

# NANOTECHNOLOGY IN PIT AND FISSURE SEALANTS: A SYSTEMATIC REVIEW

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## ABSTRACT

**Objectives:** To conduct a comprehensive analysis of the literature and offer an overview of the effects of various nanoparticles (NPs) in conjunction with pit and fissure sealants (PAFs).

**Materials and Methods:** Studies were chosen using an electronic search and evaluated based on key phrases, titles, and abstracts to see if they matched the inclusion criteria. The studies conducted between 2014-2022 were considered. Those articles which focused on the role of nanoparticles in dental sealants, published in English and had open access were studied. According to the research design, copies of all papers were gathered and analyzed for quality. Two databases (Pub Med and Google Scholar) were used.

**Results:** 78 references were obtained, out of which 20 publications were selected after eliminating duplicates and following the exclusion criteria. According to the investigations of this review, modified sealants may have antibacterial action as well as an impact on mechanical properties.

**Conclusion:** Antimicrobial efficiency can be attributed to pit and fissure sealants by incorporating nanomaterials, which might alter their mechanical and fundamental physiochemical properties as well.

**Key words:** Dental sealants, nanoparticles, antibacterial NPs, dental nanotechnology.

## INTRODUCTION

Caries is a multifactorial, dental infectious disease caused by microbes and is characterized by pathological alterations in a tooth's inorganic material and the destruction of its organic material<sup>1,2</sup>. It is the most prevalent oral condition worldwide<sup>3</sup>. It is therefore regarded as a public health concern, demanding the development of alternative therapies<sup>1</sup>. Usually, it starts with the accumulation of dental plaque on the surface of teeth due to frequent eating, consuming sugary drinks and not properly cleaning the teeth<sup>4,5</sup>. Due to the complex biofilm's ability to convert dietary sugar into acids, dental caries causes prolonged periods of low pH, which leads to a net mineral loss from the tooth. More than 700 bacte-

rial species can be found in the mouth<sup>6,7</sup>. Although Streptococcus Mutans is the most frequent bacteria associated with tooth decay, numerous lactobacilli are also linked to the development of this lesion<sup>8</sup>. When compared to other teeth, permanent molars are more prone to cavities because they have distinctive grooves on their chewing surfaces that both help with food grinding and provide hiding places for mouth germs and sticky food particles. Molars erupt between six and twelve years of age<sup>9,10</sup>. When examined, Mustafa Demirc et al., (2010) found that molars made up 45 percent of carious teeth. Susceptibility of dental caries of first and second maxillary molars are 11.5 & 1.7% respectively, whereas Lower incisors are least prone to caries formation. The maxillary jaw had more caries (62.4%) than the mandibular jaw (36.7%)<sup>11</sup>.

Since more than 60 years ago, dental sealants have been used to protect teeth from decay, and they are incredibly beneficial for youngsters who

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are exposed to high levels of dental decay<sup>12,13</sup>. They operate as a protective border to keep off bacteria and food debris from the teeth<sup>12,14</sup>. PAFs have several advantages, such as providing protective coating along with preventing plaque and food particles from building up in the difficult-to-reach areas of the oral cavity, but they also have one significant disadvantage, which would be secondary caries as a result of polymerization shrinkage<sup>15</sup>. Also, PAFs are inherently hydrophobic, they cannot be placed in moist settings, and they are prone to breaking under compressive or flexural loads, which has limited their clinical utilization. Pits & fissure sealants have been decorated with numerous fillers to alter their mechanical & antimicrobial properties to reconcile their flaws<sup>16</sup>.

Recently nanotechnology is a developed, most focused, and active research area, specifically in medical and dental health sciences<sup>17,18</sup>. NPs are solid particles, with a width of 1 to hundred nanometers which makes them extremely tiny in size. They have unique physicochemical characteristics and high chemical reactivity<sup>19</sup>. There are several applications of nanoparticles, which depend on factors such as concentration, charges, size, shape, etc. Reduced biofilm formation is the main objective of incorporating nanoparticles into dental materials thus increasing the antibacterial properties and might affect the mechanical characteristics as well. This can be accomplished by incorporating NPs into dental sealants, dental adhesives, denture soft liners, PM-MAs, collagen membranes, titanium implant fixtures, composite restorations, and orthodontic brackets<sup>20</sup>.

