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Original article

Does long-term intraoral service affect the mechanical properties and elemental composition of multistranded wires of lingual fixed retainers?

Spiros Zinelis[1,2], Nikolaos Pandis[3,4], Youssef S. Al Jabbari[2,5], George Eliades[1] and Theodore Eliades[6]

[1]Department of Biomaterials, School of Dentistry, National and Kapodistrian University of Athens, Greece, [2]Dental Biomaterials Research and Development Chair, College of Dentistry, King Saud University, Riyadh, Saudi Arabia, [3]Private Practice, Corfu, Greece, [4]Department of Orthodontics and Dentofacial Orthopedics, School of Dental Medicine, Medical Faculty, University of Bern, Switzerland, [5]Prosthetic Dental Sciences Department, College of Dentistry, King Saud University, Riyadh, Saudi Arabia, and [6]Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Switzerland

Correspondence to: Theodore Eliades, Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich 8032, Switzerland. E-mail: theodore.eliades@zzm.uzh.ch

Summary

Purpose: The aim of this study was to evaluate the elemental and mechanical alterations of stainless steel (SS) multistranded orthodontic wires used in fixed retention after intraoral ageing.
Materials and Methods: Two types of 0.022-inch, seven-stranded wires, Lingual Retainer Wire (LRW) and Tru-Chrome (TCH), from the same manufacturer (Rocky Mountain Orthodontics, Denver, Colo, USA) were tested. Thirty-three samples from LRW group and thirty-seven from TCH were collected, whereas three unused wires from each package were used as controls. The median ageing time for LRW was 7.4 years and 8.4 for TCH. All samples were subjected to scanning electron microscope/X-ray energy dispersive spectroscopy analysis. Three spectra were taken from the surface of each wire and then all samples were used for the assessment of Martens hardness, indentation modulus (E_{IT}), and elastic index (η_{IT}) with the instrumented indentation testing method (IIT). The intraoral ageing time was statistically compared between the two groups by Mann–Whitney rank sum test and the compositional and mechanical properties were compared by unpaired *t*-test. The Spearman correlation between elemental content and ageing time was carried out for all elements ($a = 0.05$).
Results: No significant differences were found for both the elemental content and for the mechanical properties between the wires tested. Spearman analysis revealed no correlation between elemental content and intraoral time while two groups share statistically equal intraoral ageing times ($P > 0.05$).
Conclusions: Both wires seemed to maintain their mechanical and elemental integrity within a period of 14-year intraoral exposure, whereas no measurable ionic release could be identified.

Introduction

Fixed retainers are used in orthodontic practice to prevent tooth relapse and maintain the orthodontic spatial orientation of teeth in the arch (1, 2). Although the choice of materials has been recently expanded to include fibre-reinforced materials to simplify the bonding process (3), bonded multistranded lingual fixed retainers are considered the gold standard (4) due to their high success rate and absence of negative effects on the periodontium (2, 5). What differentiates the standard use of archwires from that of multistranded wires in lingual fixed retention is the profound difference in the extent of intraoral service, which in retainers can easily reach a decade. In comparison with metallic archwires, the multisranded wires are also free of galvanic phenomena as they are not in direct contact with other metallic alloys. The extended service time of these wires, however, has raised questions on the potential alteration of their mechanical properties and ionic release, which taken along with their loading pattern, which includes stresses arising from teeth tending to relapse and masticatory forces, may trigger a stress corrosion process. Both ionic release and exerted stresses could adversely affect the mechanical properties of multistranded wires due to decomposition of the alloy and the introduction and propagation of cracks.

Evidence from *in vivo* studies including analysis of saliva, serum, urine, and mucosa oral cells have provided contradictory data for the ionic release of Fe, Cr, and Ni from brackets and wires (6–13), implying that different alloys such as stainless steel (SS), titanium alloys, and NiTi, used for the manufacturing of orthodontic wires and brackets may modulate the extent and kinetics of release, with a complex pattern of association between the range of metal content and release potential (7, 12). Although a substantial body of literature has contributed important information on the ageing pattern of bracket and archwire alloys in the oral cavity and the alterations induced by both simulated in various environments and actual clinical service (6–16), there is still a lack of data on the ageing pattern of wires used in lingual fixed retention following exposure times typically seen in retention protocols.

