Do NiTi wires significantly corrode in oral conditions? An in-vivo study

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Abstract

Aims: Corrosion of NiTi wires in the oral cavity has been a matter of discussion in some in–vitro studies but in-vivo tests about corrosion of NiTi wires have been rarely investigated. We designed an in-vivo study to evaluate corrosion behavior of retrieved NiTi wires compared wit h as-received wires.

Methods: Considering our criteria, 15 participants demanding orthodontic treatment entered the study, two NiTi SE(G&H) wires were inserted in bracket slots and band tubes and two passively in auxiliary tubes of molars. After 2 months wires were retrieved and were evaluated regarding clinical conditions (tarnish, deformation). Then potentiodynamic test performed on distal segment of 60 retrieved wires and Rp test (polarization resistance test) for all specimens including retrieved and as-received wires. Non-parametric tests were used to compare retrieved and as-received wire groups.

Results: Retrieved wires showed clinically & electrochemically significant corrosion compared with as-received wires ($p< 0.05$). All retrieved wires showed signs of tarnish which was more in lower arch. Among all retrieved wires, 5 wires showed deformation, 3 from lower arch, and 2 from upper arches. One of recent two wires belonged to not-engaged group.

Conclusion: Despite of adequate corrosion resistance, NiTi wires, engaged or not engaged will corrode electrochemically in oral environment and should be noticed in clinical use. (IJO; 2(1)

Keywords: NiTI wires, Corrosion, Retrieved NiTi Wires, Electrochemical Impedance Spectroscopy, Polarization resistance. (Received March29, 09; Revised and accepted June 1,09)

The large spring back, controlled stiffness, and high stored energy possessed by NiTi wires, have facilitated imaginative approaches in mechanotherapy, such as early full bracket slot engagement, leading to the introduction of the differential modulus concept.[1-3] For two reasons corrosion of NiTi wires is important: biocompatibility concerns due to high nickel contents and effect of corrosion on unique mechanical properties on NiTi wires[3-6]

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The combination of the oral environment and NiTi alloys is extremely complex and very different from in-vitro environment.[7-11] However, few in-vivo studies exist in the literature on corrosion of NiTi wires under these complex factors [3,5,8,9,12] and none of these retrieval investigations have studied electrochemical corrosion behavior of NiTi wires. To make perfect these shortcomings, an intra-oral setup was designed in order to study corrosion behavior of NiTi wires in oral environment where they will actually offer their service. Our null hypothesis in this study was: there is no difference in corrosion behavior between retrieved wires and as-received wires.

Materials and methods:

Based on the results of a pilot study, sample size of 30 was calculated corresponding to $\alpha= 0.05$ and $z=1.96$.

Inclusion criteria:

1- All subjects needed and demanded orthodontic treatment

2- All subjects were in the permanent dentition.

3- All subjects were candidate to be under fix pre-adjusted appliance system with slot size 0.022 inch and stainless steel brackets and bands.

4- All subjects had willing to participate in study by listening, reading, and signing informed consent forms (patient/parent).

Exclusive criteria: The subjects with any of following items were excluded from the study.

1- Subjects with insistence on improper hygiene (before treatment or any time during study).

2-Subjects with significant gingival/periodontal involvement before or during study.

3- Subjects who have segmental arch orthodontic treatment plans.

4- Subjects who refuse to participate in the study by rejecting informed consent or during study or who has no intention to continue orthodontic treatment.

The Institutional Ethics Committee of Tabriz Medical University granted ethical clearance and the study followed the Helsinki guidelines prescribed for human experimentation. Informed consents signed by patients/parents were taken.

After considering strict criteria 15 patients were participated in study. For each patient, two NiTi SE (G&H) wires were inserted in brackets and tubes and two in auxiliary tubes of molars, second one was secured to base arch passively by elastomeric thread After 2 months wires were retrieved. We tried to make a homogenous group and omit confounding factors with considering exclusive criteria. Patients also were educated with oral health instruction methods and were asked to quit interfering habits like very hot or very cold food/beverages, biting or sucking habits, high frequency and quantity of having fizzy drinks, fruit juices, acidic snacks, etc. Patients were under observation for these situations plus oral hygiene. These efforts would reduce confounding factors. Retrieved wires were washed with distilled water then were checked for any obvious deformation and were compared with as-received wires regarding clinical conditions (tarnish, deformation). Then wires were cut in half (midline marks) and any cinched or quenched parts were removed.

