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USE OF NANOMATERIALS IN PROSTHODONTICS: A NARRATIVE REVIEW OF THE LITERATURE

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ABSTRACT

The integration of nanomaterials in prosthodontics has garnered significant attention due to their potential to enhance the properties of dental materials. This narrative review explores the research and application of nanomaterials in prosthodontics, focusing on metals, ceramics, and resin-based materials.A comprehensive search of PubMed and Google Scholar databases was conducted for peer-reviewed articles published between 2000-2020, using keywords related to nanoparticle synthesis and incorporation in dental materials. Additionally, relevant journals were hand-searched. A total of 46 articles meeting inclusion criteria were identified for review.Studies have demonstrated the effectiveness of nanomaterials in improving the performance of dental implants. Surface modification techniques, such as anodization, have been utilized to create nanometer-scale features on implant surfaces, promoting osteoblast adhesion and osseointegration. Similarly, nanoceramic materials show promise in enhancing the mechanical properties of dental ceramics, including increased strength and toughness. In conclusion, the review underscores the promising role of nanomaterials in advancing various aspects of prosthodontics. Studies have demonstrated that nanoscale modifications, such as anodization and nanophase formulations, enhance osteoblast adhesion on implant surfaces, suggesting potential benefits for implant integration and osseointegration.

Keywords: Nanomaterials, Prosthodontics, Nanotechnology, Randomized Control Trials.

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INTRODUCTION

Nanomaterials have been developed promptly and some researches of nanomaterials have been carried out on prosthodontics. Many of the current dental materials are available through nanocrystallization to improve their original performance and play continuously key role in oral applications. Research of nanotechnology in dental materials is mainly focused on two ways: one is the preparation of new inorganic nanoparticles, and the other is to modify the surface with inorganic nanofillers and thereby to develop ultralow shrinkage rate of repair resin [3]. Through the development of nanocomposites, properties such as modulus of elasticity, surface hardness, polymerization shrinkage, and filler loading were enhanced by the addition of nanomaterials [1, 2].

In this paper, we briefly reviewed the development history of prosthodontics materials including metals, ceramics, and resin and evaluated the research and application of nanomaterials in prosthodontics.

METHODS

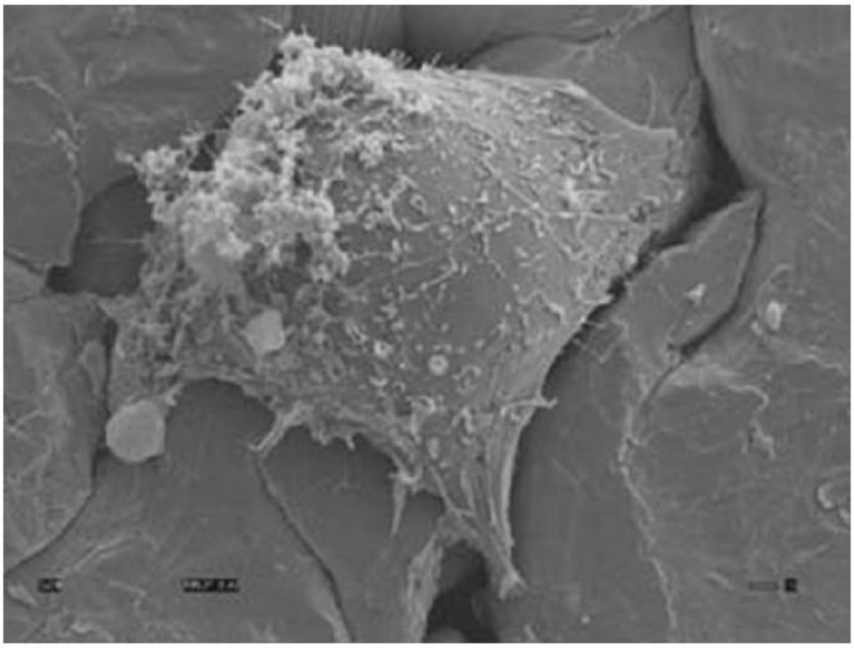
PubMed and Google scholar databases were accessed to search for pertinent peer-reviewed articles written in English published between 2000-2020. Keywords entered were “nanoparticles synthesis”; “incorporation of nanoparticles”, “nanoparticles in dental materials”; either individually or in combination. The hand search of the Journal of Prosthetic Dentistry, International Journal of Biomaterials, International Journal of Dental Research and Journal of Prosthodontics were performed for the period from 2000-2020. The abstracts were reviewed and articles were sorted based on the following inclusion and exclusion criteria. Articles published in English peer-reviewed journals, describing an original research, synthesis of nanoparticles, investigating the physical, mechanical and antimicrobial properties of denture base resins and maxillofacial silicone elastomers were included. Technical reports, abstracts, personal communications related articles were excluded.