The aim of this study was to evaluate the elemental and mechanical alterations of SS multistranded orthodontic wires used in fixed retention after intraoral ageing. The null hypothesis was that no significant differences will be found before and after intraoral ageing.

Materials and methods

Sample collection

Two 0.022-inch, seven-stranded wires [Lingual Retainer Wire (LRW) and Tru-Chrome (TCH)] from the same manufacturer (Rocky Mountain Orthodontics, Denver, Colo, USA) were included in this study. Eighty patients who had already fixed retainers placed in their mandibular arches after the completion of their orthodontic treatment by the same clinician, were selected according to the following criteria: no active caries, mandibular teeth free of restorations or fractures, satisfactory oral hygiene and plan for a planned removal of lingual fixed retainer because of reasons relevant to the completion of this stage of therapy, or planned move of patients to another city, or own wish of patient. As a standard protocol, the lingual surfaces of the selected teeth had been pumiced and etched with 37% orthophosphoric acid and had been bonded employing an unfilled light cured bonding resin and adhesive (Assure and Flow-Tain; Reliance Orthodontics Products, Itasca, Illinois, USA). Forty patients received fixed retainers made of LRW and forty patients received retainers made of TCH. Upon retrieval of the retainers, the wires were stored in plastic boxes and the intraoral times were recorded. Ethical approval was obtained from Research Ethics Committee of the University of Athens, Greece. Thirty-three fixed retainers were collected from the LRW group and thirty-seven from the TCH. Three wires from each package were stored in plastic boxes and were used as controls. As per standard retrieval protocol, analysis of the samples progressed from the least invasive or non-destructive technique to the destructive one.

Optical microscopy (stereomicroscopy)

All retrieved fixed retainers and the unused wires were studied under a stereomicroscope (Leica M80, Leica Microsystems, Wetzlar, Germany) and photographed with a digital camera (Leica DFC295, Leica Microsystems).

Scanning electron microscope/X-ray energy dispersive spectroscopy analysis (SEM/EDX)

All retrieved samples were imaged by backscattered electron (BE) emission with a scanning electron microscope (Quanta 200, FEI, Hillsboro, Oregon, USA) operating at high vacuum chamber conditions (4.9×10^{-6} Torr pressure), 20 KV acceleration voltage, and 76 μA beam current. The elemental composition of each sample was determined by X-ray energy dispersive spectroscopy (EDX). Three spectra were collected from the surface of each wire on successive wire strands employing an X Flash 6|10 Silicon Drift Detector (Bruker, Berlin, Germany) under the aforementioned conditions and spot analysis mode. The quantification of EDX spectra was carried out by the dedicated software (ESPRIT version 1.9, Bruker) operating in a standardless mode with ZAF (atomic number, absorbance, fluorescence) correction factors. Under these conditions the detection limit of the method was set to 0.2% w/w.

Cross sectional analysis (SEM/EDX and instrumented indentation testing)

All samples and ten 2-mm length wire segments from the unused wires were embedded in epoxy resin (Epofix, Struers, Belarup, Denmark) and ground from 220 to 2000 grit SiC papers under water cooling and polished with diamond pastes (DP, Struers) up to 1 μm in a grinding polishing machine (Dap-V, Struers). Afterwards the surfaces were cleaned in an ultrasonic bath and the microstructure and elemental composition of cross sections were studied by SEM/EDX employing the aforementioned operating conditions. The mechanical properties of all samples were identified by instrumented indentation testing. One force-indentation curve was recorded on each strand using a Vickers indenter, 1.96 N load and 2 seconds contact time with a universal hardness-testing machine ZHU0.2/Z2.5 (Zwick Roell, Ulm, Germany). The Martens hardness (HM), indentation modulus (E_{IT}), and elastic index (η_{IT}; the elastic to total work ratio) were the mechanical properties tested. The mean value of seven measurements was used to characterize the sample.

Statistical analysis

The intraoral ageing time was statistically compared between two groups by Mann–Whitney rank sum test. The elemental content of all probed elements and mechanical property comparisons between control and the clinically aged group were compared by unpaired *t*-test, whereas no comparisons were made between wire types. The Spearman correlation between elemental content and ageing time was carried out for all elements in order to check possible trends over intraoral ageing time. Statistical analysis was carried out the by SigmaPlot (v12) software (Systat Software, Inc., San Jose, CA, USA). In all cases statistical significance was set at 5% ($a = 0.05$).

