RESEARCH ARTICLE

The effect of silver nanoparticles incorporation in the self-etch adhesive system on its antibacterial activity and degree of conversion: an in-vitro study [version 1; peer review: 1 approved, 1 not approved]

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Abstract

Introduction: Despite of the recent advances in the adhesive dentistry, high possibility of microbial biofilm development at the resin restoration surfaces may lead to marginal gaps and recurrent caries. Degree of conversion of the dental adhesive represents a relative assessment to its quality, and a direct correlation with its mechanical behavior. This in vitro study was carried out to investigate the minimum inhibitory concentration of antimicrobial silver nanoparticles incorporated in two forms into the self-etch adhesive system and the effect of their incorporation on the degree of conversion of the self-etch adhesive.

Methods: Minimum Inhibitory Concentration of the self-etch adhesive system incorporated with nanosilver powder and solution against Streptococcus mutans was tested using an agar diffusion test. The effect of nanosilver incorporation (powder and ethanol-based solution) in the self-etch adhesive system on its degree of conversion was assessed using Attenuated Total Reflectance/ Fourier Transform Infra-Red spectrometer (ATR/ FTIR).

Results: The results showed that silver nanoparticles incorporation (powder or ethanol based at 12.5 µg/ml concentration) significantly increased the antibacterial efficacy of the self-etch adhesive against Streptococcus mutans (P< 0.05). Nanosilver powder possessed higher significant antibacterial effect when compared to silver ethanol based solution (P< 0.05). Degree of conversion of self-etch adhesive containing nanosilver powder showed non-significant difference from the control group (p > 0.05). In contrast, self-etch adhesive with nanosilver solution recorded significantly lower values when compared to the control or nanosilver powder group (P< 0.05).

Conclusion: The antibacterial efficacy of the adhesive system can be greatly potentiated with the addition of silver nanoparticles (12µg/mL.
concentration) especially the nanosilver powder. Incorporation of the antibacterial nanosilver powder in the adhesive system didn't compromise the degree of conversion of the adhesive resin.

**Keywords**
Silver nanoparticles, Antibacterial, Self-etch adhesive, Streptococcus mutans, Minimum inhibitory concentration, Degree of conversion.

This article is included in the Nanoscience & Nanotechnology gateway.
Introduction
Dental resin composite is a widely used restorative material that has superior aesthetic properties and strong bonding ability to the tooth structure in comparison to other restorative materials like amalgam. In spite of the recent advances in the dental adhesives, there is a high possibility of microbial biofilm development at the resin restoration surface, which may lead to marginal gap and recurrent caries.

Silver is an antimicrobial agent that has broad spectrum activity against gram positive and gram negative bacteria. Nanoparticles are insoluble particles smaller than 100 nm. Their unique size provides higher surface area, thus much more potent antimicrobial activity in comparison to the usual particles size. Silver nanoparticles can cause cell membrane disruption and damage of the bacterial DNA. Degree of conversion of the dental adhesive represents a relative assessment to its quality and directly correlates with its mechanical behavior. Proper polymerization of the dental adhesive can increase the longevity of the bonded restoration. Therefore, it seems valuable to investigate the minimum inhibitory concentration of silver nanoparticles incorporated in two forms into the self-etch adhesive system and their effect on the degree of conversion.

Methods
The materials, preparations, manufacturers, composition and batch numbers are listed in Table 1.

