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Original article

# Changes in the corrosion rate and microstructure of beta titanium wire using kiwi peel extract

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## *ABSTRACT*

***Background:*** *Beta titanium orthodontic wire is known to have good corrosion resistance but is weak in acidic environments, which advance the corrosion rate. One natural inhibitor that can be used to decrease corrosion is kiwi peel extract, which has a high antioxidant level.* ***Purpose:*** *This study aims to examine the ability of the extract to decrease the corrosion rate and microstructural changes of beta titanium at an acidic pH (pH 5).* ***Methods:*** *The samples used were beta titanium with a diameter of 0.016 x 0.022 in and a length of 6 cm. A total of 28 samples (n=28) were divided into four groups—a control group immersed in pH 5 artificial saliva and three treatment groups immersed in kiwi peel extract at concentrations of 400, 500, and 600 ppm (n=7), respectively. The samples were immersed for seven days at 37°C in an incubator. The corrosion rate was tested using the weight-loss method and microstructure change was analyzed using a scanning electron microscope (SEM).* ***Results:*** *One-way ANOVA showed that there are significant differences in corrosion rates between beta titanium immersed in artificial saliva and beta titanium immersed in kiwi peel extract with p=0.01 (p<0.05). SEM analysis results showed that the group with the least surface changes was the one immersed in 400 ppm of kiwi peel extract.* ***Conclusion:*** *Weight-loss and SEM methods show similar results. Kiwi peel extract proved to decrease the corrosion rate and changes in the microstructure of the wire most effectively at a concentration of 400 ppm.*

***Keywords:*** *beta titanium; corrosion rate; kiwi peel extract; medicine; dentistry*
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## INTRODUCTION

Beta titanium orthodontic wire, also known as titanium molybdenum alloy (TMA), is a type of orthodontic wire developed by Burstone and Goldberg in 1980. This wire is composed of 78% titanium, 11.5% molybdenum, 6% zirconia, and 4.5% tin.[1,2] Beta titanium orthodontic wire has a rough surface with irregular grooves that affect plaque accumulation and increase friction.[3] Orthodontic wire alloy characteristics and surface roughness play an important role and can change the behavior of the wire. Studies show that surface characteristics of orthodontic wires affect their performance and biocompatibility. The surface topography can also critically modify the aesthetics, the performance efficiency of orthodontic components, and the corrosion rate. Plaque accumulation is affected by surface roughness and plays an important role in other properties of orthodontic wires. Surface roughness can also change the coefficient of friction.[4] Increased friction due to corrosion will cause non-optimal static or dynamic friction movement. Friction can reduce available forces up to 40%, which causes loss of anchor.[5–7] Corrosion in the beta titanium wire can also cause titanium ion release that can cause hypersensitivity reactions in some individuals. Studies report that sensitivity to titanium is between 0.6% and 5% in the general population.[8]

Corrosion is unavoidable, but the rate of corrosion can be reduced. One way to prevent corrosion is to add an inhibitor. Corrosion inhibitors are chemicals that will effectively reduce the corrosion rate when added. Chemical corrosion inhibitors can be inorganic or organic, but since inorganic corrosion inhibitors have toxicity, organic inhibitors are preferred for their nontoxic properties. Various types of organic inhibitors have been studied for their ability to inhibit corrosion, but their effectiveness and potential depends on their being used properly.[9]


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Kiwi (*Actinidia deliciosa*) is commonly consumed worldwide. Kiwi peel has a high level of antioxidants, such as flavonoids, carotenoids, polyphenols, and minerals, which form a protective layer and reduce corrosion rate. Flavonoids are one of the most common secondary metabolic compounds found in plant tissues and play important roles in plant biochemistry and physiology, acting as antioxidants, enzyme inhibitors, precursors of toxic substances, and pigments. Flavonoids belong to a group of phenolic compounds with a C6-C3-C6 chemical structure. Quercetin is one of the most commonly occurring natural flavonoids and is a secondary plant metabolite with anti-inflammatory, antibacterial, antiviral, and antioxidant activities. Kiwi peel has a 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging rate of 95.16%, which is very effective in inhibiting corrosion.[10–14]

