REVIEW PAPER

The applications of nanotechnology in restorative dentistry: a review study

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ABSTRACT

Nanotechnology has various applications in restorative dentistry in order to achieve reliable treatment outcomes. The present study aimed to comprehensively review the studies focused on the applications of nano-based materials, technologies, and methods used in restorative dentistry. Related articles were retrieved via searching in databases such as PubMed, Google Scholar, and Scopus. Afterwards, the appropriate references regarding the research subject were assessed, and findings were collected to achieve a comprehensive review study. According to the obtained results, the utilization of nanotechnology in restorative dentistry could yield beneficial outcomes. The dispersion of nano-sized structures in restorative materials could enhance mechanical properties such as diametral and flexural strength and fracture toughness. However, the improvement of the mentioned mechanical properties depends on the type of the nano-sized materials, their content, and type of the additional materials used along with nano-based restorative materials.

Keywords: *Composite, Mechanical Properties, Nanotechnology, Restorative Dentistry*

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INTRODUCTION

Nanotechnology is a field of science concerning the materials in nanoscale dimensions [1, 2]. This branch of science has attracted the attention of researchers owing to its broad range of applications in medicine and engineering [3-6]. Various devices function by the utilization of nano-sized materials as a novel approach to achieving optimal performance and efficiency [7, 8].

The nanoscale particles found in these materials could improve their antimicrobial properties and mechanical strength [9-11]. Considering the role of nanotechnology in enhancing the properties of the materials, it could be applied in dentistry and medicine [12].

According to a review study conducted by Zarchi et al. [13], utilizing smart nanocarriers along with external stimuli could remarkably improve drug potency and significantly reduce possible adverse side-effects. In another research [14], gold particles in nano dimensions were used in radiotherapy in order to remove colorectal cancer cells. According to the obtained results, the use of these nanoparticles resulted in the enhanced function of radiotherapy.

In addition to drug delivery and the related medical applications, nano-sized materials are extensively applied in dentistry. Nanomaterials are applicable in various areas of dentistry, including endodontics, orthodontics, and restorative dentistry. In orthodontics, nano-based materials are considered proper candidates for the conventional archwires used in orthodontics owing to their improved mechanical properties [9]. In addition to significant mechanical properties, nanotechnology could facilitate orthodontic treatments. According to Kachoei et al. [15], the coating of some nanomaterial (e.g., zinc particles) on the wires used in orthodontics could decrease the friction force between the brackets and wires, thereby facilitating the

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treatment procedure compared to conventional materials. Nanotechnology has also proven effective in the other areas of dentistry, such as endodontics. Nano-based materials could be used to modify the efficacy of the irrigants applied in endodontics. In this regard, Monzavi et al. [16] used a magnesium oxide solution as a nano-based irrigant (concentration: 5 mg/lit), which resulted in higher long-term efficacy in the elimination of *E. faecalis* compared to 5.25% sodium hypochlorite as a conventional irrigant. Restorative dentistry is a branch of dental sciences focused on dental and oral tissue restoration [17].

Several materials and tools are used in restorative dentistry, which could be modified by applying nanotechnology.

The present study aimed to review and investigate various applications of nanoscale materials in restorative dentistry. Details on the applications of nanotechnology in restorative dentistry have been represented, along with the summarization of their most important outcomes.

MATERIALS AND METHODS

This comprehensive review study was conducted via searching in databases such as Google Scholar, Scopus, PubMed, and Medline for the related articles published during 1990-2019 using various keywords, including nanotechnology, restorative dentistry, nanocomposite, and nanofiller.In addition, manual search was carried out in order to find the references that could not be found electronically.