Incorporation of silver nanoparticles into the self-etch adhesive system
1 ml of ethanolic solution of silver nanoparticles was added to 5 ml of self-etch adhesive system and serially diluted. To produce the adhesive system with the nano-silver powder incorporated, it was accurately weighed first using a scale (AE Adam, October City, Egypt). The previously measured powder (1000 µg) was added to 1 ml of adhesive solution, sonicated in an ultrasonic mixer (Eumax model: UD100SH-3LQ, China) and directly correlates with its mechanical behavior. Proper polymerization of the dental adhesive can increase the longevity of the bonded restoration. Therefore, it seems valuable to investigate the minimum inhibitory concentration of silver nanoparticles incorporated in two forms into the self-etch adhesive system and their effect on the degree of conversion.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specifications</th>
<th>Composition</th>
<th>Manufacturer</th>
<th>Batch number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal Bond</td>
<td>One-step, Self-etch adhesive system (Ethanol based)</td>
<td>Phosphorylated Meth-acryloyloxydecyl phosphate (MDP)- 2-Hydroxyethyl methacrylate HEMA - Ethanol Photoinitiators-Silane Nanofillers (10% by weight 5 nm spherical silica particles)</td>
<td>3M ESPE, St. Paul MN, USA.</td>
<td>19970303</td>
</tr>
<tr>
<td>Silver Nanoparticles Solution</td>
<td>Nanosilver in ethanolic solution (Antibacterial agent)</td>
<td>10 ml ethanolic solution of Polyvinyl pyrrolidone + 0.2 ml Silver nitrate powder.</td>
<td>Nanotech Company, 6th October City, Egypt</td>
<td></td>
</tr>
<tr>
<td>Silver Nanoparticles powder</td>
<td>Nanosilver powder form (Antibacterial agent)</td>
<td>25 ml Silver nitrate+ Sodium Hypoboride+ Polyvinyl pyrrolidone.</td>
<td>Nanostream Company, 6th October City, Egypt</td>
<td></td>
</tr>
<tr>
<td>Tryptic Soy Agar Medium</td>
<td>Culture Media for <em>Streptococcus mutans</em> (ATCC 25175)</td>
<td>15 gm Tryptone + 15 gm agar+ 5gm Soytone + 5gm Sodium Chloride.</td>
<td>Becton and Dickinson (BD) Company</td>
<td>236950</td>
</tr>
</tbody>
</table>

Determination of minimum inhibitory concentration (MIC) of self-etch adhesive system with and without nano-silver incorporation
The minimum inhibitory concentration (MIC) defined as the lowest concentration of nanosilver in micrograms per milliliter (µg/ml) that inhibits the growth of an organism. Tryptic soy agar medium; culture nutrient media for *Streptococcus mutans* (ATCC 25175) was poured in 10 petridish plates in a laminar flow (Telstar BIO- II-A, VWR Company, UK.). *Streptococcus mutans strains; ATCC 25175* (Cairo MIRCEN, Faculty of agriculture, Ain Shams University, Egypt.) were cultured on Tryptic soy agar medium at 37°C for 24 hours.

10 petridish plates were punched with a cork-borer with a 6 mm diameter to produce rounded holes in each plate and the bacterial strain was applied equally on the agar plates. The specimens were grouped as $N_i$: Self-etch adhesive system + nanosilver solution and $N_j$: Self-etch adhesive system+ nanosilver powder. Each agar plate contained 5 holes representing the different concentrations of the nanosilver. For $N_i$ and $N_j$ groups; the self-etch adhesive system was serially diluted to produce 5 subgroups with different concentrations. $C_1$: 100 µg/ml, $C_2$: 50 µg/ml, $C_3$: 25 µg/ml, $C_4$: 12.5 µg/ml and $C_5$: 6.25 µg/ml. The minimum inhibitory concentration (MIC) defined as the lowest concentration of nanosilver in micrograms per milliliter (µg/ml). Tryp- tic soy agar medium; culture nutrient media for *Streptococcus mutans* (ATCC 25175) was poured in 10 petridish plates in a laminar flow (Telstar BIO- II-A, VWR Company, UK.). *Streptococcus mutans strains; ATCC 25175* (Cairo MIRCEN, Faculty of agriculture, Ain Shams University, Egypt.) were cultured on Tryptic soy agar medium at 37°C for 24 hours.