Twenty mm from distal of segments were dock taped and except 5mm from proximal part the remaining surface was covered by Cyanoacrylate adhesive (InterLok, Switzerland). Then wire segments were cleaned and disinfected by Ethylalcohol 90%, blind coded, put in paper bags, and sent to laboratory. Sixteen as-received wires (8 cut in half) were also subject for this test. They supposed to act as control group or internal standard for study.

The electrochemical measurements including open circuit potential and electrochemical impedance spectroscopy were performed using AUTOLAB PGSTAT 30 (AUTOLAB PGSTAT 30, Eco Chemie BV, Utrecht, The Netherlands) potentiostat-galvanostat and frequency response analyzer software (FRA). We used artificial saliva with modified Fusayama formula 9-13 and adjusted the pH on 6.25. The working electrode was immersed for 48 hours at 35.5±1◦C (which was suggested as the most appropriate temperature for these kind of studies 14) in 50 ml of experimental solution inside Polyethylene containers before each electrochemical measurement to obtain stable open circuit potential (OCP). EIS tests were over a frequency range between 10 kHz to10mHz, a sine wave with 35mV amplitude was applied. EIS data was analyzed using Zview2 software and fitted to an equivalent circuit model. We had 3 lost segments in laboratory as drop outs. In this study, we measured Rp: The polarization resistance (Rp). Rp is inversely proportional to the corrosion rate.

Statistical analyses:

Rp from testing 117 segments of retrieved wires and 16 segments of as-received wire segments was analyzed in SPSS 13/Win (SPSS Inc., Chicago, IL, USA). α was set to 0.05 so difference in findings with p-value greater than 0.05 was defined as "not significant". This test was double-blinded due to using coded test subjects in laboratory and having statistical analyses done on coded groups by a third person. Non-parametric analysis (Wilcoxon test) was used to evaluate differences between two groups.

Results

Participants were 5 males and 10 females with mean age of 18 years & 2 months (± 4 years & 3 months). Wires were served for a mean of 63.71±16.434 days (range: 48-116 days). All retrieved wires (before sectioning) showed signs of tarnish which was more in lower arch. Among all retrieved wires, 5 wires showed deformation, 3 from lower arch, and 2 form upper arch. Interestingly one of these two wires belonged to not-engaged group (Figure 1).

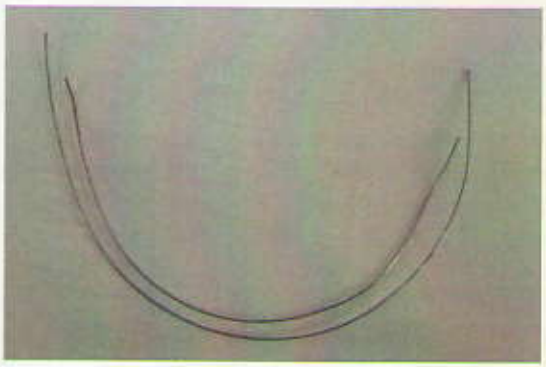


Figure 1 – a couple of deformed wires

Table 1 shows descriptive statistics for these variables. Contrast between mean Rp of study groups can be seen in Figure 2.

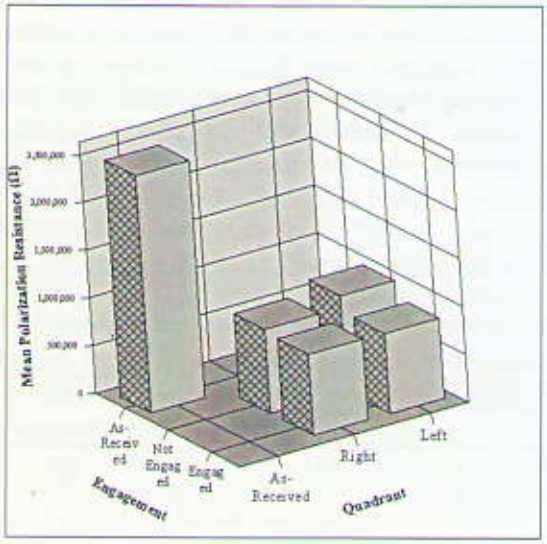


Figure 2 – 3D bar graph for mean Rp of different study groups

Normality tests by Shapiro-Wilk analysis failed

Polarization Resistance (Rp) in ohm of wire segments (Ω)	N	Minimum	Maximum	Mean	Std. Deviation
As-Received	16	245000	7450100	2480442.50	2368701.60
Retrieved as a whole	117	98247	4224800	888875.19	716056.27
Engaged	59	131300	2619800	841450.68	625052.83
Not-Engaged	58	98247	4224800	937117.36	800763.70
Right side	59	98247	3293800	862000.63	643820.04
Left side	58	104330	4224800	916213.10	787514.83

Table 1- Descriptive Statistics of study groups

to show normal distribution. So, nonparametric (Ranking) method was used. Wilcoxon analysis (assuming these two groups are related) was used to compare as-received wire segments with retrieved wire segments (engaged or auxiliary). Wire segments were divided to subgroups using Quadrant variable and performed the same analysis. Results were similar: significant difference ($p<0.05$) between as-received wire segments and retrieved wire segments in all groups. Table 2 shows the statistics for Wilcoxon analyses.

