscopic techniques (22-24) supplemented by scattering (22) and scanning probe methods (24,26) the morphology of different molecular composites and nano-composite systems (27-29) were investigated.

Free surfaces of the samples are studied by scanning electron microscopy (SEM) and scanning force microscopy (SFM). A successful SFM imaging requires that the samples are properly prepared with flat, clean, and artifact-free surfaces. Equally important are the choice of the imaging modes, the selection of the probes, and other experimental parameters. Smooth surfaces required for this purpose are prepared either by ultra-microtome or by solution casting procedures (such as spin coating). The free surface can be etched by reactive ions (called as reactive ion etching or by using chemicals such as in permanganic etching (32,33). The significance of the EM in nano-composites science and technology arises principally from two causes. First, electron microscopic information is much more detailed than that from other sources. Using electron microscopy, information of the morphology of the matrix as well as of the filler and the adhesion between them can be simultaneously assessed with nanometer resolution. Second, electron microscopy allows studying the response of all the structural details of the composite towards applied load (sometimes even *in situ*) enabling the design of tailored materials.Electron microscopy offers straightforward information on such very fundamental questions of nano-composite science and technologies as whether the filler has really been dispersed on nanoscale and how the filler has modified the matrix's structures and properties. Microfilled hybrid composites with a mean filler particle size of 0.04 μm maintain the gloss produced after polishing. Unfortunately, because of their low tensile strength and fracture toughness, microfilled composites are contraindicated for class IV and stress-bearing restorations (34).

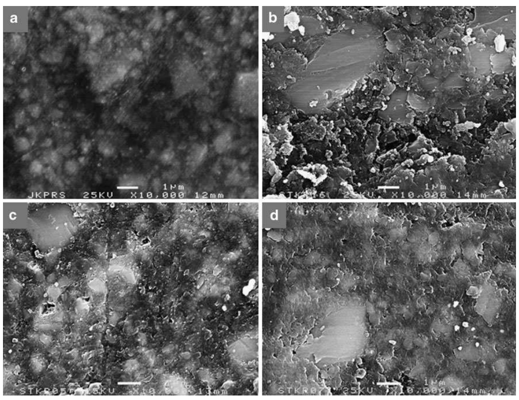

Fig 2. SEM of nanohydrib composite : Clinical Oral Investigation (2011)

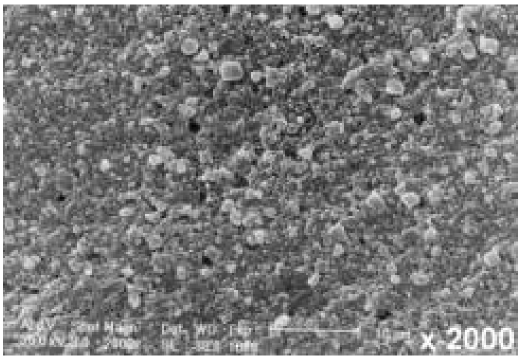

Fig 3. SEM of microfilled hydrib composite (M. Spillers , 2000).

The microfilled hybrid does not having the aesthetic characteristics such as tend to more opaque compare to resin glass composite. High viscosity makes it strenuous during handling the material.

Smooth surface execute to restrain recurrent caries (35). Mair (36) defines wear as the last consequence of the interaction between the surfaces, leading to the steady removal of the material. Clinically, surface roughness must be observed, as it plays a decisive role in the retention and accumulation of dental biofilm. Surface roughness has been used as a criterion to foresee and evaluate the deterioration of restorations made from different materials. While surface roughness of aesthetic materials *in vivo* is put down to mechanical abrasion, attrition and erosion, most of the current *in vitro* studies have evaluated surface roughness after mechanical abrasion and polishing. Bollen (37) reported that, on a rough surface, the microorganisms are less exposed to the dislocation forces and have the necessary time to adhere to this structure. The surface and the border of the restorative materials, when colonized by cariogenic bacteria, especially *Streptococcus mutan*s, favor the development of caries and future damage to the dentin-pulp complex. Bagheri (38) usually after finishing and polishing of restorative materials always pose a difficulty because particles and matrix differ in hardness and thus cannot be abraded uniformly. Particle size played an important role in a material can be polished smoothly (39). Some investigations based on surface roughness measurements recorded the highest values for the materials with larger particle sizes. Other parameters such as differences in shape, hardness, distribution and amount of particles, and interfacial bonding between particles and matrix, may contribute to a material's surface finish. However, (40) believed there is similar surface smoothness between micro hybrid and nano hybrid.