A total of 465 articles were identified through the PubMed and Google scholar searches. Abstracts were reviewed to confirm the articles met the inclusion criteria. A total of 48 articles published between 2000-2020 were identified and read in their entirety. Forty-six articles were selected of literature reviews and invitro studies.

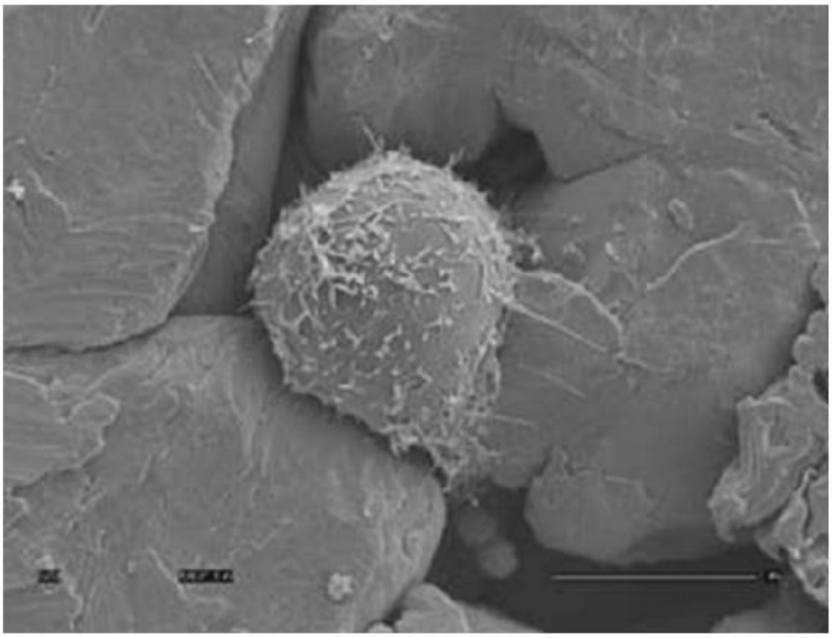
RESULTS

Yao et al. [4] created nanometer surface features on titanium and Ti6Al4V implants by anodization, which was a quick and relatively inexpensive electrochemical method. The results showed that the anodized surfaces had higher root-mean-square roughness at nanoscale dimensions than the unanodized Ti-based surfaces. Most important of all, as compared to respective unanodized counterparts, osteoblast adhesion was enhanced on the anodized metal substrates according to the results of *in vitro* studies. Thus, it demonstrated that anodization of Ti-based metals might create nanometer surface features that could promote osteoblast adhesion.