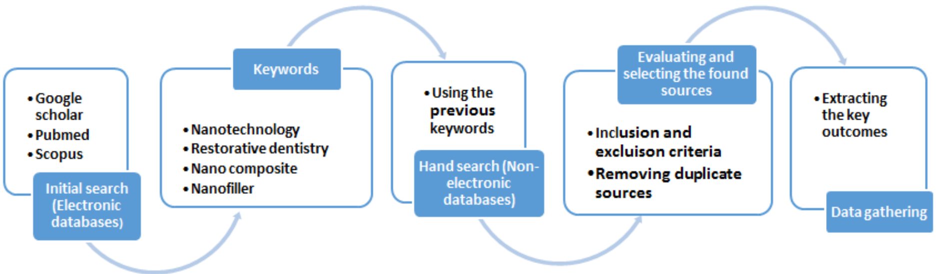

Fig 1. Process of review study

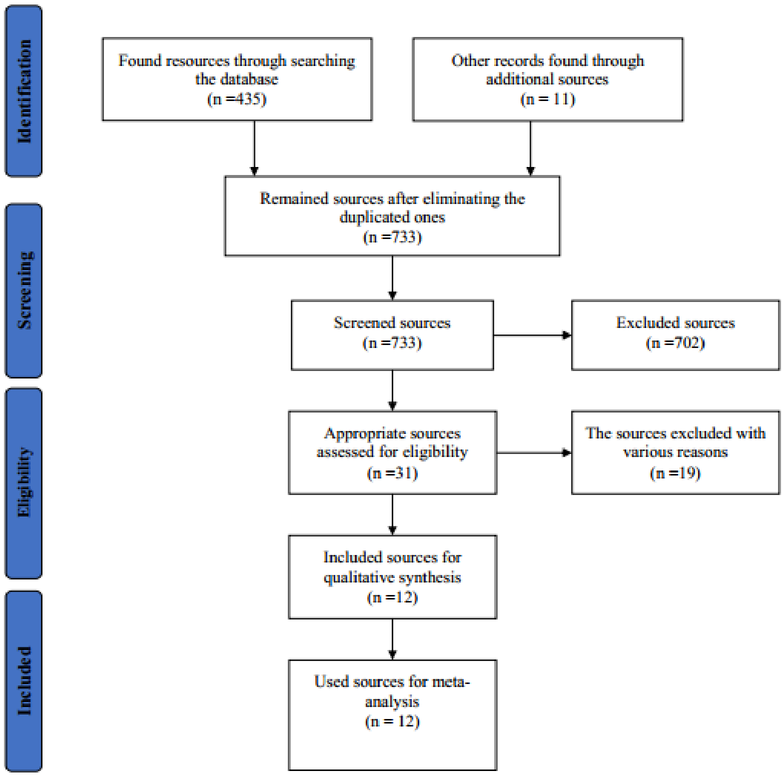

Fig 2. PRISMA diagram of study

In the second step, all the retrieved articles were screened in accordance with the inclusion and exclusion criteria, and the studies focused on the utilization of nanotechnology in restorative dentistry were reviewed. The studies without the comparion of nano-based approaches and materials with conventional approaches were excluded, and duplicate references were eliminated as well. It is also notable that only English articles were selected for further review and analysis. Afterwards, the full texts of the appropriate articles were obtained, and their outcomes and results were extracted. Moreover, the articles were evaluated in terms of eligibility by two independent researchers. In case of disagreement between the researchers, the decision was finalized based on discussion with the first author. The process of performing this review study is depicted in Fig 1.

As mentioned earlier, studies comparing the nanotechnology-based methods and materials with conventional methods were reviewed in the current research. In addition, the sample sizes and age of the studied patients were reviewed. The PRISMA diagram of the current review is shown in Fig 2.

Nanotechnology in restorative dentistry

As mentioned earlier, nanotechnology is applicable in various fields of dentistry [18, 19]. In this section, the main applications of nanotechnology in restorative dentistry are reviewed and investigated. Various composites are utilized in restorative dentistry, and nanotechnology has the potential to improve the properties of these composites, thereby increasing their efficacy for therapeutic purposes [20]. In a study in this regard, Schirrmeister et al. [21] assessed the function of a nano-based restorative material (Ceram.X/K) and a primer adhesive (K-0127) in clinical treatment. According to the findings, acceptable clinical outcomes were achieved in 96.8% of the cases receiving the procedure. Furthermore, the use of Tetric Ceram/Syntac Classic resulted in 100% acceptable outcomes. Therefore, the function of the nano-based restorative material revealed the potential of the technology in achieving proper dental treatment outcomes.

Nanotechnology improves the quality of resin-based composites in terms of hardness, shade characterization precision, smoothness, and polishability [22, 23]. In this regard, Hemalatha et al. [24] evaluated the roughness of various composites used as restorative materials in 80 specimens. In addition, the researchers investigated two types of restorative materials, including resin-modified glass ionomer composite (GIC) and nano-filled composite. In the mentioned research, each study group was divided into four subgroups (Table 1).