Results

Intraoral time of tested groups

The median ageing time for the LRW group was 7.4 years with 5.8 and 11.6 years indicating the 25th and 75th percentiles, respectively, whereas for the TCH the median was 8.4 years with 7.1 and 10.0 percentiles. No significant differences were identified between two groups ($P > 0.05$).

Optical microscopy

Figure 1 presents representative images from the surface of retrieved samples (Figure 1A and 1B) and unused wire (Figure 1C). Region of interest is the area of wire, which is in direct contact with oral fluids (Figure 1A) while all retrieved samples demonstrated the formation and retention of intraoral integuments between successive wire strands.

SEM/EDX

Figure 2 illustrates low magnification representative BE images from the surface of retrieved and unused multistranded wires. The presence of intraoral integuments is easily identified between successive strands (pointed by the arrows) due to mean atomic number contrast. Figure 2B shows an unused wire and the spots for spectra acquisition placed on three successive wire strands. The results of EDX analysis appear in Table 1. No statistical significant differences were observed between unused and retrieved groups for all elements tested for both wire types, whereas no correlation of probed elements over intraoral ageing time was identified after Spearman analysis. Table 2 presents both the correlation coefficients and *P* values found after Spearman analysis, while only Cr and Ni content over time for both wires are presented in Figure 3.

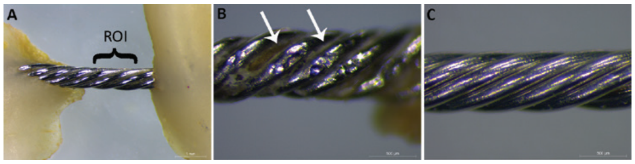

Figure 1. Representative images from the surface of retrieved and unused multistranded wires. (A) Region of interest (ROI) is located at the wire portion between adhesive points which is constantly exposed to oral fluids (nominal magnification ×1.6). (B) The ROI of A in higher magnification. The white arrows indicate the formation of intraoral integument in the fissure between successive wire strands (nominal magnification ×4). (C) Unused sample with bright surface (nominal magnification ×4).

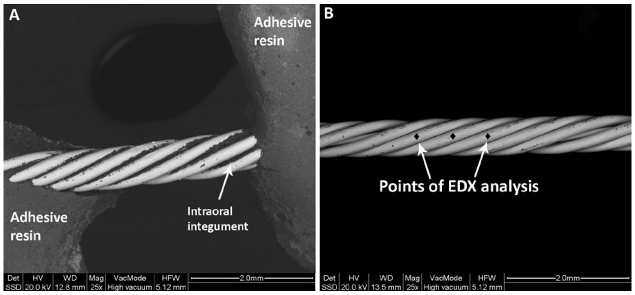

Figure 2. Backscattered electron images from the surfaces of retrieved (A) and unused multistranded wire. The intraoral integument (white arrows) is easily identified due to mean atomic number contrast between successive strands (A). The points of EDX analysis are indicated by white arrows. Nominal magnification ×25.

Table 1. Mean values and standard deviations (in parentheses) for the elemental composition of retrieved (RET) and as-received (CON) multistranded wires. No significant differences (*P* > 0.05) were identified between control and retrieved groups for both wires tested. LRW, Lingual Retainer Wire; TCH, Tru-Chrome.

	Material			
	LRW		TCH	
Element	CON	RET	CON	RET
Fe	69.9 (0.3)	69.9 (0.6)	72.2 (0.7)	70.0 (1.8)
Cr	18.3 (0.4)	18.4 (0.5)	18.2 (0.4)	18.5 (1.2)
Ni	8.1 (0.2)	7.9 (0.4)	8.1 (0.4)	9.5 (1.2)
Mn	1.1 (0.1)	1.2 (0.1)	0.5 (0.1)	0.5 (0.3)
Si	0.5 (0.1)	0.5 (0.1)	0.2 (0.1)	0.5 (0.3)
Cu	2.1 (0.2)	2.1 (0.2)		

Cross-sectional analysis (SEM/EDX and instrumented indentation testing)

Cross-sectional analysis revealed that both wires consisted of a central wire with a slightly larger diameter than its surrounding six counterparts. Moreover, the central wire acts like an axis while the rest six are twisted over it (Figure 4A and 4C). BE image showed mean atomic contrast denoting that different materials are involved in the case of LRW (Figure 4A). Spot EDX analysis revealed that the central wire had a core of almost pure Cu covered by a layer of pure Ni while the rest six wire strands are made of stainless steel (Figure 4B).