The adsorption of organic corrosion inhibitors on the surface of the wire begins with a replacement of water molecules on the metal surface with inhibitor molecules (Inh). The molecular shift occurs because the water tension is higher than the surface tension of the inhibitor. The inhibitor binds to the ions on the metal surface to form a metal-inhibitor complex compound. This is necessary to resist and limit direct interaction between the metal and the corrosive solution.[15]

Kiwi peel extract is thought to decrease corrosion and microstructural changes of beta titanium orthodontic wires due to its high antioxidant levels, which play a role in forming a protective layer and reducing the corrosion rate. Currently, very little research has been done on the use of kiwi peel extract as a corrosion inhibitor for beta titanium wire. Therefore, investigated the differences in the corrosion rate and microstructure of beta titanium wire after immersion in pH 5 artificial saliva and in macerated kiwi peel extract at concentrations of 400, 500, and 600 ppm. This study is expected to provide a reference for dentists considering the use of kiwi peel extract as an alternative mouthwash during orthodontic treatment to decrease the corrosion of beta titanium orthodontic wires.

## MATERIALS AND METHODS

The experiment has a pre- and post-test design and includes a control group. Twenty-Eight Beta titanium orthodontic wires from American Orthodontics (Sheboygan, Wisconsin, US), each with a diameter of 0.016 x 0.022 in and a length of 6 cm, were used. Each wire was weighed before immersion using an analytical scale. The wires were then divided into four groups. Group 1 was a control group immersed in artificial saliva with pH 5, while groups 2–4 were treatment groups immersed in 400, 500, and 600 ppm of kiwi peel extract, respectively (Figure 1).

Making kiwi peel extract began with peeling the skin of the kiwi fruit that had been washed thoroughly. It was then weighed to 500 g and placed in a drying cabinet for two days until the whole kiwi peel dried or became simplicia. The simplicia was weighed again to 95 g and then gradually blended into a smaller form. The blended simplicia was put into a closed container and dissolved in a liter of 70% ethanol, stirred, and soaked for 3 x 24 hours. After that, the solution was filtered to obtain a liquid extract of kiwi peel, or macerate I. The pulp extraction process was repeated using 70% ethanol to obtain macerate II. Then evaporation was carried out to obtain a thick extract of 100% pure kiwi peel. Concentrations of 400, 500, and 600 ppm of kiwi peel extract were obtained by mixing 0.04, 0.05, and 0.06 g of the thick extract with distilled water to a total volume of 100 ml, respectively.

Each group was stored in an incubator for seven days at 37°C. The wires were then taken out, rinsed, and dried. They were weighed again after immersion using the same analytical scale. The corrosion rates of the wires were calculated using the weight-loss method based on American Standard Testing and Material (ASTM) G I "Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens" with the following formula:

$$Corrosion\ rate = \frac{K \times W}{A \times T \times D}$$

where:
K = constant ($3.45 \times 10^6$)
T = time of exposure (h)
A = surface area ($cm^2$)
W = mass loss (g)
D = density ($g/cm^3$).

Samples were analyzed with a scanning electron microscope (SEM) to determine microstructure changes in the orthodontic wire surface after immersion. Statistical analysis was carried out using the Statistical Package for the Social Sciences (SPSS) with the Shapiro-Wilk normality test. The one-way ANOVA parametric test was then used with a confidence interval of 95%.