The most frequent clinical issues with sealants include impaired resistance to abrasion, lower compressive strength, and low tolerance under flexural forces. To produce a favorable environment that will prolong the longevity of the restoration, an ideal sealant carries enhanced mechanical and improved antimicrobial properties. To conclude whether the inclusion of these NPs in trace levels affect their qualities, the impacts of various nanoparticles added to standard fissure sealant will be studied in this study.

## MATERIALS AND METHODS

TA thorough and well-structured search of published articles was carried out. Studies were chosen using an electronic search and assessed based on keywords, titles, and abstracts to check if they matched

the inclusion criteria. The stated procedures were then followed shown in Figure 1. Copies of every manuscript were acquired, and their quality was assessed following the research design.

### Data sources:

Three reviewers conducted a systematic review using “PubMed and Google Scholar databases” from where available articles between 2014-2022 were obtained, with the help of Boolean descriptors and operators: “(Dentistry- Dental) AND (sealants), (Nanotechnology OR nanoparticle) ,anti-bact/anti-bact OR antimicro OR antibiofilm/anti-biofilm OR anti-micro OR antiinfect/anti-infect OR bactericidal/ bacteriostatic) OR (Sealants) & (mechanical properties)”. The screening was carried out by reading the abstracts of these articles. 20 articles were finally selected that fulfilled the eligibility criteria.

### Data extraction:

In the reviewed articles, the study quality, study groups, size of the sample, type of NPs, tests for anti-bacterial and mechanical properties, and conclusions were recorded.

### Quality Assessment:

Quality evaluation was done on the appropriateness of the size of the sample, effective control group, material uses as per producer directions, standardized specimen manufacturing methods, assessment of anti-bacterial effects, analysis of the mechanical characteristics, and sufficient statistical evaluation (i.e., st. deviation, mean, and p-values).

### Inclusion criteria:

Studies that evaluated pit & fissure sealants for their mechanical and anti-bacterial properties treated with NPs. All authentic publications which had open access.

### Exclusion criteria:

Studies lacking an appropriate control group were excluded. Those articles that were printed in languages other than English were excluded.

## RESULT

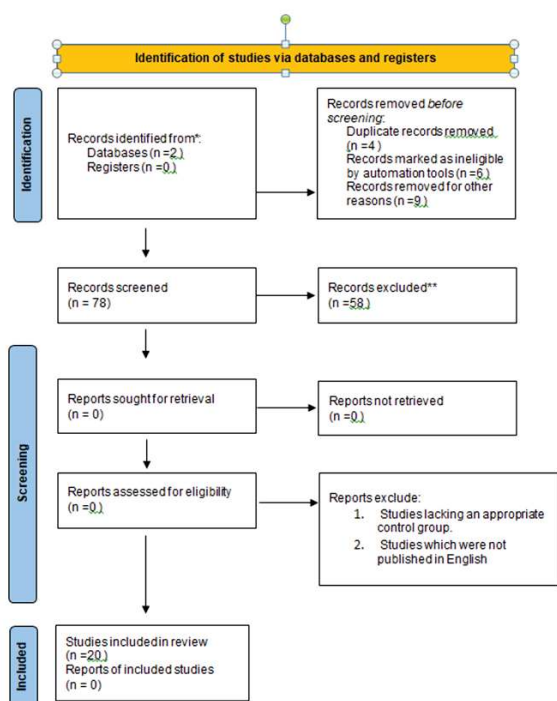
All 78 research articles initially identified were from the year 2014-2022. Following the thorough screening, only 20 studies were included. NPs may release more of their corresponding ions, resulting

