Original Article

Variation in Corrosion Resistance of Nickel-Titanium Wires from Different Manufacturers

Her-Hsiung Huang[a]

Abstract: Nickel-titanium (NiTi) wires produced by various manufacturers may have different corrosion resistance in acidic oral environments. The purpose of this study was to investigate the variation during *in vitro* corrosion resistance of commercial NiTi dental orthodontic wires from different manufacturers using the fast electrochemical technique. The linear polarization test was used to evaluate the corrosion resistance, in terms of polarization resistance (R_p), of as-received commercial NiTi wires in acidic artificial saliva at 37°C. One-way analysis of variance was used to analyze R_p with the wire manufacturer as the variable factor. Atomic force microscopy was used to analyze the three-dimensional surface topography and roughness (R_a). Electron spectroscopy for chemical analysis was used to identify the chemical structure of the passive film on the NiTi wires. The results showed that NiTi wires from different manufacturers had a statistically significant difference in R_p ($P < .001$). Different surface topography was present among the tested NiTi wires, whereas the same surface chemical structure was observed for the tested NiTi wires. The surface roughness of the commercial NiTi wires with similar surface chemical structure does not correspond with the difference in corrosion resistance. (*Angle Orthod* 2005;75:661–665.)

Key Words: NiTi; Orthodontic wire; Corrosion resistance; Polarization resistance; Roughness

INTRODUCTION

Nickel-titanium (NiTi) alloy is a prospective material for dental orthodontic wires because of its favorable mechanical properties and corrosion resistance. Although a protective passive film exists on the NiTi alloy, Ni or Ti ions may still be released from the metal surface in the acidic oral environment through the corrosion processes.[1]

The potential danger associated with corrosion in the use of NiTi wire comes from the biologically negative effects of the Ni ion.[2–5] NiTi wire with good corrosion resistance is crucial to dental prosthesis biocompatibility.

Many studies on NiTi and stainless steel wire corrosion resistance for dental orthodontic applications have been conducted.[5–10] NiTi wires produced by various manufacturers may have different corrosion resistances in the acidic oral environment. However, related information in the literature concerning the comprehensive difference in corrosion resistance among commercial NiTi wires from various manufacturers is still limited.

In this investigation, the dissimilarity of in vitro corrosion resistance of commercial NiTi wires, produced by different manufacturers, in acidic artificial saliva was studied. The surface analyses results were compared and correlated with the corrosion resistance.

MATERIALS AND METHODS

Four different commercial NiTi dental orthodontic wires (as-received condition) with 0.016 inch diameters were used. The studied wires were designated as RMO (Orthonol® Nickel-Titanium Wire, RMO Inc, Denver, Colo), Ormco (NI-TI®, Ormco, Glendora, Calif), SY (NiTi Wire, Shin-Ya Co, Taipei, Taiwan), and KH (Orthodontics-NiTi Wire, Kuo-Hua Co, Taipei, Taiwan). Chemical compositions (in wt %) of the as-received NiTi wires were analyzed using an energy-dispersive spectrometer (LINK exLII, Oxford, UK) and shown in the following: 57% Ni–43% Ti for RMO; 57% Ni–43% Ti for Ormco; 57% Ni–42% Ti–1% Fe for SY; 56% Ni–44% Ti for KH.

A scanning electron microscope (SEM) (ABT-150S, Topcon, Tokyo, Japan) was used to observe the sur-

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face morphologies of the NiTi wires. Three-dimensional surface roughness (R_a) of the NiTi wires was evaluated using atomic force microscopy (AFM) (Nanoscope III, Digital Instruments Inc, Santa Barbara, Calif). The outermost surface chemical analyses of the passive film on NiTi wires were assessed from electron spectroscopy for chemical analysis (ESCA) (ESCALAB 210, VG Scientific Ltd, East Grinstead, UK).

