Table 2 Average nickel ions' release from the superelastic NiTi group and the heat-activated NiTi group before ("as received") and after ("retrieved") clinical exposure

Average nickel ions' release, ppb	Superelastic NiTi group ($n = 24$)			Heat-activated NiTi group ($n = 24$)			P value between the two groups
	Mean	SD	P value in the same group	Mean	SD	P value in the same group	
"as received"	8.36	1.81	0.005	7.92	1.89	0.008	NS
"retrieved"	5.81	2.14		5.65	1.6		NS
Difference between "as received" and "retrieved"	−2.55	1.54		−2.27	1.10		NS

SD standard deviation, *NS* not significant

Neither volunteers nor researcher nor data analyzer knew the wire type in each side (triple blindness) in order to increase the validity of the conducted work.

Similar to previous reports, SEM micrographs revealed only descriptive characteristics of wires' surfaces, whereas AFM images provided us with numeric values of the surface roughness and reconstructed three-dimensional images suitable for quantifying different aspects of micromorphology [23, 31, 32].

More rough texture was found in the non-used heat-activated NiTi wires when compared with superelastic ones. This could be attributed to the different procedures applied on heat-activated wires during manufacturing or tumbling and pickling stage. Other papers that reported the opposite finding [23, 24] compared the two types of wires but from different manufacturers with different chemical compositions.

Surface integrity of both types of NiTi wires were affected by oral environment conditions, i.e., temperature and pH variations, flora, masticatory and brushing forces, etc. The data from AFM showed an increase of 25.74 nm in superelastic NiTi wires' roughness (i.e., 46.2 % increase) and an increase of 12.63 nm in heat-activated NiTi wires' roughness (i.e., 14.7 % increase). This confirms the fact that crevice corrosion happened or calcified protein capsule was formed on the retrieved wires [6]. Other studies which demonstrated that there was no effect of clinical use on the NiTi roughness either used optical microscopy and/or SEM only [6, 11] or applied multiple disinfection procedures on wires before AFM measurements [25] that may have affected the accuracy of their results.

This study showed that heat-activated NiTi wires withstood oral conditions to a greater extent and the increase in their surface roughness was less than that recorded in the superelastic ones. This could be due to the fact that heat-activated NiTi wires used in this study had been originally fabricated to express all memory shape properties in 35 °C, whereas the superelastic archwires were not constructed to react favorably against different oral temperature variations. However, both types of wires maintained an acceptable degree of fine surface topography after clinical exposure based on the classification of Bourauel et al. [28], due to the fact that all Sa values were less than 200 nm at the final assessment.

Several factors that may have changed the current picture of results were not included in this study. The period of clinical use in our study was 30 days only, and this duration might be considered relatively short by some authors. The attached wires to braces were set neutrally and did not apply any active forces to the teeth. In addition, there were no big molecular changes on the archwire structure since superelastic wires were not exposed to stress and heat-activated wires were not exposed to cooling.

Though nickel is considered a toxic and cariogenic element, it is an essential component of orthodontic wires [15]. This made the biocompatibility of NiTi wires an important issue for researchers [11, 15, 33]. It is difficult to determine the exact amount of released nickel from NiTi wires in the oral cavity. So, in order to measure the potential release of nickel from NiTi wires in artificial saliva, a GF-AAS was used which is considered a reliable device in detecting released ions in a liquid sample by particle per billion [33–35].

An interaction was recorded between the nickel-titanium alloy and the surrounding environment (i.e., the artificial saliva) and both new superelastic and heat-activated NiTi wires released nickel ions. This is a support to the notion that this alloy is not an inert one [19]. Only tiny amounts of Ni ions were detected when evaluating unused superelastic and heat-activated NiTi wires (8.36 and 7.92 ppb, respectively). This may be because of the redundant Ni ions on the wires' surfaces [19], those Ni ions unlinked to Ti in both types of wires ("used" and "unused") could be easily released in artificial saliva. Kuhta et al. [36] found that superelastic NiTi wires released more Ni than heat-activated NiTi wires, but they studied wires from different manufacturers and immersed them in a different artificial saliva than that used in the current study.

After clinical exposure, GF-AAS detected less Ni ions released in artificial saliva from both types of wires with decrease of 2.55 ppb from superelastic NiTi wires that equals to −30.5 % and with decrease of 2.72 ppb from heat-activated NiTi wires that equals to −28.6 % that indicates a partial damage of the titanium oxide protecting layer causing the release of other alloy components [20]. This is the same result that Gil et al. [37] found after incurring NiTi wires to thermal sterilization treatments.