Antibacterial Effect of Visible Light Reactive TiO$_2$/Ag Nanocomposite Thin Film on the Orthodontic Appliances

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This study evaluated the antibacterial effect of a visible light reactive TiO$_2$/Ag nanocomposite thin film on dental orthodontic wire (STS 304 wire). The growth of S. mutans and A. actinomycetemcomitans was suppressed on the specimens coated with TiO$_2$/Ag compared to the uncoated specimens. The antibacterial effect of the TiO$_2$/Ag nanocomposite thin film was improved under visible light irradiation.

**Keywords:** Visible Light Reactive TiO$_2$/Ag, Antibacterial Effect.

1. INTRODUCTION

More patients are receiving orthodontic treatment as interest in esthetics increase. However, the process of orthodontic treatment is esthetic, due to the gray color of orthodontic wire and bracket. Because of the wire and bracket, there is also a higher risk of plaque formation on the tooth surface, dental caries, and periodontal disease adjacent to the fixed appliances. To prevent this problem, methods to inhibit the activity of pathogenic oral microbes have been reported. Most of these methods inhibit bacteria via fluoride and chemical therapy, and require additional time and cost. The application of TiO$_2$/Ag photocatalysis, which is harmless to human and has antibacterial effects, may result in antibacterial and sterilization effects that might prevent dental plaque formation or tooth demineralization.

Therefore, this study examined the antibacterial effect of visible light reactive TiO$_2$/Ag nanocomposite thin films on orthodontic appliances.

2. EXPERIMENTAL DETAILS

2.1. TiO$_2$/Ag Coating Procedure

TiO$_2$/Ag thin films were coated on STS 304 plates and wires by arc ion plating under the following deposition parameters: 16 V, 60 A, target and substrate distance of 15 cm, substrate temperature of 350 °C and base pressure of 5.0 × 10$^{-6}$ Torr. The Ar:O$_2$ gas ratio was changed to determine the conditions for optimal antibacterial ability in response to visible light. The Ti:Ag ratio was controlled to alter the expression of dentin color to obtain esthetics.

2.2. Characteristics of TiO$_2$/Ag Coating

The morphology of the TiO$_2$/Ag films was observed by field-emission scanning electron microscopy (FE-SEM, HITACHI S-4700, Japan) operated at 3 kV. Phase identification was performed by X-ray diffraction (XRD, MACMXP3, Japan) operated at 40 kV, 20 mA with a scan rate of 5′/min.

To investigate the optical properties of the nanocomposite film, the adsorption ratio was investigated using an UV/VIS/NIR spectrum (MU-3501, Hitachi), and the energy band gap was calculated by extrapolation of the following absorbance plot: $(a bh v)^2 = c(h v - E_g)$.

2.3. Cell Experiments

The antibacterial ability of each specimen coated with TiO$_2$/Ag was examined by culturing Streptococcus mutans and Aggregatilacter actinomycetemcomitans (ATCC 33384), which are dental caries pathogen and periodontitis pathogen, respectively.
Brain heart infusion broth (BHI, BactoTM, Difco Laboratories, USA) 25 g and lactose 100 g were added to 1 ℓ of the culture medium of S. mutans. Tryptic soy broth (TSB, Difco Laboratories, USA) 30 g and yeast extract 1 g was added to 1 ℓ of the culture medium of A. actinomycetemcomitans. After sterilization, the temperature of the culture medium was reduced to below 50 °C, and 100 ml of fetal bovine serum (FBS) was added. After fixed culturing in a 37 °C aerobic culture tube, 200 μℓ was extracted every 2 hours. The optical density at 630 nm was measured using a spectrophotometer (Bio-Tek Instruments, USA) to determine the antibacterial ability of the specimen in S. mutans and A. actinomycetemcomitans.

The survival rate of S. Mutans was measured from various concentrations of anions isolated from the TiO₂/Ag coated specimens.

3. RESULTS AND DISCUSSION

Figure 1 revealed an increase in the thickness on visible-light reactive TiO₂/Ag film with decreasing O₂ content. Unlike inert N₂, active O₂ combines and collides with the titanium in the vapor phase, which decreases reaching the substrate surface. This results a longer free path, leading to a lower deposition rate on the substrate surface.

At an O₂ content of 2.4%, the film thickness and the particle size increased by up to 2.5 μm and 250 nm, respectively (Fig. 2). The cross sectional view revealed a uniform coating thickness. There were no residual clusters or porosity on the TiO₂/Ag surface.

XRD revealed only anatase when the O₂ ratio was >4%. Both anatase and rutile were observed when the O₂ ratio was <4%, and only rutile was observed when the ratio was <1.4% (Fig. 3). A majority of previous studies carried out on TiO₂ photocatalysis reported that only anatase has high photocatalytic activity. However, recent studies reported that rutile has similar photocatalytic activity to anatase in thin film form.

The optical energy band gap was determined by measuring the absorption spectrum using the UV/VIS/NIR spectrum (MU-3501, Hitachi). The results showed that the absorption rate increased with decreasing O₂ ratio (Fig. 4). This is because a lower O₂ ratio results in a distribution of titanium atoms or electrons in the thin film.

To fit the characteristics of the visible light reactive TiO₂/Ag nanocomposite thin film, the basic absorption
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Fig. 4. Absorption ratio of the TiO2 thin film according to each Ar:O2 ratio (DC Power:300 mA, Sputtering time:30 min).

Table I. Survival rate of S. mutans and A. actinomycetemcomitans.

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<thead>
<tr>
<th>Absorbance (A630)</th>
<th>Non-coating TiO2/Ag coating</th>
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<tbody>
<tr>
<td>S. mutans</td>
<td>0.70 ± 0.05</td>
</tr>
<tr>
<td>A. actinomycetemcomitans</td>
<td>0.16 ± 0.01</td>
</tr>
</tbody>
</table>

Fig. 5. Survival rate of S. mutans in the anions isolated from Ag.

The survival rate of S. mutans and A. actinomycetemcomitans was measured on each specimen. The growth of bacteria was suppressed on the specimens coated with TiO2/Ag compared to the uncoated specimens (Table I).

The survival rate of S. Mutans was measured from various concentrations of anions isolated from the TiO2/Ag coated specimens. The suppression of bacterial growth increased with increasing anion concentration (Fig. 5).Ag itself is known as one of the most interesting antibacterial materials. It is generally believed that Ag can bind to bacterial cell wall membrane, damage it and so alter its functionality. Ag can interact with thiol groups in proteins, which inactive respiratory enzymes and produce reactive oxygen species. In addition, because of the interaction between the Ag and DNA structure of bacteria, their multiplication may be prevented.5,9

4. CONCLUSION

Visible-light reactive TiO2/Ag thin films on dental orthodontic wire appear to have good antibacterial ability under blue-purple visible light.

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References and Notes


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