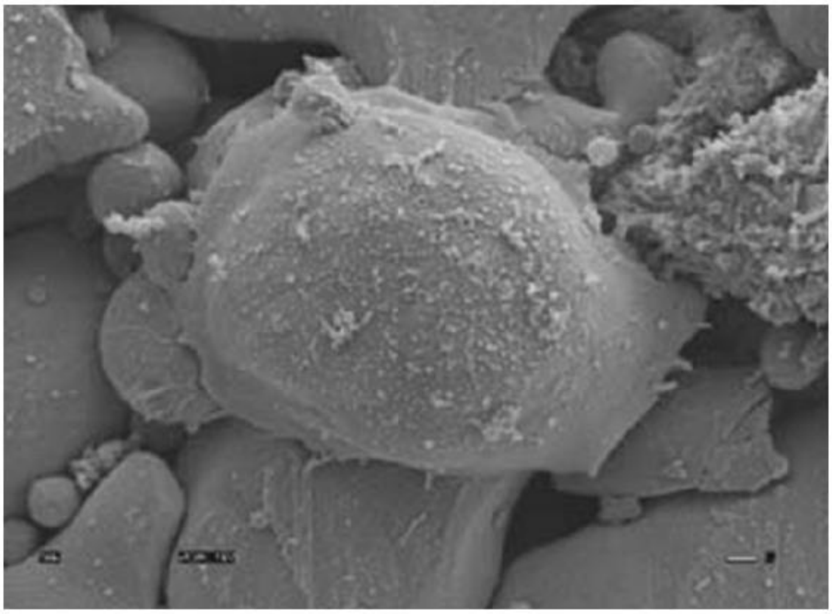
Webster and Ejiofor further provided the evidence of increased osteoblast adhesion on Ti, Ti_6Al_4V, and CoCrMo compacts with nanometer compared to conventionally sized metals [5]. In their study, each respective group of nanophase and conventional metals possessed the same material properties (chemistry and shape) and altered only in dimension. Human osteoblasts were seeded and placed in standard cell culture conditions for either 1 or 3 h. As expected, the dimensions of nanometer surface features gave rise to larger amounts of interparticulate voids in nanophase Ti and Ti_6Al_4V. Osteoblast adhesion was significantly greater on nanophase Ti, Ti_6Al_4V, and CoCrMo when compared to their conventional counterparts after 1 and 3 h and osteoblast adhesion occurred primarily at particle boundaries (Figure 1) [6,7,8,9]. Since nanophase materials possess increased particle boundaries at the surface (due to smaller particle size), this may be an explanation for the increased osteoblast adhesion measured on nanophase formulations. This study implies further enhanced adhesion of osteoblasts on nanophase Ti, Ti_6Al_4V, and CoCrMo. The result suggests that nanophase metals may be a kind of potential materials in prosthodontics or implant applications [10,11,12,13].



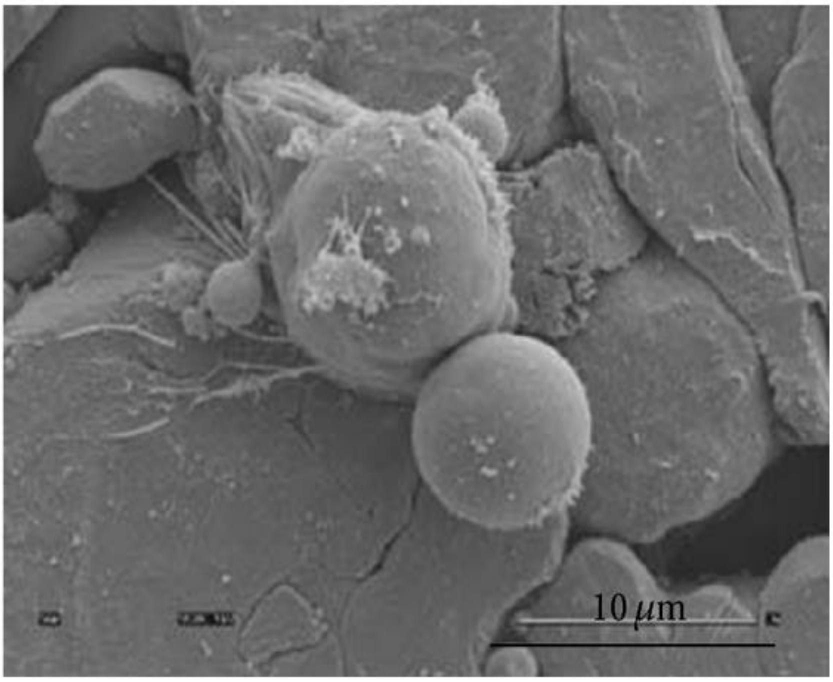
(a) Osteoblasts on nanophase Ti



(b) Osteoblasts on conventional Ti



(c) Osteoblasts on nanophase Ti6Al4V



(d) Osteoblasts on conventional Ti6Al4V

Figura 1: SEM images of osteoblasts on Ti and Ti_6Al_4V compacts, respectively [5].

Nanoceramics Materials in Prosthodontics

Ceramics have been used in the production of dental dentures due to their low thermal and electrical conductivity, appropriate colour, and high strength [14]. Currently, zirconia and alumina ceramics make up the majority of ceramic dental crowns. Modern high-tech ceramics employ zirconia, alumina, and silicon carbide, whereas traditional ceramics are formed of clay and other naturally occurring minerals. Ceramic materials, including glass, alumina, zirconia, and hydroxyapatite (HA), were used extensively in the creation of ceramic crowns. Alumina ceramics are aesthetically pleasing, glossy, chemically stable, wear-resistant, durable, and biocompatible and do not influence magnetic resonance imaging (MRI). However, their primary flaw is that they are prone to porcelain cracking. This was noted in a study [15]. ZrO2 has superior abrasion resistance, physiological corrosion resistance, and biocompatibility when compared to HA and titanium alloys. Its modulus of elasticity, flexural strength, and hardness are also greater. Through computer-aided design and manufacturing, zirconia ceramics have much greater strength and bending resistance than alumina ceramics, but they still lack toughness and a high sintering temperature [16, 17].