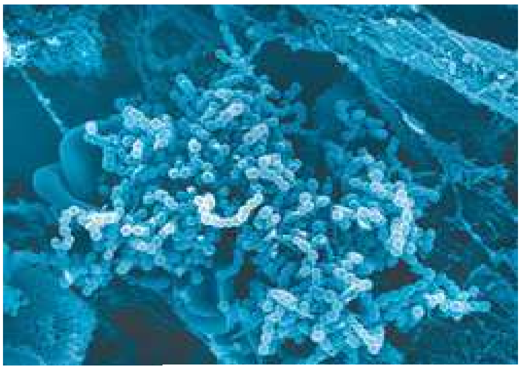

Fig 4. SEM micrograph shows a colony of streptococci, which are typically arranged in long bacterial chains.

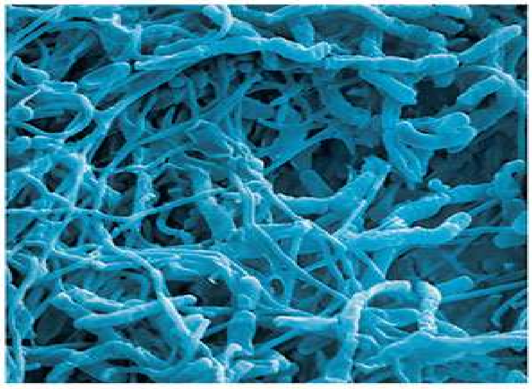

Fig 5 . SEM of the colony biofilm grown *in vitro* from human saliva .*Dimensions Digest of Dental Hygiene*.

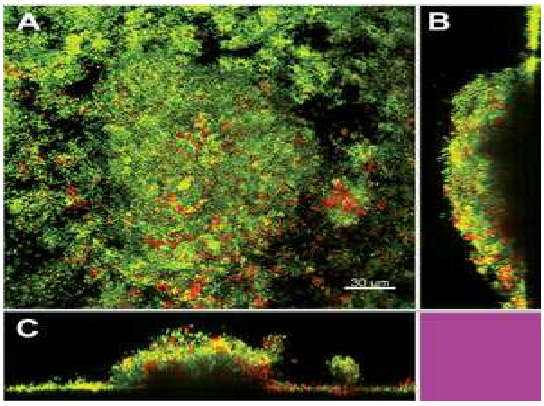

Fig 6. Three-dimensional reconstruction of confocal scanning laser microscope images shows a biofilm grown. Live bacteria appear green, while dead bacteria appear red. (A) Shows the top view, while B and C show side views.

Occusal activity which is associated with contact, sliding and twisting load and decay can result seriously damage to the human tooth (41). In oral mouth not only the deglutition activity in can be affected to the tooth but also the restorative materials. Fluid absorption can causes dimensional change that has potentially important clinical consequences as mentioned aboved (42). It influence the stress bearing restoration.

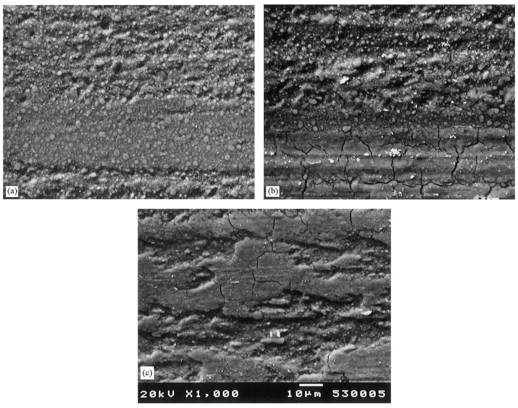

Fig. 6 SEM of the wear surfaces under different loading conditions, 1000: (a) typical wear surface after 5 N sinusoidal loading, (b) typical wear surface after 5N static loading, (c) typical wear surface after 15N sinusoidal loading.

Most of the testing is to find nano-hydrib materials are believed to offer excellent wear resistance, strength and ultimate esthetics due to their excellent polishability, polish retention and lustrous appearance. Micro-hybrids have the needed strength and wear for posterior composites due to their particle size and filler load. They have the polish and aesthetic characteristics for anterior restorations but these properties are not sustained long term. They are the most opaque of all composites and, therefore, are great for supporting a microfill layer. Micro-hybrids are considered a universal composite that can be used in anterior and posterior teeth (43). Nanohydrib contain the smallest particles and are the most recently introduced composite. Nanohybrids are composed of various nano-sized particles and fillers. They share the excellent wear and strength properties of micro hybrid composites (44). They are superior to micro hybrids in surface smoothness and polish. Nanohydrib continue to gain popularity and acceptance due to their excellent strength, wear resistance and polishability.

Conclusion

Microscopy, complemented by other integral techniques, has been, and will continue to be, the principal technique for the characterization of nanocomposites.The recent finding shows there is no differences between the nanohybrid and microhydrib. Both shows the same performance. Innovation is important to advancement for field of dentistry but this is must be based on the findings to prove greater effectiveness. The utilization materials demand on varies according to the importance of each operator needs.

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