A potentiostat (AUTOLAB PGSTAT 30, Eco Chemie BV, Utrecht, The Netherlands) was used to perform the linear polarization test. NiTi wires were used as working electrodes. A saturated calomel electrode and platinum sheet were used as the reference electrode and counter electrode, respectively. Modified Fusayama artificial saliva[1,11] was used as the corrosion test electrolyte, which consisted of NaCl (400 mg/L), KCl (400 mg/L), $CaCl_2 \cdot 2H_2O$ (795 mg/L), $NaH_2PO_4 \cdot H_2O$ (690 mg/L), KSCN (300 mg/L), $Na_2S \cdot 9H_2O$ (five mg/L), and urea (1000 mg/L). The electrolyte was adjusted to a pH of 6.25 using sodium hydroxide and maintained at 37°C. The artificial saliva used in this study has good correlation in corrosion trends with the results obtained from natural saliva[12] though it lacks some biological species. The electrolyte was deaerated with argon gas for one hour before the specimen was dipped into the electrolyte for the following corrosion test. The linear polarization curves of the test specimens were measured from -10 to $+10$ mV (vs corrosion potential) with a scan rate of 0.1 mV/second after dipping the specimen into the test electrolyte for two hours. The polarization resistance (R_p), which is inversely proportional to the corrosion rate, is defined as the slope of the potential vs the current density near corrosion potential in the linear polarization curves.[13] The R_p value was statistically analyzed using one-way analysis of variance (ANOVA) for analyzing the wire manufacturer factor ($\alpha = 0.05$). The sample size for the corrosion test of each NiTi wire was 10.

RESULTS

Figure 1 shows the SEM observations of the as-received NiTi wires. Figure 2 shows the AFM observations and the corresponding surface roughness (R_a: nm) of the as-received NiTi wires. Surface defects produced during the manufacturing processes were noticeably observed on Ormco, SY, and KH wires (Figures 1 and 2). A rougher surface was visible on Ormco (R_a: 1272 nm) and KH wires (R_a: 1078 nm), whereas RMO wire had the lowest surface roughness (R_a: 187 nm) (Figure 2). ESCA surface analysis results, which are not shown here, indicated that the outermost surface of the passive film on all tested NiTi wires was the same and contained mainly TiO_2 with trace amounts of NiO.

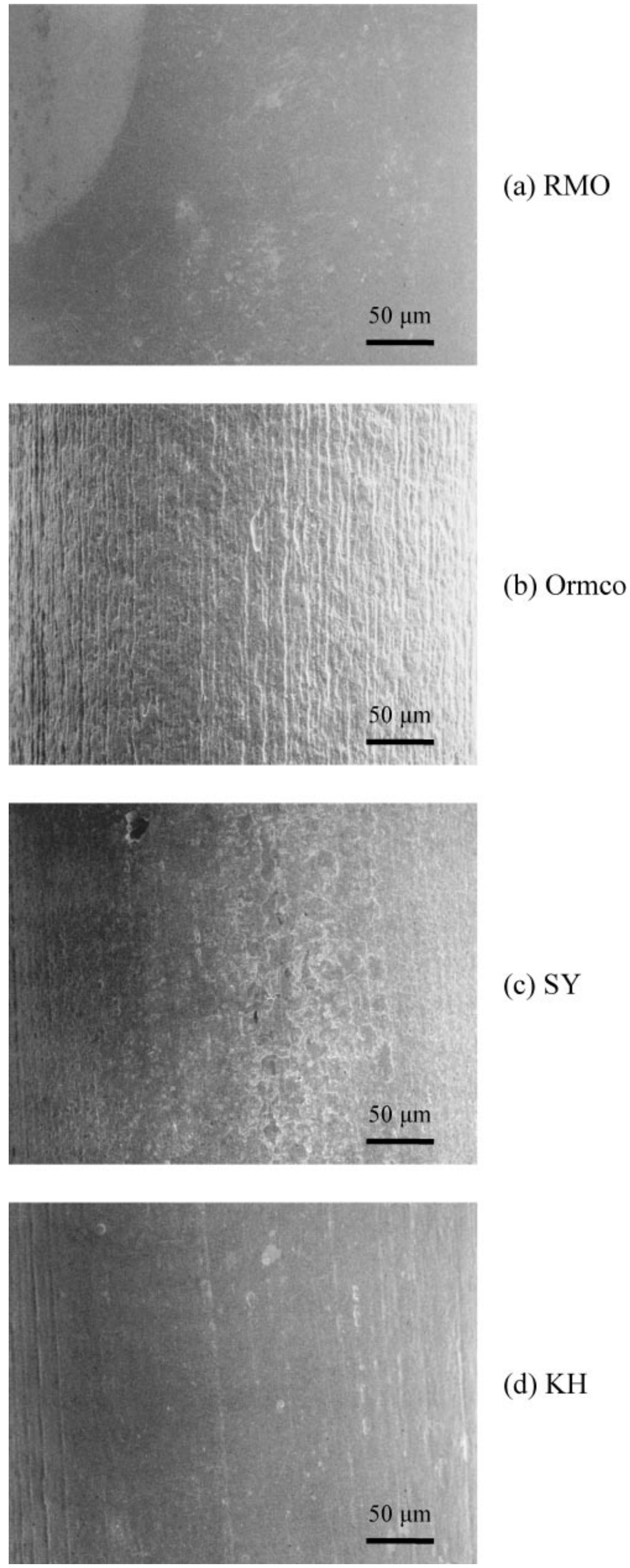

FIGURE 1. Scanning electron microscope (SEM) observations of the as-received commercial nickel-titanium (NiTi) wires from different manufacturers.