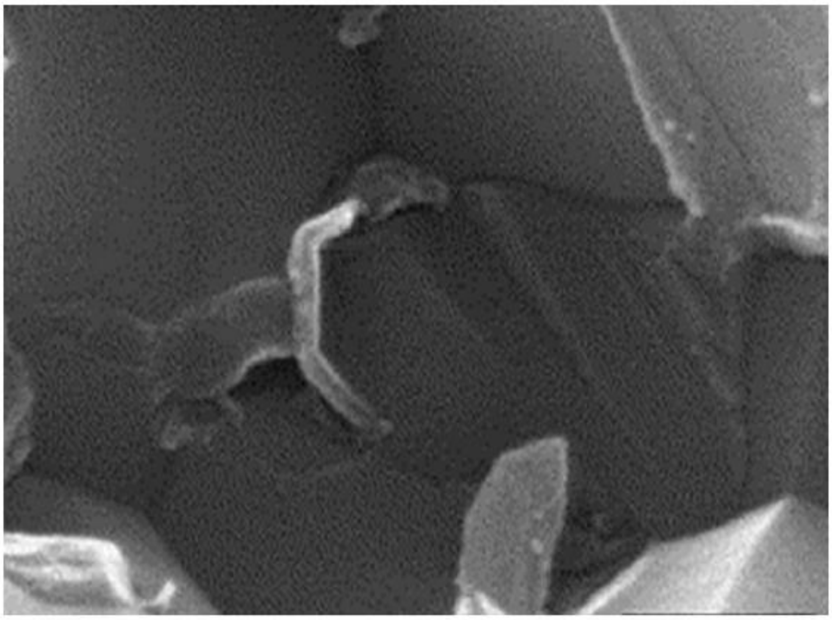
We anticipate that nanostructured ceramics will be able to provide certain particular enhancements since the poor ductility and brittleness of ceramics have a direct impact on and restrict the development of conventional ceramic materials. Furthermore, the mechanical standards of ceramic materials used in dentistry are supplemented by aesthetic requirements (clarity, colour). The need for dental repair translucency could be satisfied using nanostructured ceramics. Although they are not specifically focused on clinical use, examples of transparent or very translucent ceramics (alumina, YAG, etc.) have previously been described [18, 19]. The term "nanoceramic" describes ceramic materials in the microstructure phase that have dimensions on the nanoscale. Because of their distinct qualities over traditional ceramics, nanoceramics are now a popular issue in material science research.

To begin with, nanoceramics are superplastic. Although ceramics are basically brittle materials, nanoceramics exhibit high ductility and toughness. Although the atoms in the nanoceramics interface are arranged in a confused way, they move extremely easily when force deformation occurs. Second, nanoceramics have better mechanical qualities than traditional ceramics, with notable increases in hardness and strength. Many nanoceramics have strengths and hardnesses four to five times greater than those of conventional materials. For instance, at 100°C, the microhardness of nano-TiO2 ceramics is 13,000 kN/mm2, compared to less than 2,000 kN/mm2 for regular TiO2 ceramics. Most notably, compared to conventional ceramics, nanoceramics have much-increased toughness. The nano-TiO2 ceramic has very high toughness at room temperature. It did not break even when squeezed to 1/4 of its original length [20, 21].