**Table 1: Shows data tabulation according to author, year, title of the study, nanoparticles used in sealants, and outcomes.**

Author	Year	Title of the study	NPs used in sealant	Outcomes
Sara Tavassoli-Hojjati et al <sup>21</sup>	2014	Analysis of various tricalcium phosphate concentrations of nanoparticles on fissure sealants	Tricalcium Phosphate NPs	The possibility for remineralization improved without impacting mechanical qualities
Elisa Morales-Quiroga et al <sup>22</sup>	2014	Evaluation of marginal seal and microleakage of a sealant modified with silver nanoparticles	Silver NPs	There were no discernible changes between the standard sealant and the sealant incorporating silver nanoparticles in terms of the marginal seal or microleakage.
Rayia J. Al-Naimi et al <sup>23</sup>	2015	Effect of silver and zinc oxide nanoparticles on resin based pit and fissure sealants	Silver and zinc oxide NPs	Addition of Ag and ZnO NPs increased the micro-hardness for the fluoridated and non-fluoridated sealants, which made them more resistant to wear.
Koorosh Teymoornezhad et al <sup>24</sup>	2016	Evaluation of the micro shear bond strength of composites containing zinc oxide nanoparticles	Zinc oxide NPs	ZnO NPs incorporation up to 3 wt % did not impair shear bond strength, but it could be favorable in delivering anti-microbial outcomes with minimal micro-leakage.
Enid Karina Salas-López et al <sup>25</sup>	2017	Effects of Silver NPs-added pit and fissure sealant in the prevention of caries	Silver NPs	Reduced tooth demineralization
Rajabnia et al <sup>26</sup>	2017	The inhibitory effect of sealants containing chitosan NPs against streptococcus mutans	1%, 2%,3%, 4% and 5% Chitosan	Improved results with 2.5% CH, with the highest activity between the first and third month. The minimum inhibitory concentration was 2%.
Jun, Soo-Kyung et al <sup>27</sup>	2018	Effect of bioactive glass NPs on physical properties and bacterial adherence inhibition of pit and fissure sealant	Bioactive glass NPs	No significant effect on physical properties however, an antibacterial effect was observed.
Shivani Utneja et al <sup>28</sup>	2018	Evaluation of properties of pit and fissure sealants fortified with nano-hydroxyapatite and nano-amorphous Calcium Phosphate fillers	Nano-hydroxyapatite and nano-amorphous calcium phosphate fillers	Results suggested that admixture of nHAP and nACP to PFS showed remineralizing capability, without declining their mechanical and physical properties.
Kumar, Vyshiali Sivaram et al <sup>29</sup>	2018	Evaluation of shear bond strength of conventional and nanohydroxyapatite crystals incorporated pit and fissure sealants	Nanohydroxyapatite crystals	The shear bond strength of pit and fissure sealant containing NHAP crystals was higher.
Dara Lakshmi Swetha <sup>30</sup>	2019	Antibacterial and mechanical properties of pit and fissure sealants modified with Zinc Oxide and Calcium Fluoride NPs	Zinc oxide and Calcium Fluoride NPs	There was enhanced antimicrobial activity. The mechanical characteristics were still on par with those of traditional sealants.
Mahtab Mermarpour et al <sup>31</sup>	2019	Effect of hydroxyapatite NPs on enamel remineralization of fissure sealant	Hydroxyapatite NPs	May be regarded as a modest treatment to seal fissures and pits in demineralized enamel.
XiuzhiFei et al <sup>13</sup>	2020	Novel pit and fissure sealant containing nano-CaF <sub>2</sub> and dimethylaminohexadecyl methacrylate NPs	CaF <sub>2</sub> and dimethylaminohexadecyl methacrylate NPs	High fluoride release and strong antibacterial performance
Kritika et al <sup>32</sup>	2020	Effects of hydrophobic nano chitosan on resistance of dental sealants	Hydrophobic nano chitosan	Modified sealants' wear behavior was slightly better than that of unmodified sealants.