## RESULTS

The Shapiro-Wilk normality test results showed that the average corrosion rates of groups 1, 2, and 3 had significance values of p=0.771 (≥0.05), p=0.738 (≥0.05),

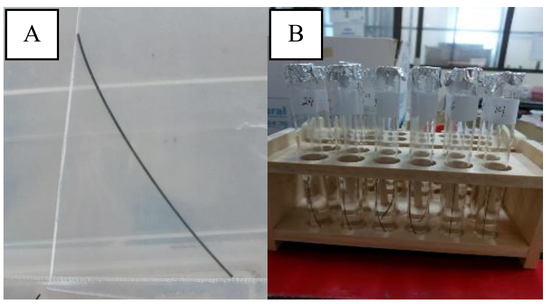


**Figure 1.** Beta titanium orthodontic wire with a diameter of 0.016 x 0.022 in and a length of 6 cm (A), beta titanium orthodontic wires immersed according to the control and treatment group protocols (B).


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**Table 1.** Differences between the control and treatment groups using the LSD test

| Group | Control | 400 ppm kiwi peel extract | 500 ppm kiwi peel extract | 600 ppm kiwi peel extract |
|---|---|---|---|---|
| Control | - | 0.004* | 0.006* | 0.060 |
| 400 ppm kiwi peel extract | 0.004* | - | 0.837 | 0.222 |
| 500 ppm kiwi peel extract | 0.006* | 0.837 | - | 0.307 |
| 600 ppm kiwi peel extract | 0.060 | 0.222 | 0.307 | - |

* There is a significant difference.

**Table 2.** Corrosion rate differences between the control and treatment group beta titanium orthodontic wires after immersion

| Group | Mils per year (mpy) Mean ± SD | *P* |
|---|---|---|
| Control | 0.63±0.422 | |
| 400 ppm kiwi peel extract | -0.16±0.263* | 0.014** |
| 500 ppm kiwi peel extract | -0.11±0.602* | |
| 600 ppm kiwi peel extract | 0.15±0.336 | |

* (-) indicates that the corrosion rate obtained per year (mils per year) after being given a corrosion inhibitor is below 0.
** $P$=0.014 (< 0.05) which means that there is a significant difference between groups.