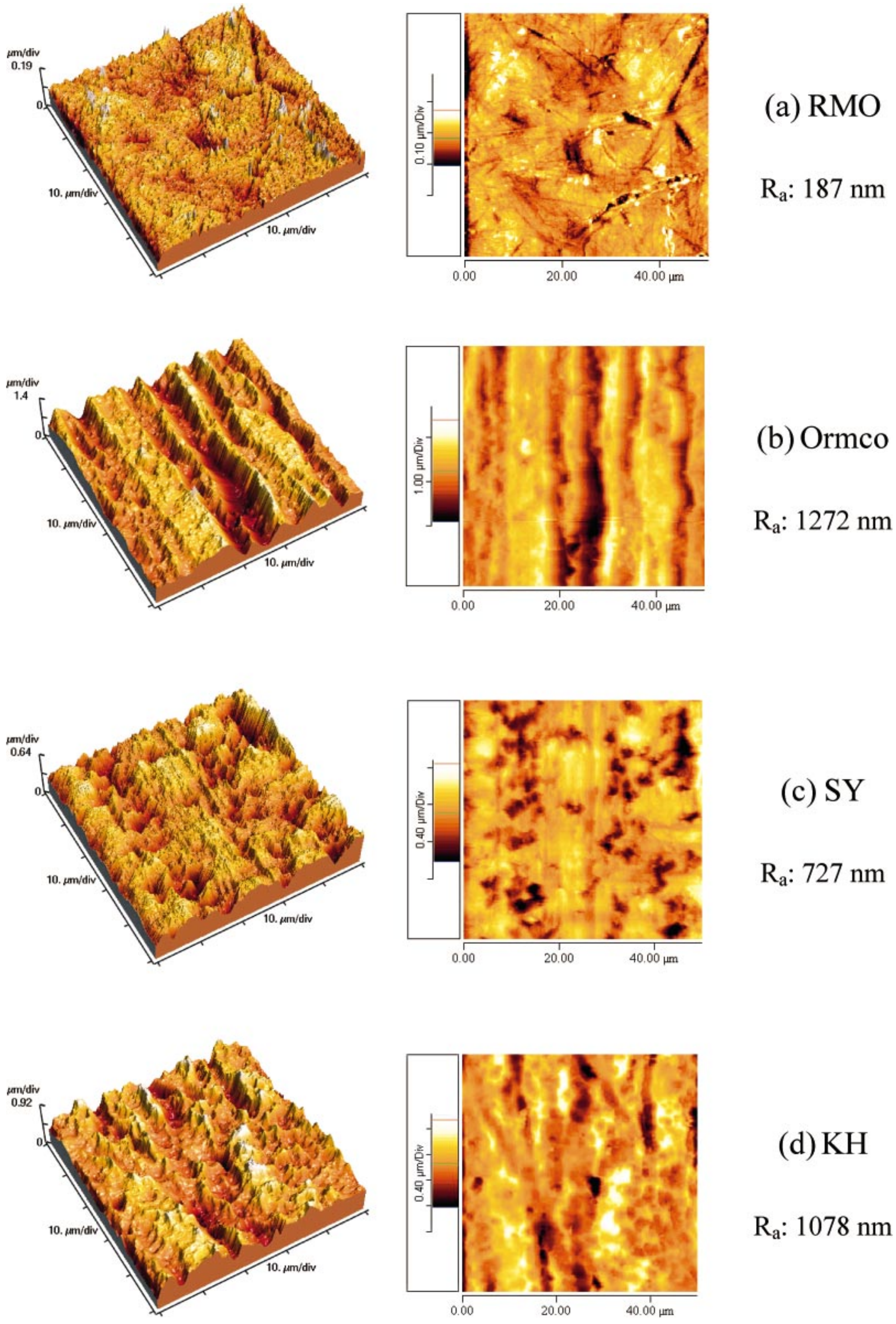

FIGURE 2. Atomic force microscope (AFM) observations (left: three-dimension, right: top view) and corresponding surface roughnesses of the as-received commercial nickel-titanium (NiTi) wires from different manufacturers.

TABLE 1. Polarization Resistances (R_p [Ω cm^2]) of the As-Received Commercial Nickel-Titanium Wires From Different Manufacturers After Linear Polarization Tests in Acidic Artificial Saliva

	RMO	Ormco	SY	KH
R_p	6.26×10^4 (915)[a]	9.12×10^4 (1401)	4.55×10^4 (1156)	1.02×10^5 (2785)

[a] Standard deviations are given in parentheses.