**Table 1: Shows data tabulation according to author, year, title of the study, nanoparticles used in sealants, and outcomes.**

Lee, Seong-Sook, et al <sup>33</sup>	2020	Changes in adhesion of Streptococcus mutans to pit and fissure sealant modified with cerium oxide NPs	Cerium oxide NPs	Antibacterial effect was observed
Sarah M. Khairy et al <sup>34</sup>	2020	Evaluation of microleakage of silver NPs added pit and fissure sealant	Silver NPs	Addition of silver nanoparticles to pit-and-fissure sealant did not affect its sealing ability
Hesaraki et al <sup>35</sup>	2020	Evaluation of the effect of SrF2, YSZ NPs, and ε-PL additives on the properties of resin-based pit and fissure sealants	5%, 10% and 20% SrF2; 5% and 10% YSZ; 0.5% ε-PL	SrF2 NPs and ε-PL showed good antimicrobial properties but caused mechanical weakening which was partly compensated by YSZ NPs.
H Zareian et al <sup>36</sup>	2021	Evaluation of antibacterial effects of dental sealants containing Chitosan NPs	Chitosan NPs	Reduced the colony counts of all the 3 types of bacteria tested.
N Aidaros et al <sup>37</sup>	2021	Effect of incorporating nano-pearl and nano-seashell Particles into fluoride-based pits and fissure sealant	Nano-Pearl and Nano-Seashell Particles	The enamel surface microhardness and mineral content were both dramatically enhanced.
BP Sarcev et al <sup>38</sup>	2021	Properties of flowable resin composites modified with low addition of hydrophilic and hydrophobic TiO2 NPs	Hydrophilic and Hydrophobic TiO2 NPs	The mechanical qualities could be improved more successfully using hydrophobic nanoparticles. Agglomeration was discovered to reduce mechanical characteristics at larger loadings of hydrophobic and hydrophilic nanoparticles.
Abdulaziz Abdullah Alkheraif et al <sup>39</sup>	2022	Minocycline incorporated cobalt oxide nanoparticles in dental sealants	Minocycline incorporated cobalt oxide NPs	The generation of S. sobrinus biofilms is significantly inhibited, although there are no changes in physical qualities.



**Fig 1: Depicts the flow chart of reviewed literature and selection criteria.**

in a more potent antibacterial effect, improved mechanical properties, and remineralization of teeth as shown in Table 1.

## DISCUSSION

### 1. Tricalcium Phosphate (TCP) NPs:

According to Tavassoli-Hojjati et al., Tricalcium phosphate NPs could be added to resin materials to effectively promote remineralization and inhibit demineralization of enamel. As these NPs have a larger propensity for diffusion into the demineralized layer therefore, they are being further investigated for their potential as re-mineralizing agents. Also, they are highly soluble at the critical PH of 3.5-4 and dissolve quickly as compared to hydroxyapatite compounds when surrounded by bodily tissues. TCP access into the subsurface layer is less than that of surface enamel layer; as a result, the interference effect of TCP is primarily restricted to the surface layers. When applied to teeth with superficial enamel demineralization or microleakage, fissure sealants containing -TCP nanoparticles could prove to be effective in

caries prevention and might also strengthen the resistance of surface enamel to demineralization<sup>21</sup>.