Table 2. Spearman correlation coefficients (*r*) and *P* values of elemental content over time for both wires tested. No correlation (*P* > 0.05) was identified for all elements tested. LRW, Lingual Retainer Wire; TCH, Tru-Chrome.

	LRW		TCH	
Element	Correlation coefficient (*r*)	*P* value	Correlation coefficient (*r*)	*P* value
Fe	−0.140	0.521	−0.003	0.983
Cr	0.273	0.205	0.020	0.898
Ni	0.195	0.366	0.009	0.951
Mn	−0.370	0.081	0.046	0.775
Si	0.073	0.736	0.108	0.503
Cu	−0.247	0.252		

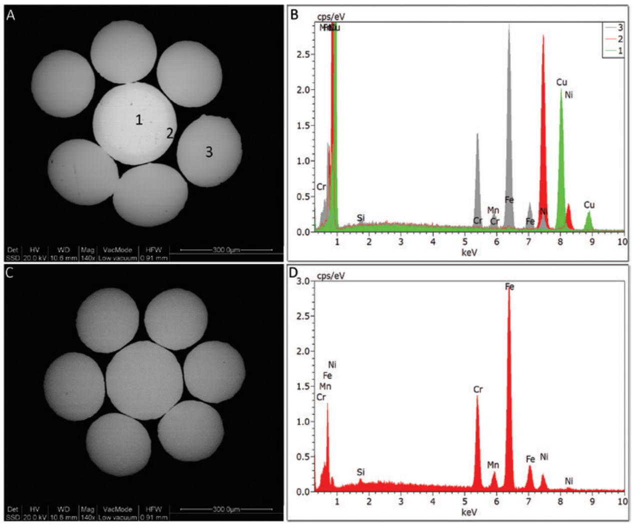

Figure 3. Backscattered electron images (A and C) demonstrate that both wire tested are consisted of a central wire with a slightly larger diameter (original magnification ×140). Representative spectra taken from different point are presented in B and D.