Table 1. Divided Subgroups for Evaluation of Surface Roughness [24]

Groups / Subgroups	Nano-filled Composite (A)	Resin-modified GIC (B)
1	Composite in Gatorade	Resin-modified GIC in Gatorade
2	Composite in Tang	Resin-modified GIC in Tang
3	Composite in Jeera Fizz	Resin-modified GIC in Jeera Fizz
4	Composite in 10% Sucrose (control)	Resin-modified GIC in 10% Sucrose (control)

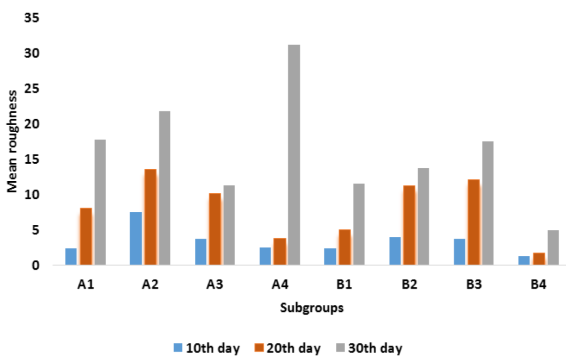

Fig 3. Roughness values in investigated subgroups

Surface roughness was measured on days 10, 20, and 60 as the determined intervals for evaluation (Fig 3). As is illustrated in Fig 3, the most significant changes in roughness were observed in the RMGIC group, and this finding was attributed to the lower wear resistance and mechanical strength of this group. Several studies have focused on adhesives and the influential factors in their reliability [25, 26]. The adhesives used in restorative dentistry could be modified by nanotechnology. In a study by Nagano et al. [27], colloidal platinum nanoparticles (CPNs) were applied prior to the utilization of a conventional resin cement (4-META/MMA-TBB) in order to assess their impact on bond durability. According to the findings, bond strength doubled with this technique compared to the control group. Therefore, it was concluded that using CPNs is a reliable method to achieve higher strength.

In a similar research by Ataiet al. [28], nano-porous silica fillers were thermally sintered and added to a conventional composite. In the mentioned study, various mechanical properties of the investigated materials were also evaluated, including micro-filled composites, nano-filled composites, and Filtek Supreme®. According to the obtained results, the maximum flexural modulus and fracture toughness belonged to the nano-based composites as illustrated in Figs 4 and 5, respectively.

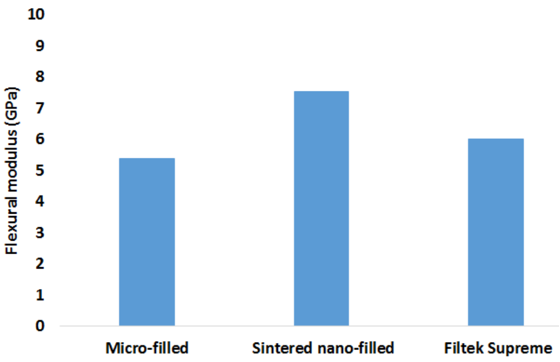

Fig 4. Mean flexural modulus of materials [28]

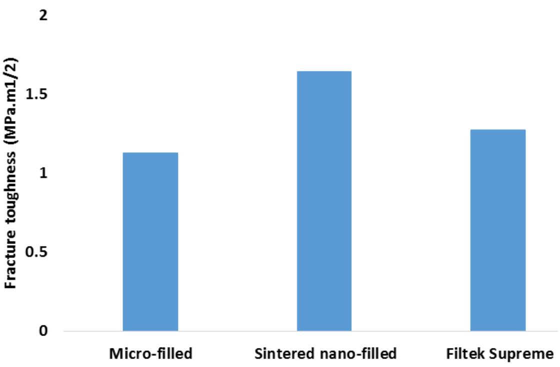

Fig 5. Mean fracture toughness of materials [28]

Furthermore, the highest flexural strength and degree of conversion were observed in Filtek Supreme® and micro-filled composites, respectively. Comparison of strength with the micro-based composites in the mentioned research is depicted in Fig 7. According to the literature, the concentration of the nano-sized materials used in composites affects the mechanical properties of composites. In a research in this regard [29], various concentrations of micro- and nano-sized fillers were examined in a monomer system, which was composed of 40% TEGDMA and 60% Bis-GMA. Seven types of the samples used in the mentioned study are presented in Table 2. In the mentioned research, the mechanical properties of the samples were compared in order to assess the impact of the compositions.