## 2. Silver (Ag) NPs:

Morales-Quiroga et al., evaluated the marginal seal and microleakage of a sealant modified with silver nanoparticles. When compared to the control group, adding Ag NPs to sealants did not affect the marginal seal. QDs were used to determine marginal sealing. The circumference of the tooth's occlusal surface was measured and the areas which reflected greater fluorescence demonstrated greater loss of marginal sealing. Additionally, QD microleakage was assessed. Although methylene blue could enter cracks but QDs were used in these tests because nanoparticles can diffuse to the deepest section of the fissure while methylene blue cannot. Moreover, occlusal surfaces' morphology provides an ecological niche for the growth and development of caries-causing bacteria, and it becomes challenging to clean food debris from surfaces near dental fissures and pits. Between conventional sealants and those containing Ag NPs, no appreciable variations in terms of marginal seal or microleakage were found. So, the adhesion or resistance of the sealant were not affected by the addition of Ag NPs<sup>22</sup>. Also, in another study performed by Sarah M. Khairy et al., addition of silver NPs to dental sealants did not affect its sealing ability which could be attributed to thermocycling that was employed to assess ageing in in-vitro settings. Thermal alterations controlled in a lab setting were used to mimic the oral environment and the natural ageing process. During the contact between the resin and the tooth structure, recurrent contraction and expansion strains were produced in thermocycling which is explained by the resin material's stronger coefficient of contraction-expansion than the tooth structure, that might cause cracks to spread along the resin-tooth structure interface. Also, sealant modified with silver NPs showed microleakage in only 40% of the specimens while it occurred in 60% of the conventional Clinpro<sup>TM</sup> sealant. These findings may be explained by the fact that Ag NPs, when added to particular polymers, may increase the heat stability of the resulting nano-polymer. Another possible limitation would be that extracted teeth do not have the pulp pressure and intratubular fluid pressure as in natural teeth. This could have an impact on tooth moisture level, affecting microleakage at tooth restoration interface<sup>34</sup>. While in another study,

the addition of silver NPs in sealants reduced tooth demineralization significantly. The results of the current study showed that the group lacking Ag NPs had much more decalcification, which indicated a higher chance of developing dental caries, whereas the Ag NPs containing group most likely had more remineralization. Furthermore, compared to the typical sealant, higher rates of detachment and microleakage were not observed. There were no variations in color either. By enrolling both control and experimental teeth from the same patients, this study was able to control variables that might have had an impact on sealant retention and caries prevention<sup>25</sup>.

## 3. Silver and Zinc NPs:

In the experiment carried out by Al-Naimi, the non-fluoridated sealant when compared with the fluoridated sealant, displayed higher microhardness values initially. This could be explained by the fact that the fluoridated sealant's filler particle content, according to the manufacturer, was not greater than 7%, including the fluoride particles that were incorporated into it. However, the non-fluoridated sealant's filler particle content was not noted in the sealant pamphlet. By incorporating fillers into both types of the resin-based sealants, an improvement of the hardness values was observed. Fissure sealants containing silver NPs were found to have the highest hardness values, followed by sealants mixed with zinc oxide. This may be due to the fact that metals are harder than metal oxides even at lower concentrations, and incorporation of 3% w/w silver nanoparticles and 7% w/w zinc oxide nanoparticles increased the microhardness of both sealants<sup>23</sup>.

## 4. Zinc oxide (ZnO) NPs:

In the study conducted by Teymoornezhad et al., The micro shear bond strength of the clearfill resin composite was decreased when 3% ZnO particles were added. While in the case of Z-350, the bond strength was increased slightly. The change in strength might be due to the different composition of each of the composites. In the Z-350 groups, the ZnO particle concentration decreased the likelihood of microleakage, but no appreciable change was seen in the clearfill group. Since each specimen's enamel structure is unique, the potential structural flaws of some of the specimens could account for the variance in the results of the microleakage test<sup>24</sup>.

### 5. Chitosan:

The antibacterial effect of chitosan NPs against *S. mutans*, *S. sanguis* and *L. acidophilus* was evaluated by Houtan Zareian et al., The overall findings demonstrated that adding 1% chitosan NPs to the fissure sealant showed antibacterial characteristics. This could be due to chitosan being a biopolymer which is made from the shells of other crustaceans and prawns and having a positive charge that causes it to adhere to the bacterial cell wall or where it can exert its bactericidal effect<sup>36</sup>. According to another study, hydrophobic chitosan NPs improved the wear resistance of dental sealants. The reason for this could be that the NPs' structural feature might have given a scaffold-like architecture, which had improved the mechanical properties of the sealants<sup>32</sup>.