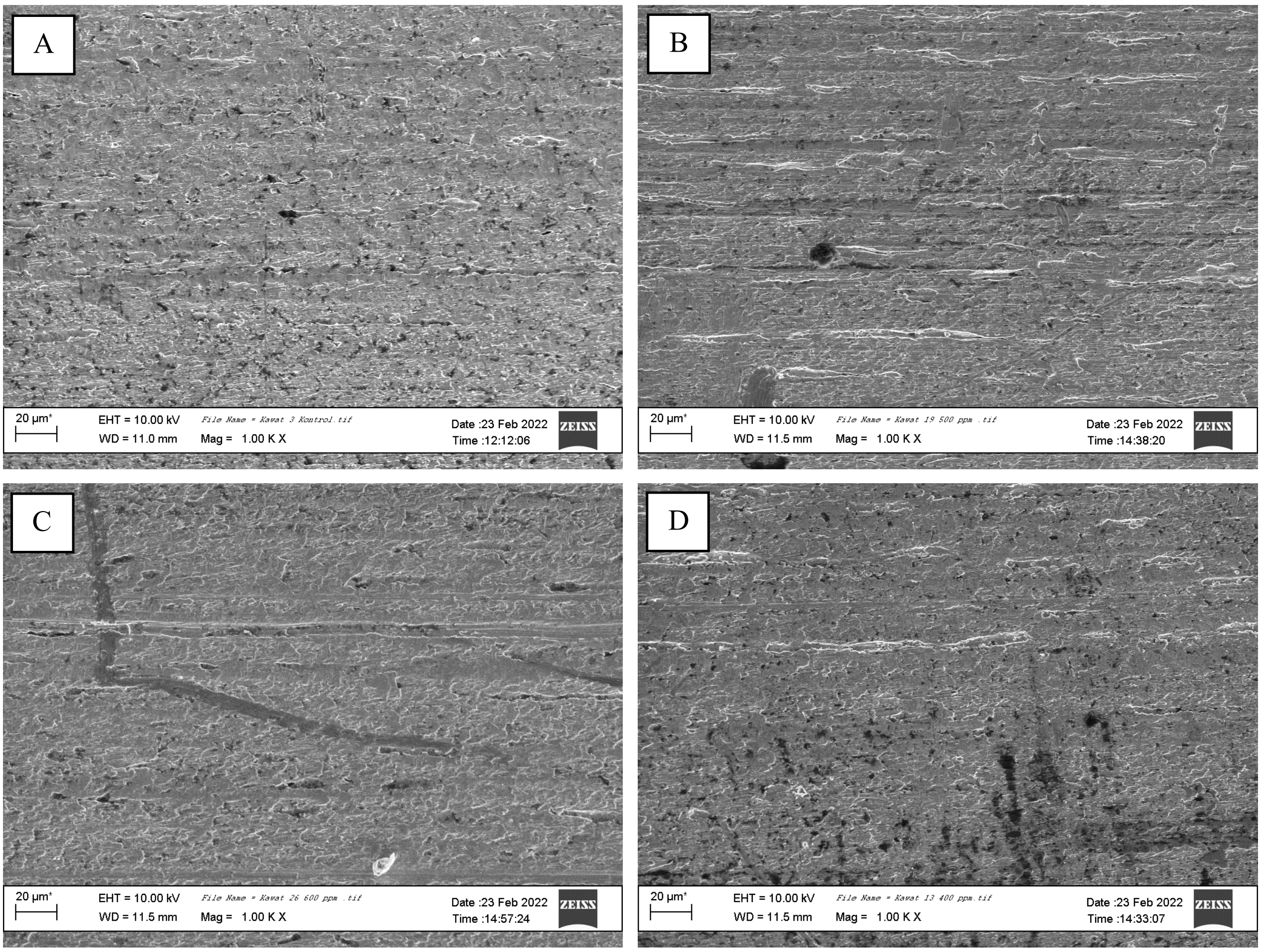


**Figure 2.** The beta titanium orthodontic wire of the control group shows a wire surface with many round and oval grooves with a black base (A), the 400-ppm kiwi peel extract wire surface shows a long groove shape that is more regular and more closely resembled unused beta titanium orthodontic wire (B), the 500-ppm kiwi peel extract shows a wire surface with a regular groove shape, but there is also a small round groove around the wire surface (C), the 600-ppm kiwi peel extract shows a surface with many round and oval grooves on a black base (D). 1000x magnification.


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and p=0.583 (≥0.05), respectively, while the control group had a significance value of p=0.120 (≥0.05). The results showed that all treatment group data met the assumption of normality or were normally distributed because all groups had a significance value of p≥0.05.

Table 1 shows the differences between the treatment groups using the Least Significant Difference (LSD) test. The basis for decision-making was as follows: looking at the probability numbers, if the p-value was <0.05, the difference between the two treatment groups was taken as significant.

Table 2 shows the changes in the corrosion rates of beta titanium orthodontic wire after immersion in either artificial saliva or kiwi peel extract (*Actinidia deliciosa*) at 400, 500, and 600 ppm concentrations**.** One-way ANOVA results showed a p-value of 0.014 (p<0.05), which means that there is a significant difference between the groups. These results also indicate that the alternative hypothesis ($H_1$) is accepted and kiwi peel extract has an inhibiting effect on the corrosion rates of beta titanium orthodontic wires and on changes in the microstructure of the wires.

SEM analysis of each group, seen in Figure 2, showed that the smoothest wire surface microstructure was seen at 400 ppm of kiwi peel extract, and the smoothness decreased with increasing extract concentrations. The results of the SEM test in the control group showed a wire surface with many round and oval grooves with a black base; the normal structure of the beta titanium orthodontic wire was also grooved. SEM analysis of the 400-ppm kiwi peel extract showed a wire surface with a long groove shape that was more regular and more nearly resembled unused beta titanium orthodontic wire. SEM test of the 500-ppm kiwi peel extract showed that the wire surface had a regular groove shape, but additionally, there was a small round groove all around the wire surface. The results of the SEM test on the 600-ppm kiwi peel extract showed that the wire surface had many round and oval grooves on a black base.