Table 2. Compositions of investigated samples containing micro- and nano-sized materials [32]

Sample Code	Type of Filler Content (wt %)
N1	Nano-sized $\alpha - Al_2O_3$ (10)
N2	Nano-sized $\alpha - Al_2O_3$ (20)
N3	Nano-sized $\alpha - Al_2O_3$ (30)
M1	Micro-sized $\alpha - Al_2O_3$ (45)
M2	Micro-sized $\alpha - Al_2O_3$ (50)
M3	Micro-sized $\alpha - Al_2O_3$ (55)
M4	Micro-sized $\alpha - Al_2O_3$ (60)

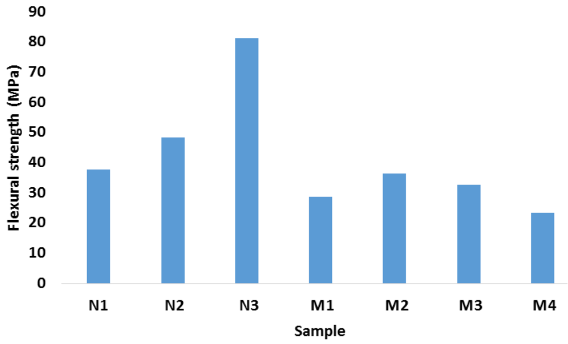

Fig 6. Mean flexural strength of samples containing micro- and nano-sized materials [32]

As shown in Fig 6, the addition of nano-sized materials resulted in more significant improvement of flexural strength, while the nano-based samples showed higher diametral tensile. The superior mechanical properties of the nano-based samples were attributed to the use of a more favorable polymer/filler interaction. In addition to concentration, the type of the nanostructures utilized in the material was reported to influence the properties.

In another study, Korkmaz et al. [30] investigated the shear bond strength (SBS) of nano glass ionomer and nanocomposite using various types of nano-based materials, including Filtek Supreme XT-3MESPE nanocomposite, Filtek Supreme XT Flow-3M ESPE (as a flowable nanocomposite), and a glass ionomer (resin-modified; Ketac N100-3M ESPE). The case samples were divided into various subgroups (Table 3). According to the findings, the mean SBS of the mentioned subgroups was 13.64, 7.83, 11.20, 4.12, and 0.64 MPa, respectively. Based on these values, applying self-etch adhesives was observed to increase the SBS compared to etch-and-rinse adhesive systems.

In another research [31], the function of Ceram X (Dentsply/DeTrey as a nanohybrid composite) was clinically investigated. The material was assessed using one-step self-etch and two-step etch-and-rinse adhesives. According to the obtained results, the failure rate was 7.7% and 5.6% in the first and second treatment procedures, respectively.

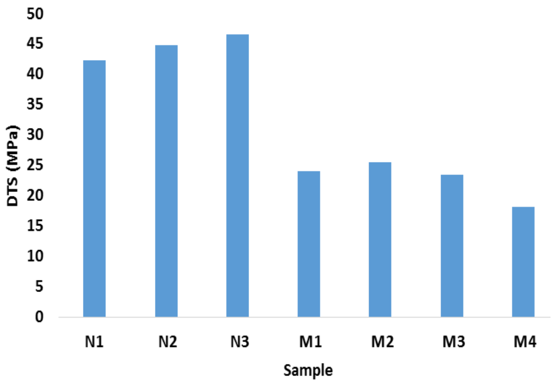

Fig 7. Mean diametral tensile strength of samples containing micro- and nano-sized materials [32]

Table 3. Investigation of Nano-based Materials in Terms of Shear Bond Strength

Group Number	Approach
1	NC+two-step self-etch adhesive (SE)
2	NC + etch-and-rinse adhesive (SB)
3	FNC + SE
4	FNC + SB
5	GI+ Ketac nano primer

Among other advantages of nano-based materials in restorative dentistry are more favorable abrasive wear and lower biodegradation compared to conventional materials. In a research in this regard [33], two nano-based materials (Ketac N100 as resin-modified GI and Filtek Z350) were compared with TPH Spectrum and Vitremer as conventional restorative materials.

The materials were also examined in terms of biofilm and abrasion due to tooth-brushing. According to the obtained results, Filtek Z350 had an optimal function, while Ketac N100 had poor function against the process of biodegradation [33].

Therefore, it could be concluded that the type of nanostructures has a significant impact on their behavior in the oral environment.

Similar to other properties, the wear resistance and flexural strength of nano-based composites depend on the type of the material and their structure. In a study in this regard, five types of composites (Table 4) were investigated in terms of flexural strength, flexural fatigue limit, volumetric loss, and maximum wear depth. The measured values of the mentioned factors in various composites are shown in Table 5. According to the findings, some types of nano-based composites had improved mechanical properties compared to the control group. In addition, the type of nanostructures was reported to have a significant effect on these properties. In addition to the type of nanostructures, their mass fraction in the composite is considered to be another influential factor in their mechanical properties. In this regard, Tian et al. [35] assessed the impact of the mass fraction of nano fibrillar silicate on the mechanical properties of a type of dental resin/composite. The base material was Bis-GMA/TEGDMA with (composite) without glass filler (resin).