### 6. Bioactive glass NPs:

When BG NPs were incorporated in non-fluoridated pit and fissure sealant, physical and antibacterial characteristics were observed. There was no significant effect on physical properties, however, an antibacterial effect was noticed which was attributed to increase of pH and osmolarity in the surrounding environment<sup>27</sup>.

### 7. Nano-hydroxyapatite (nHAP) and nano-amorphous calcium phosphate (nACP) NPs:

Hydroxyapatite (HAP) fillers were shown to offer the potential for stress-bearing restorations due to their superior mechanical qualities and strong bioactivity. ACP-filled nanocomposites showed a significant degree of Ca and PO<sub>4</sub> release at a cariogenic pH4, which would be most required to prevent caries. Additionally, they had elastic modulus and flexural strength that were on par with or better than those of a commercial load-bearing composite. Due to these biologic characteristics of nHAP and nACP, it was desirable to add them to dental sealants. The study conducted by Shivani Utneja et al., suggested that admixture of nHAP and nACP to PFS showed remineralizing capability, without declining their mechanical and physical properties<sup>28</sup>. Also in another study by Mahtab Memarpour et al., The use of nano-HA admixed in fissure sealant might be an effective method to enhance remineralization in enamel. Gaps or voids appear on the surface of the tooth because of the demineralization of the enamel and

the loss of minerals like calcium and phosphorus. On the enamel surface, the acid etch method also leaves microporosities. Both procedures create areas that make it easier for resin to infiltrate and for the resin and tooth to bond properly. When using nano-HA solution, calcium and phosphorus ions enter the porous enamel and provide remineralization seeds<sup>31</sup>.

### 8. Zinc oxide (ZnO) and Calcium Fluoride (CaF<sub>2</sub>) NPs:

In concentrations (0.5 wt% and 1 wt%), ZnO, CaF<sub>2</sub> NPs, and their combination showed better antibacterial activity against *S. mutans* and *L. acidophilus*. The production of active oxygen species like H<sub>2</sub>O<sub>2</sub> that prevent bacterial growth by internalization into the bacterial cell membrane and causing destruction of cellular components like lipids, DNA, and proteins could explain ZnO NPs' antimicrobial behavior. Another reason might be that zinc ions interfere with bacterial enzyme systems by displacing magnesium ions, which are necessary for the enzymatic activity of dental plaque. The primary cause of the antibacterial action of CaF<sub>2</sub> NPs might be their fluoride-releasing ability. Many enzymes are inhibited by these fluoride ions, either directly or by the formation of metal complexes. Enolases in *S. mutans* and other glycolytic enzymes can be inhibited by the hydrogen fluoride molecule, which is created when fluoride ions combine with hydrogen ions<sup>30</sup>.

### 9. Calcium Fluoride (CaF<sub>2</sub>) and dimethyl-aminohexadecyl methacrylate (DMAHDM) NPs:

nCaF<sub>2</sub> and DMAHDM were used in the study done by XiuzhiFei et al., to create a new nano-structured, bioactive pit and fissure sealer. Due to nCaF's small particle size and large surface area, the new sealant released fluoride more readily than commercially available fluoride releasing sealant. In addition, the new sealant had stronger antibacterial properties than the commercial sealant. DMAHDM inhibited the early attachment of *S. mutans* and had a "contact-killing" effect on the bacteria, which may have affected further development of the biofilm<sup>13</sup>.

### 10. Cerium oxide (CeO<sub>2</sub>) NPs:

Cerium oxide NPs particularly in the concentration of 1% and 2%, in pit and fissure sealants have shown an antimicrobial effect which could be due to its small particle size while no difference was seen in

the surface roughness of both the CeO<sub>2</sub> NPs modified sealant and the commercial sealant<sup>33</sup>.