200 µl of the adhesive agent was injected in each hole by micropipette and polymerized for 20 seconds using light emitting diode unit (Woodpecker Medical Instrument Company, Model LED. F; Model No. L14A0116F, China.) (Figure 1). The plates were incubated for 48 hours in the incubator at 37°C under completely anaerobic conditions (Shell lab Company, SM16, Canada). The diameter of bacterial inhibition zone halo of each adhesive was measured in millimeters using a ruler.
Degree of conversion measurement of the self-etch adhesive system with and without nanosilver incorporation

The specimens were prepared using a cylindrical Teflon mold surrounded by metallic ring (3mm diameter and 2mm height) (Figure 2). The mold was placed on a Mylar strip (Universal strips of acetate foil, Germany) that was placed on a clean flat glass slab. 200 µl of self-etch adhesive resin was injected in the hole of the mold using a micropipette then covered with the Mylar strip (to avoid the presence of oxygen inhibiting layer and pressed to obtain a uniform smooth specimen surface). The adhesive resin was cured in the presence of the top Mylar strip by LED device for 20 seconds according to manufacturer instructions. The light curing tip was applied perpendicular and with intimate contact with the top surface of the Mylar strip (Zero distance).

15 disc shaped specimens were prepared of self-etch adhesive system. The specimens were divided into 3 equal groups (n=5) according to the form of incorporated nanosilver ($N_0$: Adhesive system without nanosilver, $N_1$: Adhesive system+ nanosilver solution, $N_2$: Adhesive system+ nanosilver powder). The concentration of the incorporated nanosilver was set according to the minimum inhibitory concentration (MIC) that was tested before.

Degree of conversion was measured using an Attenuated Total Reflectance/ Fourier Transform Infra-Red spectrometer (ATR/FTIR) (Vertex 70, Bruker Company, Germany). All the data were recorded and plotted on a special computer software (OPUS Bruker Spectroscopy Software, version 7, Germany) to draw the linear graphs from which the degree of conversion of each specimen was calculated.

Data statistically was described in terms of mean values and standard deviation (SD) using ANOVA test (IBM® SPSS® (SPSS Inc., IBM Corporation, NY, USA, Statistics Version 22 for Windows)).

Results

Agar Diffusion test

Mean ± SD measures of the diameter of inhibition zone (DIZ) were summarized in Table 2 and Table 3 and graphically drawn in Figure 3 (underlying data available from OSF[1]). The largest zone of inhibition was at 100 µg/ml concentration of nanosilver powder while the smallest was at 6.25µg/ml concentration of nanosilver solution.

Table 2. Mean and standard deviation (SD) for diameter of inhibition zone (DIZ) (mm) of self-etch adhesive as a function of nanoparticles incorporation at different concentrations.

<table>
<thead>
<tr>
<th>Concentration of nanosilver in adhesive system</th>
<th>Nanosilver solution ($N_1$)</th>
<th>Nanosilver Powder ($N_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$: 100 µg/ml</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>20.00 ± 1</td>
<td>22.00 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>$C_2$: 50 µg/ml</td>
<td>15.20 ± 0.84</td>
<td>18.80 ± 0.45</td>
</tr>
<tr>
<td>$C_3$: 25 µg/ml</td>
<td>14.80 ± 0.45</td>
<td>17.20 ± 0.84</td>
</tr>
<tr>
<td>$C_4$: 12.5 µg/ml</td>
<td>13.80 ± 0.45</td>
<td>15.60 ± 0.55</td>
</tr>
<tr>
<td>$C_5$: 6.25 µg/ml</td>
<td>10.40 ± 0.55</td>
<td>12.00 ± 0.55</td>
</tr>
<tr>
<td>Control ($N_0$): 0 µg/ml</td>
<td>11.60 ± 1.35</td>
<td>11.60 ± 1.35</td>
</tr>
</tbody>
</table>

* P value ≤0.001

Table 3. Comparison of diameter of inhibition zone (DIZ) values in mm (Mean ± SD) as a function of nanosilver incorporation in two different forms in the adhesive system at different concentrations.