## DISCUSSION

Beta titanium orthodontic wire immersed in kiwi peel extract had a lower corrosion rate compared to the control group. This result was in line with Dehghani et al.[16] and Arias-Montoya et al.,[17] who stated that the addition of kiwi peel extract can decrease the corrosion rate of wires. Organic corrosion inhibitors are usually used in low concentrations. They can decrease the reaction between the metal and its environment. Kiwi peel extract is effective in decreasing corrosion rate due to the mixture of phytochemicals it contains. This mixture has various functional groups that can adsorb on the surface of the wire.[18]

Compounds such as flavonoids, steroids, tannins, and terpenoids can adsorb on the surface of the wire. Flavonoids present in kiwi peel act as antioxidants by donating hydrogen atoms, by their ability to adhere to metals as glucosides (containing a glucose side chain), or in a free form called aglycone. A common natural flavonoid occurring as a plant secondary metabolite is quercetin. As synthetic flavonoid production is still uncommon, plants are the only source of quercetin. Vegetables and fruits are composed of various groups of flavonoids in different amounts.[11,12,18]

In this study, Kiwi peel extract at a concentration of 400 ppm had the best inhibition strength compared to higher concentrations of 500 ppm and 600 ppm. Increasing the concentration of organic inhibitors can increase the complex compounds formed and the corrosion rate is lower due to the inhibitor being adsorbed on the metal surface. However, a high concentration of the corrosion inhibitor can cause the inhibitor molecules on the metal surface to be replaced by other molecules, thus reducing the protective effect of the corrosion inhibitor.[19]

Titanium is the highest component of the beta titanium orthodontic wire with a percentage of 78%. It can withstand mechanical pressure during mastication and has very good chemical stability due to a highly protective titanium dioxide layer ($TiO_2$) on its surface. Titanium can withstand corrosion. However, if the stable oxide layer on its surface is gone or cannot be regenerated, corrosion can occur. Disintegration in metal alloys can occur due to moisture, acid or base solutions, or certain chemicals.[20]

The surface structure of the wire depends on the alloy used, the complex manufacturing process, and the final treatment of the wire surface. Beta titanium orthodontic wire has a surface microstructure that looks rough compared to other types of wires. It has a surface structure with large pores that are evenly distributed and also has a deep groove. The surface roughness of beta titanium wire is due to adherence or cold welding of titanium to the mold during processing.[21] SEM results of beta titanium orthodontic wire immersed in pH 5 artificial saliva in this study were in line with Pataijindachote et al.,[22] who investigated four types of orthodontic wires immersed in pH 2.5 and pH 6 for 90 days. Their results showed that the mean corrosion rate at pH 2.5 was higher than at pH 6, and the mean corrosion rate for 90 days of immersion was higher compared to untreated wire. The SEM image of the beta titanium wire after immersion for 90 days at pH 2.5 showed a widened beta titanium normal groove with additional grooves, while the wire at pH 6 showed smaller grooves.[22] These results indicate that the more acidic the pH in contact with the wire, the greater the damage to the wire surface due to corrosion and the more different it is from the normal structure of the beta titanium orthodontic wire.

Corrosion rates tested using the weight-loss method and microstructure changes of beta titanium orthodontic wire observed using SEM showed significant differences between the groups. The lowest corrosion rate was found in the 400-ppm kiwi peel extract group, with a wire surface microstructure that was most similar to the wire image before use, followed by the 500-ppm kiwi peel extract group, with a wire surface microstructure that had an


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additional small round groove around the wire surface. The kiwi peel extract group with a concentration of 600 ppm had a microstructure depiction of the wire surface with many round and oval grooves with a black base. The control group wire had a normal structure, though it was covered with additional grooves due to corrosion.

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