#### 11. SrF<sub>2</sub>, YSZ NPs, and ε-PL fillers:

Modified sealants showed good antibacterial activity owing to the synergistic effect between SrF<sub>2</sub>, and ε-PL fillers. Metal fluoride nanoparticles, such as SrF<sub>2</sub>, have demonstrated a significant antibacterial impact against oral microorganisms because they can delay the onset of secondary caries and prevent decay due to their sustained fluoride release. Although the exact mechanism for ε-PL's antibacterial activity is not entirely understood. Scientific literature indicates that the ε-PL's absorption on the cell's outer wall plays a significant part in its antibacterial action. The addition of SrF<sub>2</sub> and ε-PL resulted in a mechanical weakening of the sealants because the chance for agglomeration increases as the amount of NPs increases (10 to 20 wt% ) due to their high surface activity and as the load-bearing NPs are distributed unevenly throughout the polymer matrix, the sealant is unable to endure the high applied forces as a result of uneven force distribution but this was partially offset by the addition of YSZ nanoparticles (up to 10 wt%). The key elements for the increased strength of the YSZ-containing sealants are the high inherent strength of the YSZ nanoparticles and their excellent dispersion throughout the polymer matrix.

#### 12. Nano-Pearl and Nano-Seashell particles:

Nano-pearl and nano-seashell particles incorporated into fluoride-based pits and fissure sealant resulted in improvement of enamel microhardness and the mineral content was enhanced through the massive Calcium and Phosphate ions release. Ca ions were found to be substantially more abundant in nano-pearl pit and fissure sealant groups than in nano-seashell groups. This might have occurred because CaCO<sub>3</sub> is a pH-sensitive substance. The transfer of the reactant to the surface (surface reaction) caused the dissolution of calcite in the acidic solution with pH values below 2.9. This might be the cause of the considerably greater leaching out of Ca ions from calcite crystals than aragonite<sup>37</sup>.

#### 13. TiO<sub>2</sub> NPs:

The Mechanical properties of sealants modified with TiO<sub>2</sub> are highly dependent on the type and loading amount. Hydrophobic NPs proved to be more effective in improving the mechanical properties of

flowable composite material. At higher loadings of hydrophobic and hydrophilic NPs, agglomeration was found to degrade mechanical properties. The reason for this might be that agglomerates possess little strength because of the presence of relatively weak secondary bonds between individual NPs, their behavior under load might further lead to reduction in the mechanical properties of the nanocomposite. After the agglomerate fractures, the stress is shifted to the matrix, whilst the crack propagates to the nearby NPs. Subsequently, the stress in the agglomerates suddenly increases, causing matrix overload and premature failure<sup>38</sup>.

#### 14. Minocycline (MNC) incorporated cobalt oxide NPs:

Pit and fissure sealant modified with 2.5% minocycline and cobalt oxide NPs released MNC over an extended period at various pH levels (7.4, 5.0, and 3.5) and effectively prevented the growth of *S. sobrinus* biofilms while maintaining the PFS's physical properties. The use of three different pH levels served to simulate various oral conditions. For example, pH 7.4 represented saliva under physiologically normal conditions, pH 5.0 represented the initial demineralization of enamel caused by endotoxins produced by cariogenic bacteria (primarily *S. sobrinus*), and pH 3.5 represented an increased number of cariogenic bacteria leading to advanced lesion. However, adding MNC only to resin-based materials led to voids forming because of MNC aggregates which dissolve in the resin, resulting in decrease mechanical qualities. Therefore, an appropriate delivery approach was created to maintain the mechanical qualities of the restorative materials while retaining the antibacterial capacity of MNC for long-term prevention of carious lesion<sup>40</sup>.

### CONCLUSION

The findings of this systematic review show that most of the various nanoparticles which were integrated with sealants exhibited excellent antibacterial effects as displayed in table 1. They may also enhance, deteriorate or not alter the mechanical characteristics of a sealant at all as evident by the studies mentioned in table 1. The specific mechanisms responsible for causing improvement or changes in the properties are still unknown, so more research is needed to determine this aspect.

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