<table>
<thead>
<tr>
<th>Concentration of nanosilver in adhesive system</th>
<th>Nanosilver solution ($N_1$)</th>
<th>Nanosilver Powder ($N_2$)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$: 100 µg/ml</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>0.006*</td>
</tr>
<tr>
<td>20.00 ± 1</td>
<td>22.00 ± 0.7</td>
<td>≤0.001*</td>
<td></td>
</tr>
<tr>
<td>$C_2$: 50 µg/ml</td>
<td>15.20 ± 0.84</td>
<td>18.80 ± 0.45</td>
<td>≤0.001*</td>
</tr>
<tr>
<td>$C_3$: 25 µg/ml</td>
<td>14.80 ± 0.45</td>
<td>17.20 ± 0.84</td>
<td>≤0.001*</td>
</tr>
<tr>
<td>$C_4$: 12.5 µg/ml</td>
<td>13.80 ± 0.45</td>
<td>15.60 ± 0.55</td>
<td>≤0.001*</td>
</tr>
<tr>
<td>$C_5$: 6.25 µg/ml</td>
<td>10.40 ± 0.55</td>
<td>12.00 ± 0.55</td>
<td>0.006*</td>
</tr>
</tbody>
</table>

* NS; non-significant (p>0.05), *; significant (p<0.05).
All the concentrations recorded significantly higher DIZ when compared to the control group ($P \leq 0.05$) except $C_5; 6.25 \mu g/ml$. The MIC of adhesive containing nanosilver (powder and solution form) was determined at 12.5 µg/ml concentration. All the concentrations of nanosilver powder recorded significantly higher mean values of DIZ when compared to the different concentrations of nanosilver solution.

**Degree of conversion results**

(Mean ± SD) measures of degree of conversion in % were summarized in Table 4 and graphically presented in Figure 4. Groups of adhesive system with incorporated nanosilver solution ($26.14 \pm 4.47 \%$) recorded a statistically significant lower degree of conversion when compared to control ($50.31 \pm 4.04 \%$) and nanosilver powder ($47.72 \pm 4.47 \%$) ($P \leq 0.001$). There was no significant difference in the degree of conversion between the control group and the group of the adhesive system containing nanosilver powder ($p \geq 0.05$).

**Discussion**

Self-etch adhesives exhibit limited antibacterial activity against *Streptococcus mutans* due to the presence of a low molecular weight monomer that possesses bacteriostatic action against *Streptococcus mutans*.

The MIC for adhesive containing nanosilver in ethanol solution and powder was 12.5 µg/ml concentration which was significantly different when compared to the control group ($P \leq 0.05$). These results confirmed the potential antibacterial effect of low concentrations of nanosilver. Adhesive resin with nanosilver powder at different concentrations showed significantly higher inhibition rates than that with nanosilver/ethanol dispersion.

The higher significant efficiency of nanosilver powder may be attributed to the presence of the ethanol as a dispersion medium for nanosilver solution that can act as a diluting agent of the adhesive system. That was observed at concentration 6.25 mg/ml in nanosilver solution as it showed lower significant value than the control group despite the presence of silver nanoparticles.

The nanosilver powder group recorded a statistically non-significant difference in the degree of conversion when compared to the control group. Presence of nanofillers in the adhesive system had no harmful effect on the degree of conversion.

Besides reducing the amount of residual monomer, the nanoparticles size is less than the wavelength of the blue light of the curing units that allow the passage of the light without scattering; thus doesn’t affect the degree of conversion and the depth of cure of the adhesive system.

