Degradation of lingual orthodontics archwires

The effect of corrosion and nickel release on their properties

Carlos Suárez Martínez

Directors

Dr. María Teresa Vilar Martínez (UB)
Dr. Francesc Xavier Gil Mur (UPC)

Department of Odontostomatology
PhD Program: Clinical Techniques in Odontostomatology (2003-2005)

Faculty of Dentistry. University of Barcelona
4th of December 2007

5. Conclusions

As it was pointed out in the introduction of the present thesis, the aim of the research was to study the corrosive behaviour of the orthodontic archwires currently used in the lingual technique.

The corrosive behaviour study has been performed with the pontentiostatic anodic polarization as a mean by which corrosion is forced at the archwires. At the same time the potentiostatic technique was aimed at characterising the basic corrosive parameters that the studied archwires have and that, to our knowledge, still had not been described.

According to the results obtained at the OCP it could be concluded that wires could be classified in three different groups according to the points at which general corrosion could arise. The highest tendency to general corrosion has been found at the Respond, D-Rect and stainless steel 0.016 archwires, whose OCP individual values were similar. Although the stainless steel 0.016x0.022 archwires OCP averages were similar to the obtained by D-Rect archwires, the individual values were found to be under -400 mV, so they have been considered to be a second group in terms of general corrosion characteristics. The third group is the one that comprises the Titanium alloyed archwires: NiTi, CuNiTi and TMA. All of them showed OCP values under -300 mV.

The OCP gives a rough understanding of the tendency that a material has to corrosion. Many limitations have been pointed out at the discussion, so results are put in the context of a parameter very difficult to stabilise and that it can be modified by different factors. It seems that surface characteristics and manufacturing defects are the main responsible of the variability found at the OCP results among specimens of the same material and section. This is in agreement with the SEM findings which showed a poorer surface finishing for the archwires showing a highest tendency to general corrosion in the OCP test.

In any case, OCP sets the starting point for the CV test so that results obtained can be comparable.

Unlike OCP values, CV test was seen to be very consistent among the tested specimens, confirming first of all that a study of corrosion based only on OCP findings could lead to erroneous conclusions. CV findings showed that Ecorr values were very similar for Respond, D-Rect and stainless steel 0.016x0.022 archwires, being -600 mV, -650 mV and -610 mV respectively. These archwires showed an estimated i_{corr} around -4 and -4,5 mA/cm^2. Stainless steel 0.016 archwire was found to have the lowest E_{corr} value, being the most prone to general corrosion with an E_{corr} value around -845 mV and an i_{corr} estimated to be between -3 and -3,5 mA/cm^2.

The Ti alloyed archwires were found to be very resistant to general corrosion. In this group, the archwires with a highest tendency to corrosion were found to be the CuNiTi wires. E_{corr} was found to be around 1000 mV and their i_{corr} estimated around -2 mA/cm^2. The NiTi archwires showed an E_{corr} around 1000 mV and an estimated icorr that would be around -2 mA/cm^2. TMA was found to be inert to corrosion and no values can be obtained from the graphs besides the E_b value that seems to be around 2000 mV. Pitting potential is followed by the 1700-1850 mV obtained for the NiTi archwires and the 600-1187 mV range for the CuNiTi wires.

Pitting potential was the lowest for the Respond at -75 to 10 mV, followed by the D-Rect at 41 to 79 mV and the stainless steel 0.016 at 90 to 205 mV. Higher range of pitting was found for the stainless steel 0.016x0.022 which it was seen to be between 95 and 673 mV.

Therefore, pitting corrosion could be easily found in the stainless steel wires due to the fact that these potentials could be easily found at the oral cavity. Pitting corrosion would be more difficult to be observed in the Ti alloyed archwires given that the required potential are slightly higher than those than can be found in the oral cavity.

These findings are also confirmed by the SEM and photographic findings on the polarised archwires.

Unforced corrosion was performed on the wires by means of an immersion test for 30 days. The first aim was studying the effects of the contact of the electrolyte that simulated the oral environment on the surfaces of the archwires. This effect was to be assessed through the SEM comparison of the scans of as-received specimens and the submerged specimens. AFM was also performed to compare both groups so to obtain more information in case that SEM images did not shed differences. The second aim was to study the Ni leaching in this oral simulated scenario in order to see whether the Ni leached would be or not hazardous for a patient, and also to characterise the Ni leaching kinetics and to establish a comparison with published data on the topic.

The SEM scans taken at x 1500 augments of the stainless steel archwires show microscopic evidence of the effect that the electrolyte had on the surface of the wires after a 30 day exposure. The surface shows an increase in pores that might be explained by the theory of pitting corrosion.

Immersion changes on NiTi and CuNiTi do not seem to be very clear as studied through SEM although some subjective considerations could be done that had to be confirmed by the AFM study.

As it has been seen, SEM scans are not clear when it comes to establishing the evidence of surface changes between archwires immersed for one month in HBSS compared to as-received archwires surfaces. In any case, conclusions drawn from the comparative study of the images obtained at the SEM are subjective in the sense that they rely on the qualitative aspects of the observed changes.