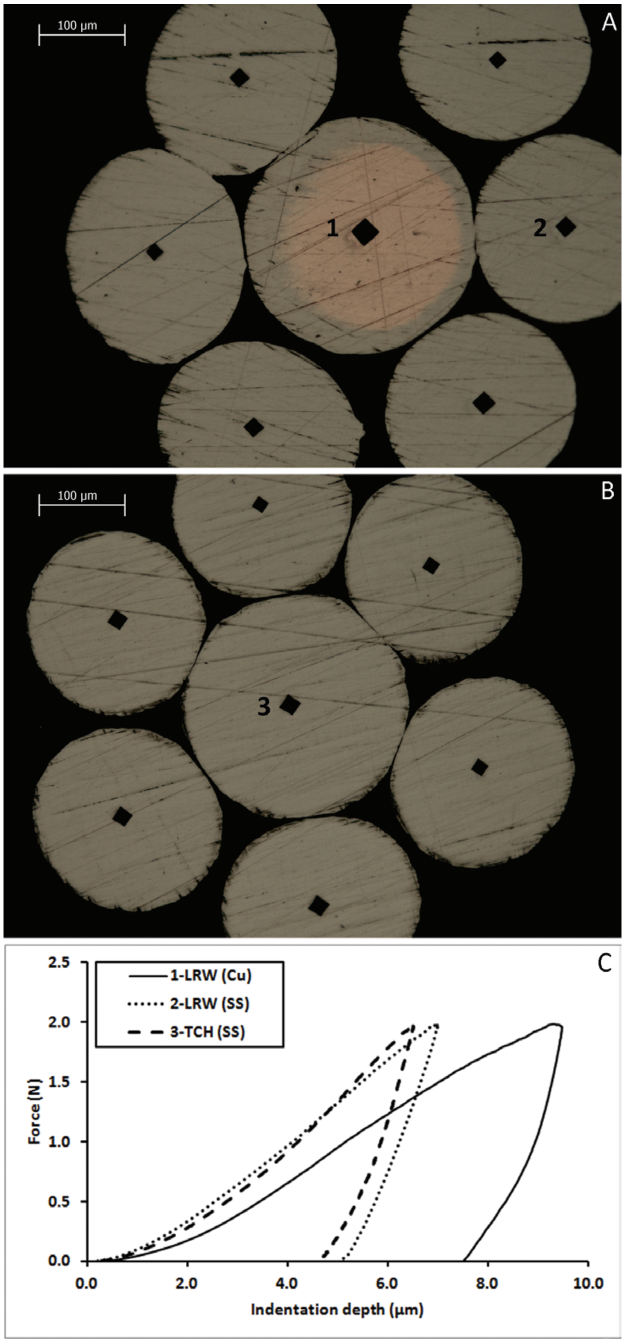

Figure 4. Cross sectional images from the surface of Lingual Retainer Wire (LRW) (A) and Tru-Chrome (TCH) (B) multistranded wires where Vickers indentations are easily identified at the centre of each wire. A larger Vickers indentation is shown at the central wire of LRW (C). Representative force indentation depth curves from the central wire or LRW (1), the surrounding LRW wires (2), and TCH (3).

In contrast to the LRW group, similar spectra were obtained from central and all strand wires from the TCH group (Figure 4D).

Figure 5 illustrate representative images from the cross sections of both wires tested with Vickers indentation clearly shown in the middle of each wire strand. A larger indentation is shown at the centre of central wire in Figure 5A implying a softer material. Figure 5C illustrates representative force indentation depth curves from all materials tested. The mean values, standard deviations, and statistical outcome for all mechanical properties tested are presented in Table 3. No significant differences were found for both materials before and after intraoral exposure for all properties identified.

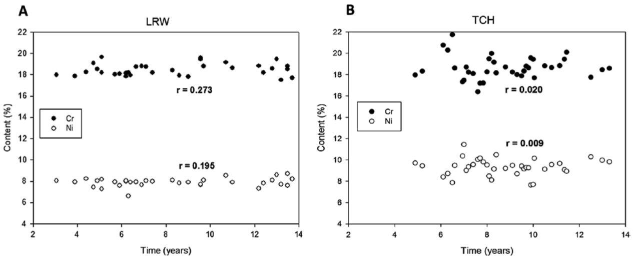

Figure 5. Graphical representation of Cr and Ni content over intraoral ageing time. The elemental content is irrelevant to intraoral exposure time.

Discussion

The results of this study showed that neither the elemental composition nor the mechanical properties of both multistranded wire types changed after intraoral ageing and thus the null hypothesis was not rejected.

The results of EDX analysis (Table 2) indicated that the elemental composition of LRW fits the nominal composition of precipitation hardened (PH) 17-4 martensitic SS while that of TCH is identical to the 304 austenitic grade SS. Both wires consisted of a central wire with slightly larger diameter, which probably acts as a central axis where the strand wires are twisted around it, during the manufacturing process. The selection of a Ni coated Cu wire as a central wire for the case of LRW might have be chosen in order to increase the flexibility of multistranded wire, as the modulus of elasticity of pure Cu (110 GPa) is substantially lower than those of both, American Institute of Steel (AISI) 304 type (193 GPa), and PH 17-4 (204 GPa) SS (17). This apparently increases the compliance of the wire, allowing for efficient handling during bonding.

No significant difference was identified for the intraoral ageing time between LRW and TCH and therefore it can be assumed that both groups share the same ageing effect. There was also no significant alteration of all elements before and after intraoral exposure a finding which is in accordance with previous studies for orthodontic brackets made by PH 17-4 (14), and prefabricated paediatric crowns made by the very similar to AISI 304, 303 SS alloy (18). These findings are further confirmed by the fact that the extent of intraoral service had no effect on the elemental content of retrieved multistranded wires, implying that the alloy composition remained unaltered during the intraoral ageing (15, 16).

The use of Spearman analysis for the investigation of the time-release correlation was preferred over that of Pearson due to the limited application of the latter in linear correlations. The stability of elemental composition of wires should be assigned to the increased corrosion resistance of the aforementioned alloys, the absence of any galvanic coupling (contrary to what occurs in the bracket–archwire complex), and perhaps to the formation of intraoral integument, which covers the fissures between successive strands eliminating the occurrence of crevice corrosion mechanisms.