![Figure 3. Bar chart showing the mean values of diameter of inhibition zone (DIZ) (mm) of self-etch adhesive as a function of nanoparticles incorporation in different forms and concentrations.](image-url)

**Table 4.** Mean and SD for the degree of conversion (%) of self-etch adhesive as a function of nanoparticles incorporation.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
<th>Rank</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nano-particles incorporation in the adhesive system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control ($N_0$)</td>
<td>50.31 ± 4.04</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Nanosilver Solution ($N_1$)</td>
<td>26.14 ± 4.16</td>
<td>B</td>
<td>≤ 0.001*</td>
</tr>
<tr>
<td>Nanosilver Powder ($N_2$)</td>
<td>47.72 ± 4.47</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

Means with the same letter within each row are not significantly different at $p=0.05$. *NS= Non-significant, *Significant
Groups of adhesive system with incorporated nanosilver solution recorded statistically significant lower degree of conversion when compared to the control and nanosilver powder ($p \leq 0.05$). Presence of excessive amount of ethanol (Over 10% of the neat resin blend) lead to dilution of the adhesive resin, (decrease the percent of polymerized resin). Moreover it can cause physical separation of some reactive components of the adhesive resin with subsequent reduction of the degree of conversion. Previous research has attributed the negative effect of excess ethanol on the degree of conversion to its cooling effect (polymerization reaction is exothermic and the liberated heat increase the rate of conversion). Ethanol can absorb the liberated heat thus decrease the rate of polymerization and the degree of conversion of the adhesive.

There were no recorded studies evaluated the effect of nanosilver (powder form or ethanol based solution) incorporation in the self-etch adhesive system on the degree of conversion.

**Conclusion**

The antibacterial efficacy of the adhesive system can be greatly potentiated with the addition of silver nanoparticles (12µg/mL concentration) especially the nanosilver powder. Incorporation of the antibacterial nanosilver powder in the adhesive system didn’t compromise the degree of conversion of the adhesive resin.

Further investigation is required for assessing the mechanical behavior and chemical reactions of adhesive systems containing silver nanoparticles in short and long-term. It is also recommended to evaluate the antibacterial activity of adhesive system containing silver nanoparticles against dental plaque biofilm rather than single bacterial species.

**Data availability**

**Underlying data**

Open Science Framework: The effect of silver nanoparticles incorporation in the self-etch adhesive system on its antibacterial activity and degree of conversion: an In-vitro Study. [https://doi.org/10.17605/OSF.IO/RS4D2](https://doi.org/10.17605/OSF.IO/RS4D2)

This project contains the following underlying data:
- Raw Data DC note pads (folder containing out files from ATR/FTIR)
- raw Data final DC.docx (ATR/FTIR data with explanation of analysis pipeline)
- results heba fathy.docx (inhibition zone measurements)

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

**Grant information**

The author(s) declared that no grants were involved in supporting this work.
References


Open Peer Review

Current Peer Review Status: ✅ ❌

Version 1

Reviewer Report 10 August 2020

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Sashidhar Rao Beedu
Department of Biochemistry, Osmania University, Hyderabad, Telangana, India

This manuscript details application of nano silver incorporation into a self-etch dental adhesive system. The antibacterial efficacy of the adhesive system was tested, in vitro. Even though the experimental approach seems to be fine, the experimental design and technical details appear to be poor. This manuscript requires additional details and clarification as detailed below:

Comments:
1. What is the source of nanosilver powder? If silver nitrate is used, then the calculation needs to be based on elemental Ag.

2. If AgNPs are insoluble, then how can you get solution? It may form an emulsion or suspended particles only.

3. What is the wavelength (λ) of LED?

4. Table 1: Silver Nitrate powder is not nano silver. The valency of nano silver is ‘zero’. If you have nano-silver powder, why are you reducing it again by sodium borohydride?

5. The authors should provide an additional representative figure showing the zone of inhibition (ZOI), in addition to table 2. Delete fig. 1.

6. The authors need to check the silver nitrate ions as additional control in the agar – antimicrobial assay.

7. If the adhesive solidifies along with nano-silver, then how does it diffuse in agar medium?

8. What happens beyond 6.25µg/ml concentration of silver nano? What is the rationale to consider 10 mm ZOI as cut-off? It is appropriate to establish the IC₅₀ value for the nano metal.
Recommendation: the manuscript is not acceptable in the present form.