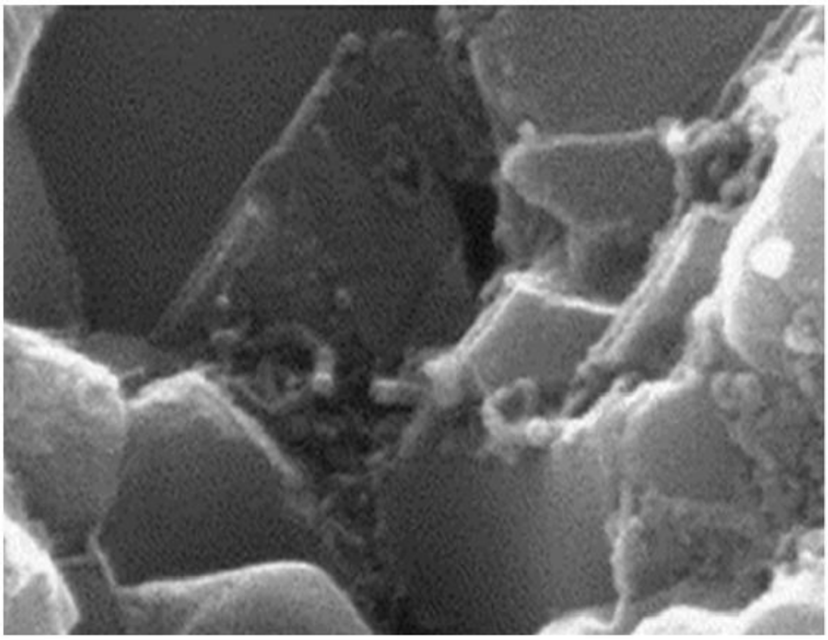
The physical characteristics of nano-ZrO2 ceramic materials vary from those of conventional ceramic materials, according to Li et al. Traditional ZrO2 often had a hardness of 1,500 and a relatively low fracture toughness, making breaking or cracking during processing a likely occurrence. On the other hand, a 20% improvement in hardness might be achieved with nano zirconia ceramics, exceeding 1,750. Its hardness increases along with a corresponding rise in fracture toughness [21]. The mechanical characteristics and microstructure of nano-ZrO2-toughened Al2O3 were studied by Wang et al. They discovered that the composite exhibited enhanced toughness at 20% nano-ZrO2, making it very appropriate for use as dental all-ceramic restoratives [22, 23, 24].

Dental crowns and veneers often employ glass ceramics based on lithium disilicate, which lacks mechanical characteristics. Failure clinical instances are often documented as a result of the poor mechanical qualities of glass ceramics. Persson et al. used a sol-gel method to produce glass-ceramics in the zirconia-silica system with nanosized grains, which were found to be translucent, with a transmittance of over 70% and possessed excellent corrosion resistance. This was done to improve the mechanical properties of glass ceramics based on lithium disilicate. In comparison to traditional lithium disilicate, it also showed a slightly lower elastic modulus but a greater hardness [25,26].

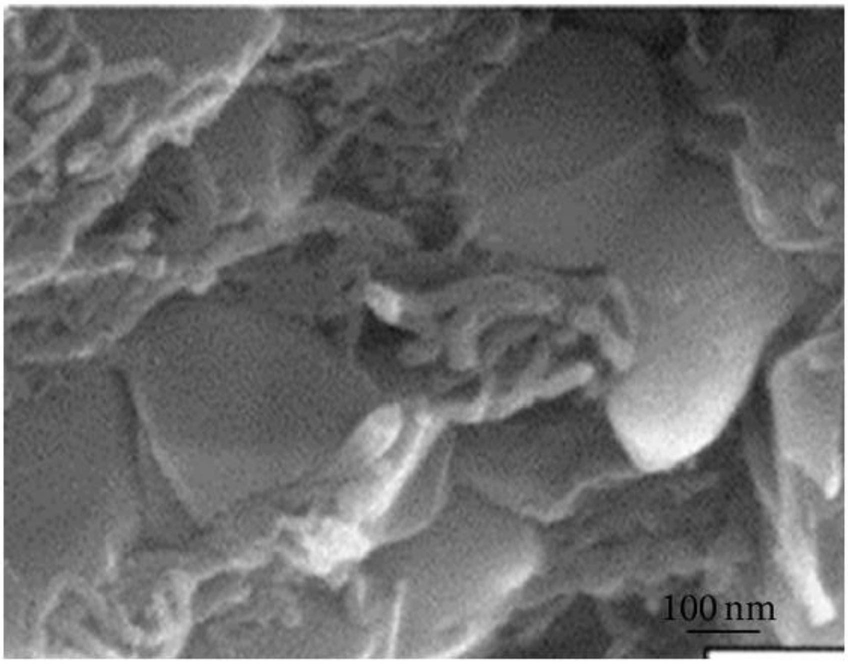
Since carbon nanotubes (CNTs) have such outstanding mechanical and electrical capabilities, they have garnered a lot of interest as material reinforcements. Furthermore, because of their special mechanical qualities, CNTs have been regarded as reinforcing components in ceramic matrix composites [27, 28]. Alumina-CNT composites were created by An et al. using hot pressing, and their mechanical and tribological characteristics were examined (Figure 3) [29, 30]. The findings demonstrated that mechanical and wear characteristics were improved in the 0–4% CNT content range and that adding CNTs up to 4% had a favourable impact on the reinforcing effect, increasing it by almost 30%.