The inability of this study to deal with wear phenomena and their resultant contribution to release of ions intraorally could constitute a limitation of this experimental approach. As fragmentation or cracking and loss of material cannot be detected by spectroscopic analysis of specimens, owing to the fact that delamination of nano- and microparticles does not alter the overall composition of

Table 3. Mean values and standard deviations in parentheses for selected mechanical properties of retrieved (RET) and as-received (CON) multistranded wires. No significant differences were found before and after intraoral ageing for both wires tested. LRW, Lingual Retainer Wire; TCH, Tru-Chrome.

	HM (N/mm^2)		E_{IT} (GPa)		η_{IT} (%)	
Material	CON	RET	CON	RET	CON	RET
LRW (SS)	972 (108)	1050 (72)	28 (3)	28 (2)	27.0 (1.9)	27.9 (0.8)
LRW (Cu)	461 (96)	439 (57)	23 (2)	22 (2)	19.1 (3.9)	18.2 (2.8)
TCH	1015 (117)	986 (48)	30 (4)	31 (3)	32.7 (2.2)	34.1 (2.5)

material, the role of these phenomena in acting as a reservoir of ionic release source remains unclear (19).

However, optical observation, albeit cumbersome, could be utilized in this case to scan and detect potential surface alterations in the wires; in this study no notable fragmentation was observed in the initial optical observation of the wires.

The absence of significant differences between the unused and retrieved wire with respect of the mechanical properties of wires denote that, despite the extent intraoral ageing, these wires do not undergo any significant work hardening effect. As it expected, Cu demonstrated lower hardness value compare to the SS alloys. Although it would be more clinical relevant if the surface than the bulk hardness was tested, this was limited by the fact that IIT requires well polished and levelled samples. This analysis can be done employing nano-indentation and would be an interesting topic for further research. The estimated values of E_{IT} was found to range well below the values reported in the literature; a possible reason for this discrepancy might be the limitations of the technique (IIT) to determine the modulus of elasticity in non stress-free samples (20). Orthodontic wires have limited ductility as they are fabricated from cold-drawn wires (21). In general, tensile residual stresses underestimate the modulus of elasticity, while compressive stresses have the opposite effect. Because high elastic indices are associated with more brittle materials, TCH showed less ductility than the LRW.

From a methodological perspective, research protocols to investigate metallic ion release from orthodontic alloys can be classified in three major categories based on the experimental environment chosen: *in vitro* using standard electrolyte solutions, retrieval studies, and detection of ions in biologic fluids (22). Alternatively, these studies could be classified based on the experimental methodology utilized into four categories: physical measurements, such as weighing before and after immersion in media; spectroscopic analyses to identify ions in media; analytical techniques, including microscopy and spectroscopy for study of retrieved specimens; and spectroscopic analyses for investigation of ions in biologic fluids.

In vitro studies lack clinical relevance due to simplifications in the models used. The majority of published *in vitro* studies have used various immersion solutions of different acidity to examine the variation in rate and total amount of ion release. The release rate is forced to rapidly reach a plateau because of the equilibrium established between the metal ions present in the solution and the metal ions at the metal-solution interface (23). This leads to the conclusion that the release rate is accelerated initially and remains constant later, an observation that lacks substantiation as for example, multiple-phase alloys, present a long-term release pattern (24).

Study of the metal content of biological fluids on the other hand, is methodologically valid and can be performed at standard conditions, however these protocols face the problem of dealing with an 'open system', implying that the recording of ions in biological liquids is transient and does not represents a cumulative effect thereby possessing poor reliability.

The performance of alloys in the oral cavity through retrieval analyses is relatively new and dates back to 2000 (19), whereas in the broader biomedical field, this approach was already initiated in the study of orthopaedic biomaterials in the early 1970s (25). The adoption of the study of used materials as opposed to *in vitro* aged ones is based on the fact that storage media used in laboratory simulations of the oral environment such as electrolytes, acidic solutions, or artificial saliva cannot reliably simulate the complex intraoral conditions, where fluctuations in temperature, pH, and stresses, the presence of enzymes, microbes and biofilm can alter the progress of corrosion and reactivity of dental alloys under fatigue or corrosion fatigue conditions (26) The results of this study are limited only to the two SS alloys tested and thus further research should include additional commercially available wires with different composition.

Conclusions

Under the limitations of the study, both mutlistranded LRWs tested were shown to maintain their mechanical properties (hardness and modulus) and elemental composition, thus showing no evidence of detectable ionic release for a service period ranging from 3.5 to 14 years.

Acknowledgments

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Conflict of Interest

None to declare.

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