Is the work clearly and accurately presented and does it cite the current literature?  
No

Is the study design appropriate and is the work technically sound?  
No

Are sufficient details of methods and analysis provided to allow replication by others?  
No

If applicable, is the statistical analysis and its interpretation appropriate?  
Partly

Are all the source data underlying the results available to ensure full reproducibility?  
No

Are the conclusions drawn adequately supported by the results?  
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Nanotechnology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 03 August 2020
https://doi.org/10.5256/f1000research.19339.r67096

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Arivalagan Pugazhendhi
Innovative Green Product Synthesis, Ton Duc Thang University, Ho Chi Minh City, Vietnam

- The manuscript reports the effect of silver nanoparticles incorporation in the self-etch adhesive system on its antibacterial activity and degree of conversion: an in-vitro study. Overall the experiments are performed well and also the manuscript was well written, I recommend this research manuscript is appropriate to be indexed with minor revision mentioned below.

- Avoid using words such as we, he, she, them, their, etc.
- Language is good, but, proof reading by a native speaker would avoid the minor errors.

- Please concrete the keywords and make it formally and academically.

- Regarding the Introduction section, to make the reading more clear and smooth, it should be organized according to the following items: i) present state of the art; ii) literature review; iii) motivation and objective of the study proposed; iv) innovative contribution in terms of methodology developed.

- The authors are suggested to read the following articles and cite them in the appropriate places. The introduction must be revised to enhance readability i.e. I would also like to see following references in the revised version:
  1. Shanmuganathan et al. (2019\(^1\)).
  2. Jacob et al. (2019\(^2\)).
  3. Saravanan et al. (2018\(^3\)).
  4. Pugazhendhi et al. (2018\(^4\)).
  5. Shanmuganathan et al. (2018\(^5\)).
  6. Saravanan et al. (2018\(^6\)).
  7. Samuel et al. (2020\(^7\)).

- Typographical errors are present throughout the manuscript. The authors are required to pay keen attention to this.

- In the materials and methods, divide them into nice sub-sections. Provide the details of all the equipment's, instruments used, their model number, company of manufacture, country, etc.

- In the introduction section, write the novelty of the work and the problem statement clearly.

- 70% of the references should be from 2017, 2018 and 2019. Kindly do a careful literature review.

- The results and discussion section is only to write your results and facilitate scientific/technical discussions. Provide mechanism-based reactions and refer to important/recent literatures in the results and discussions.

- Conclusions (<100 words) should be in line with the specific objectives of your work. Do not repeat the results and the methodology here.

- Delete unwanted old references. Refer to references from the years 2017, 2018 and 2019. Figure numbers must be rearranged in this manuscript.

- The authors must compare more results with previous publications mainly in characterization parts (Results and discussion).
Only few previous publications in discussions. Why did the authors not compare the current results with previous publications?

The authors are required to re-write the conclusion.

The authors must check the manuscript carefully before submitting to the journal. Because the manuscript still has grammar mistakes and some words are joined with some other words.

The authors must show good results in the abstract section to enhance the readers' understanding.

µg/ml or µgm/ml. Check the full the manuscript.

The authors must use any one format throughout the manuscript for example minutes must be as “min”; “ml” must be as “mL” and hours must be as “h”. throughout the manuscript.

Please avoid reference overkill/run-on - do not use more than 3 references per sentence. If you need to use more, make sure you state the key relevant idea of each reference.

Many sentences could be seen without enough evidences or justifications - you need appropriate references to justify your arguments.

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2. Similarity index shall not exceed 15% with no more than 1% from any source.
3. Citation of references with latest publications on the topic. Please also cite some relevant papers from F1000Research.
4. Manuscript shall have an adequate number of Figures and Tables.
5. Figures must be in high quality format. Please ensure also to submit a high quality Graphical Abstract representing a summary of your study.

References

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

*Competing Interests*: No competing interests were disclosed.

*Reviewer Expertise*: Nanoparticles, Anticancer, Photocatalytic degradation; Cytotoxicity; Organic and inorganic Nanoparticles, Antibacterial

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