According to the obtained results, the presence of the nano-material in the structure of the dental material resulted in the higher flexural strength of the resin-based material. Moreover, among the considered mass fractions, 2.5% and 7.5% mass fraction of the nanostructures were associated with the maximum flexural strength in the composite-based and resin-based materials, respectively.

The shrinkage of the conventional composites used in restorative dentistry is an issue that could be addressed by applying nanotechnology. In a

Table 4. Investigation of Composites in Terms of Wear Depth, Fatigue Limit, and Flexural Strength [34]

Group Number	Composite (manufacturer)	Type	Filler Loading (volume; %)
G1	Ceram+Mono (Dentsply deTrey GmbH)	Nanohybrid	57.0
G2	Filtek Supreme (3M Espe)	Nano-filled	57.7
G3	Grandio (Voco)	Nanohybrid	71.4
G4	Premise (Kerr USA)	Nanohybrid	69.0
G5 (control)	Heliomolar (Ivoclar vivadent)	Micro-filled	46.0

Table 5. Mean Values of Mechanical Properties in Various Nano-based Composites [34]

Group Number	Volumetric Loss (mm^3)	Maximum Wear Depth (μm)	Flexural Strength (MPa)	Flexural Fatigue Limit (MPa)
G1	1.628	235.19	98.0	43.6
G2	0.398	106.81	116.5	49.6
G3	0.900	147.39	120.9	52.6
G4	0.550	124.71	101.9	43.4
G5	0.593	128.19	91.9	52.7

Table 6. Composition of Composites Assessed in Terms of Shrinkage [36]

Series	Sample Number	SiO_2 (wt %)	ERL4221 (wt %)	GPS (wt %)	OPIA (wt %)	CQ (wt %)
Blank	LC-ERL4221	0	95.24	0	3.81	0.95
Micro	CUS40	37.27	59.74	0	2.39	0.60
Nano Z	Z30	27.79	68.77	0	2.75	0.69
Nano Z	Z40	37.27	59.74	0	2.39	0.60
Nano G	G30	27.19	66.75	2.72	2.67	0.67
Nano G	G40	35.79	57.74	3.58	2.30	0.58
Nano G	G50	43.96	49.18	4.40	1.97	0.49
Nano G	G60	55.64	36.94	5.56	1.48	0.37
Nano M	M40	39.69	53.65	3.96	2.15	0.54
Nano M	M50	49.34	43.54	4.93	1.74	0.44

research conducted by Chen et al. [36], various types of composites were examined in terms of shrinkage (Table 6).

The measurement of the properties of the nano-based and conventional composites indicated that utilizing nanotechnology could significantly decrease the thermal expansion coefficient in the samples (Table 7).

Table 7. Thermal Expansion Coefficient of Composites [36]

Material	Thermal Expansion Coefficient ($\frac{\mu m}{m}$ °C^{-1})
M50	56.0
G60	49.8
Commercial Methacrylate Composite	51.2
ERL4221 Epoxy Resin	123

In addition, it was observed that G60 shrinkage strain was approximately a quarter of the methacrylate-based composite.

Therefore, it could be concluded that utilizing nanostructures could effectively decrease the shrinkage of restorative materials.

Recommendations

Nanotechnology has remarkable potential to be used in dentistry in order to enhance the quality of treatment.The present study aimed to review the applications of nano-materials in restorative dentistry.

Employing nanostructures as restorative dental materials could result in the enhancement of mechanical properties.

However, further investigations are required to gain deeper insight into this branch of science. In the viewpoint of the author, the future efforts in this regard must encompass further aspects of the use of nanotechnology in restorative dentistry. Moreover, investigating the biocompatibility of nano-materials seems to be a key issue to be assessed in this regard.

In addition to the nano-materials that have been examine to date, other types of these materials should be synthesized, utilized, and evaluated.

Finally, the impact of the size of nanostructures has not been studied in the research in this regard. Considering that the size of nanostructures affects their properties, further investigations must consider this key factor.