The null hypothesis set was that the archwires do not present changes after being immersed for one month in HBSS when they are compared with a control group of as-received archwires. Therefore, any difference that could be found among the means of the RMS measurements of the two samples should not differ from zero in a significant way.

The statistiscal test chosen for the present research was the t-student test, which is thoroughly used in these kinds of studies.

The hypothesis was set in a directional way, that is, as changes in RMS are expected to be observed due to the immersion in the solution, a directional test was performed instead of the two-tail test that belongs to a non-directional set up. All t_{obs} but the obtained for the NiTi alloy show values higher than t value for a 0,01 level of significance in a directional test.

Following a significant order of variation the archwires could be placed as follows SS 0.016x0.022 (t_{obs} 6,67), Respond (t_{obs} 5,09), SS 0.016 (t_{obs} 3,66), CuNiTi (t_{obs} 3,63), D-Rect (t_{obs} 2,70), NiTi (t_{obs} 0,55). Changes in roughness were noticeable when Bourauel et al[137] roughness criteria for AFM measurements was used.

Nickel leaching was found to be really small, far under the limits established by the European Union regulations and the limits known to inflict cell damage. Nickel released was also seen to be low specially when compared to daily Ni food and drink intake levels and also Ni resulting from cooking utensils release and Ni intake resulting from inhalation.

Although any kind of discussion may be found to be an anecdote after seen the low levels of Ni released by the archwires, it is noteworthy saying that the highest Ni leaching was clearly found among the stainless steel archwires which have a low Ni (8%wt) when compared to the Ti alloyed archwires NiTi and CuNiTi (55%wt and 50%wt respectively). The reason why this happens in the 30 day immersion test should be further studied so that recommendations could be given to clinicians to be aware of Ni leakage when stainless steel wires are engaged. Differences in Ni release kinetics between NiTi and CuNiTi archwires should be studied more thoroughly in order to understand them better.

As shown, the highest amount of Ni released was obtained by the ss 0.016 and ss 0.016x0.022 wires, followed by the Respond and NiTi wires which released almost the same amount. The CuNiTi and the D-Rect wire released the lowest amounts of Ni at the end of the test.

Comparing the obtained results with the highest Ni released value of the ss 0.016 archwire, it can be seen that it is 1.35 times the amount released by the ss 0.016x0.022, it is 1.67 times the amount released by the Respond wire, it is 1.77 times the amount released by the NiTi, 2.09 times CuNiTi's release and 2.77 D-Rect's Ni leaching value.

Summing up, the ss 0.016 wire releases in one month roughly one third more Ni than the ss 0.016x0.022 wire, double the amount of Ni than Respond, NiTi and CuNiTi wires and almost three times the amount that D-Rect wire releases.

It is worthwhile noticing that at the first Ni leaching measurement after one week of immersion, ss 0.016x0.022 and NiTi archwires released roughly the same amount of Ni. D-Rect and CuNiTi archwires showed the same phenomenon at the first week's immersion test.

When Ni release predictions are calculated for the established levels, taking the Ni release rate as that kept for the second week (which would be unreal), it was seen that really long periods of time would be required to obtain the values set as limits.

As long as calorimetry testing is concerned it was seen that R-phase was not found at the CuNiTi specimens tested.

The main difference among CuNiTi specimens can be seen at the 30 day immersed specimen. The 50% austenite phase transformation temperature has significantly been moved towards a higher temperature, and an increase in the hysteresis can be declared when looking at the 50% martensite phase transformation temperature which remained unchanged when compared to the other two specimens. According to the obtained results it could be said that the 30 day immersion on a 37ºC electrolyte seems to have affected the 50% austenite transition temperature range, meaning that in order to obtain a 50% of austenite phase at the archwire, an increased temperature will be needed. As it can be seen there is also a narrowing at the curve that implies that the austenitic phase is obtained in a narrower range of temperatures. Therefore, martensite to austenite transformation can take place on a narrower range of temperatures in an arch that has been under the effect of the immersion in an electrolyte for 30 days under a 37ºC temperature.

Therefore, prolonged exposure to temperatures above the A_f should be checked and studied as a factor linked to a change in transition temperatures, especially when the archwires are under temperatures that are higher than the manufacturers' claim temperature for the A_f value.

As long as NiTi archwires are concerned, all tested specimens showed that these wires present a rhombohedral phase prior to the austenitic and martensitic transformation. The immersion of NiTi in HBSS electrolyte seems to have no impact on the transition transformation temperatures.

A final thought should frame the obtained results of the present thesis.

All the obtained results should not be unrestrictedly applied to the clinical scenario. The corrosion behaviour of the tested samples should be understood as relative to the samples and not as an absolute result.

As previously pointed out, in vitro study of corrosion has many limitations although it is the only way of establishing comparisons among specimens without introducing uncontrolled and unknown variables.