Table 1 shows the R_p values of the as-received NiTi wires from different manufacturers after linear polarization tests in acidic artificial saliva. The ranking of the mean R_p value was KH (1.02×10^5 Ω cm^2) $>$ Ormco (9.12×10^4 Ω cm^2) $>$ RMO (6.26×10^4 Ω cm^2) $>$ SY (4.55×10^4 Ω cm^2). Results of one-way ANOVA showed that the manufacturers of NiTi wires had a statistically significant influence on the R_p value ($P <$ .001).

DISCUSSION

Reports concerning the corrosion resistance of orthodontic wires focus mainly on the corrosion parameters, such as corrosion potential, pitting potential, or passive current density obtained from the potentiodynamic polarization curve.[5–10,14–17] In this study, from the linear polarization test, taken as a nondestructively fast electrochemical technique, the R_p value could be rapidly calculated and used as a parameter for corrosion resistance evaluation with respect to the abovementioned corrosion parameters. Although the ESCA analysis results showed that the chemical structure of the outermost surface of the passive film on all NiTi wires was the same, a statistically significant difference in R_p (or corrosion resistance) among the NiTi wires from different manufacturers was found ($P <$ .001).

The significant difference in R_p (corrosion resistance) could be due to the variation in surface. In this study, NiTi wires (such as Ormco and KH wires) with a rougher surface (Figure 2) and preexisting surface defects (Figure 1) did not exhibit a lower R_p (Table 1) or a lower corrosion resistance. This was similar to the results reported by Huang et al,[1] who reported that NiTi wires with rougher surfaces do not exhibit higher ion release in acidic artificial saliva. Therefore, the difference in R_p (or corrosion resistance) among the NiTi wires with the same surface-passive film, containing TiO_2 with small amounts of NiO, was believed to be related to the different surface residual stress produced during the various manufacturing processes, instead of the surface roughness, surface defects, and chemical structure. Conflicting results have been reported by Widu et al[14] who stated that surface roughness should be taken into account as an indicator of the tendency toward corrosion for orthodontic wires. Oshida et al[18] noted that surface defects on NiTi orthodontic archwire produced during the manufacturing process can be possible sites for corrosion.

It is known that the biocompatibility of a metal is related mainly to the character of the surface-passive film.[17,19–21] The TiO_2-based passive film on NiTi wires can provide a good measure of NiTi alloy biocompatibility.[5,17,19] Therefore, NiTi wire with long-term good corrosion resistance, namely, with a durably protective TiO_2-based passive film, in an acidic oral environment is crucial to biocompatibility. In this study, Ormco and KH wires showed a higher R_p (or a more protective TiO_2-based passive film) in the acidic artificial saliva. The passive film on Ormco and KH wires had a higher ion transfer resistance, although no difference in the outermost surface structure of the passive film was present. Therefore, these two NiTi wires were suggested as potential candidates for dental orthodontic applications.

For highly corrosion-resistant surgical implants, the R_p value may even reach 10^6 Ω cm^2.[13] Huang and coworkers[22,23] reported that in acidic modified Fusayama artificial saliva the R_p value for Ti with a surface structure of TiO_2 is around 10^6 Ω cm^2, whereas the R_p value for Ti-6Al-4V with a surface structure of TiO_2 and small amounts of Al_2O_3 and V_2O_5 is around 4.5×10^4 Ω cm^2. In this study, the R_p values of the investigated NiTi wires with the same TiO_2 and NiO surface chemical structure ranged between 4.5×10^4 and 10^5 Ω cm^2, which were lower than that of Ti but close to or higher than that of Ti-6Al-4V alloy. Therefore, the corrosion resistance of the investigated NiTi wires in the slightly acidic oral environment was acceptable, although the variance in the corrosion resistance of the NiTi wires was present.

CONCLUSIONS

The surface roughness of the as-received commercial NiTi orthodontic wires (RMO, Ormco, KH, and SY) with identical surface chemical structure (TiO_2 and small amounts of NiO) does not correspond with the difference in corrosion resistance for the polarization resistance in artificial saliva. From the corrosion resistance point of view, KH and Ormco wires, showing a higher polarization resistance of about 10^5 Ω cm^2, were suggested as suitable candidates for dental orthodontic applications. Surface residual stress produced during the manufacturing processes on the commercial NiTi wires may play an important role in the corrosion resistance instead of the surface roughness and chemical structure.

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