Polarization Resistance (Rp) of As-Received wire segments	vs. Retrieved	vs. Engaged	vs. Not Engaged	vs. Right side	vs. Left side
Z	-2.792(a)	-2.327(b)	-2.172(b)	-2.741(b)	-2.223(b)
Asymp. Sig. (2-tailed)	.005	.020	.030	.006	.026

Table 2- Wilcoxon Signed Rank Test

Discussion

None of in-vivo (retrieval) studies mentioned in introduction [3,5,8,9,12] had studied corrosion behavior of retrieved wires by electrochemical tests. Her-Hsiung Huang investigated the variation of corrosion resistance of as-received commercial NiTi dental orthodontic wires with the same TiO2 and NiO surface chemical structure from different manufacturers.[15] They used the same potentiostat that we had in our test (AUTOLAB PGSTAT 30, Eco Chemie BV, Utrecht, Netherlands) in order to perform the linear polarization test. They also studied surface roughness of wires but this method may not be so accurate because contamination particles with 1-2 μ on surface normally are present and may interfere with surface analysis tests. 1 Modified Fusayama artificial saliva with a formula like our study and the same pH (6.25) but different temperature (37°C) was used. They tested 10 wires in each group. Results showed that the polarization resistance (Rp) values of the investigated as-received NiTi wires was acceptable and ranged between 4.5×104 and 105 Ωcm2, which were lower than that of pure Ti implants (106 Ω cm2) but close to or higher than that of Ti-6Al-4V alloy (4.5×104 Ωcm2). One-way ANOVA in their study showed that the manufacturers of NiTi wires had a statistically significant influence on the Rp value ($p<.001$). The measured mean for Rp of wire segment groups in our study was between 7.09×105 Ω and 1.07×106 Ω. The equivalent for these measurements in Ω cm2 would be approximately between 1.77×105 and 2.67×105. Compared with Huang, our wires showed much higher resistances to corrosion, which is not reasonable. This might be due to different conditions of polarization tests. For example: they had not mentioned reference electrode they had used. We used Ag-AgCl electrode as reference. Also, they had not mentioned method of calculation of Rp from plotted potentials. We used FRA 4.9 software package form manufacturer of potentiostat.

Lower corrosion resistance potential is in correspondence with decreased corrosion resistance and increased corrosion susceptibility. In equal conditions, a wire with lower Rp will corrode faster and will loose its elasticity and strength more easily. A comparison between corrosion resistances of retrieved wires is a way to understand burden of corrosion on wires. With this method we can compare corrosion behavior of two groups of wires. Also, we can forecast whether recycling of wire is suitable (concerning corrosion) or not. In our study, although all groups showed significant nonparametric tests demonstrated significant difference between behaviors of as-received and retrieved wires. So the null hypothesis will be rejected. This result reinforces the results of other studies [7-11] and demonstrates that corrosion indeed happens electrochemically and increases corrosion susceptibility of in-vivo served wires.

But still these wires may have useful mechanical properties [3,4] and may perform their service in-vivo. Although retrieved subjects showed significant corrosion, their mean Rp were still far enough from electrochemical point of view.

Conclusion:

1) Retrieved wires show clinically & electrochemically significant corrosion

compared with as-received wires. Engaged wires show more deformation and tarnish clinically.

2) Corrosion both in all groups of retrieved wires (auxiliary-engaged, right-left, and upper-lower) is significantly higher than As-received wires. This proves that wires after use in oral environment even if were not engaged in orthodontic appliance, will electrochemically corrode and will be more susceptible to corrosion in case of recycling. Yet they could still offer acceptable intra-oral service.

Limitations

Due to ethical concerns about gingival irritation and patient comfort, we had to tie auxiliary wires in 3-4 mm distance from brackets and engaged wires. This might elicit a question about pure passiveness of these wires. In fact, we had ligated them with loose passive elastomeric threads which produced the freedom for them to bend out of occlusion under forces. Yet, it might be a good idea to find a better way to attain an absolute degree of passiveness for auxiliary wires in order to study effect of occlusal forces with higher confidence level (if it is possible).

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