Table 8. Summary of Reviewed Studies on Nanotechnology in Restorative Dentistry

Utilized Nanostructure	Application	Results
Nano-ceramic [37]	Restorative composites	96.8% acceptable treatment outcomes
Nanohybrid and nano-filled composites [34]	Resin composites	Mechanical properties of composites depended on type of nano-materials
Nano-filled composite [24]	Restorative composites	Higher mechanical strength and wear resistance of nano-sized material compared to RMGIC
Nano-porous silica [28]	Dental filler	Enhanced mechanical properties by applying nano-materials
Nanofibrillar silicate [35]	Restorative composite and resin	Enhanced flexural strength with addition of nanostructures
Nano-silica fillers [36]	Dental filler	Reduction in shrinkage by nano-sized materials
Nanohybrid composite resin [31]	Dental composite	No significant difference between use of self-etch and etch-and-rinse adhesives
Platinum nanoparticles [27]	Adhesive	Improved bond strength
Nanofliller (Filtek Z350) [33]	Dental filler	Acceptable resistance against abrasion and biofilm
Dental composites [32]	Restorative composites	Higher diametral tensile strength and flexural strength with use of nano-sized materials compared to micro-sized materials
Nanocomposites and nano-ionomer glass [30]	Restorative material	Higher shear bond strength with use of self-etch adhesive compared to etch-and-rinse adhesive
Nano-hydroxyapatite silica [38]	Glass Ionomer cement	Increased Vickers hardness, shear bond strength, flexural strength, and compressive strength with addition of nano-materials

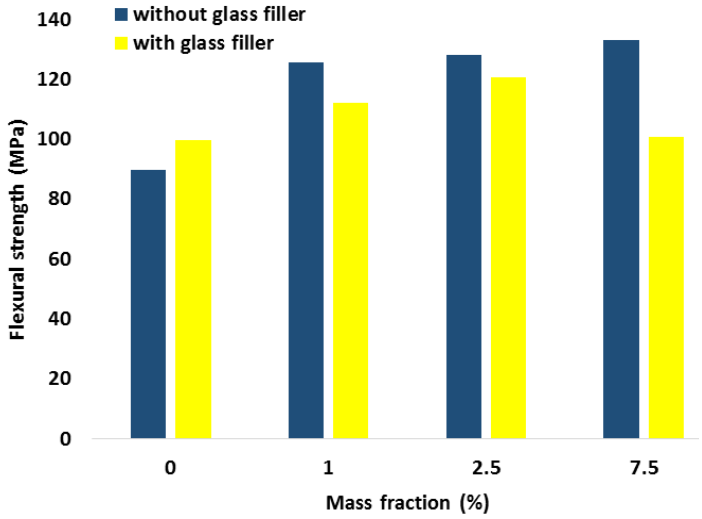

Fig 8. Flexural Strength and Mass Fraction of Nano-materials [35]

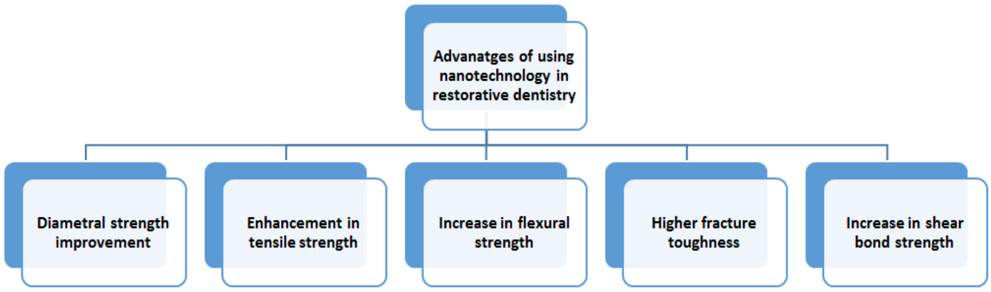

Fig 9. Main advantages of using nanotechnology in restorative materials

CONCLUSION

The quality of restorative dental treatment could improve remarkably with the use of nanotechnology. The current research aimed to review the applications of nanoscale materials in restorative dentistry. Based on the comprehensive literature review, the main concluding remarks are as follows.

The dispersion of nano-sized materials in restorative resin and composites could increase their flexural strength. The increment in the flexural strength of restorative materials depends on various parameters, including the type of nanostructures, their mass fraction, and the base material. In addition to flexural strength, the other mechanical properties of restorative materials (e.g., shear bond strength and wear resistance) could be modified by applying nanotechnology. The function of nano-based materials in restorative dentistry could be influenced by the utilization of other substances (e.g., adhesives).

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