(a)



(b)



(c)

Figure 3 The fractured surface morphologies of the hot-pressed alumina composites: (a) with 2.7 wt% CNT content, (b) with 4.1 wt% CNT content, and (c) with 12.5 wt% CNT content [17]

PMMA (polymethacrylate) resins PMMA (polymethacrylate) resins
For almost 70 years, resins have been used in prosthodontia because to their biocompatibility, optical qualities, and aesthetic appeal. Microbial adhesion and low fatigue resistance are mostly seen in long-term polymethylmethaacrylate (PMMA) users. Scholars have shown a great deal of interest in integrating nanoparticles such as zirconium oxide (ZrO). PMMA's mechanical characteristics improved when titanium dioxide (TiO2) and other materials were included.[31]
Soft liners with PMMA resins containing nano-zirconia particles
When nano-zirconia was tested with PMMA, it significantly increased the material's flexural and impact strengths.

Researchers studying nano-zirconia (1.5%) on PMMA Mohammed Gad et al. (2016)[25] and Leao et al. (2020) [26]found that it increased flexural, transverse, and impact strength, decreased wear, and shown strong antifungal and antibacterial activities.
PMMA resins and soft denture liners containing nanoparticles of titanium dioxide
According to research conducted by SuW. et al. [27] in 2009, who assessed the antibacterial qualities of resin materials including nano-titania particles and came to the conclusion that there was a 99.99% growth inhibition rate of E. coli species, the addition of 3 weight percent TiO2 produced favourable results against oral bacterial species. The study conducted by Shrikavad et al. (2014)[28] and Alrahlah et al. (2018) [29] examined the effects of nano-titania particles in polymethacrylate and liners at three different weight percentages of 0.5, 1, and 2 (wt%). The

findings indicated an improvement in tensile strength and excellent antifungal capabilities.
Silver nanoparticle-infused soft denture liners with PMMA resins
Pal et al. (2007), [30] Casemiro et al. (2008),[31] Chladek et al. (2012),[32] Hamedi Rad et al. (2014) [33], Ghafari et al. (2014) [34], Köroğlu A et al. (2016) [35], Yin et al. (2020) [36] examined the antimicrobial properties of Ag nanoparticles in various forms and concentrations and found a significant decrease in the number of microorganisms and a reduction in the hardness and tensile bond strength of resins and liners.
In 2017, Vimbela et al. [37] examined the antibacterial qualities of Ag nanoparticles at four distinct weight percentages (wt%): 1, 2, 3, and 5. Their findings demonstrated a substantial decrease in Candida albicans at a weight percentage of 5wt% in resins and liners. In 2020, Habibzadeh et al. [38] examined three distinct silver concentrations in PMMA: 0.3, 0.8, and 1.6 (wt%). The results revealed that the resins' flexural strength and elastic modulus decreased at the 0.8 and 1.6 (wt%) concentrations.
Soft denture liners and PMMA resins combined with additional nanoparticles
Tuan A 2011 research by Rahim et al. [39] using silica dioxide nanoparticles found that the surface hydrophobicity is increased by the addition of metal nanoparticles.
Xie, et al. [40] The antibacterial properties and polymerization shrinkage of PMMA of zinc oxide nanoparticles in 3 and 10 mm concentrations were studied by Lipovsky et al., [41] in 2011 and Kamonshantikul et al., [42] in 2017. The results showed 100% inhibition of microbial growth and a clinically significant decrease in polymerization shrinkage

CONCLUSION

In conclusion, the review underscores the promising role of nanomaterials in advancing various aspects of prosthodontics. Studies have demonstrated that nanoscale modifications, such as anodization and nanophase formulations, enhance osteoblast adhesion on implant surfaces, suggesting potential benefits for implant integration and osseointegration. Additionally, nanostructured ceramics exhibit improved mechanical properties, including increased toughness and hardness, which could address the limitations of conventional ceramics in dental applications. Furthermore, the incorporation of nanoparticles, such as nano-zirconia and titanium dioxide, into PMMA resins shows promise for enhancing mechanical strength and introducing antibacterial properties.

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