*Original Article*

# Galvanic coupling of steel and gold alloy lingual brackets with orthodontic wires:
## *Is corrosion a concern?*

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**ABSTRACT**

**Objectives:** The aim of this research was to assess galvanic behavior of lingual orthodontic brackets coupled with representative types of orthodontic wires.

**Materials and Methods:** Three types of lingual brackets: Incognito (INC), In-Ovation L (IOV), and STb (STB) were combined with a stainless steel (SS) and a nickel-titanium (NiTi) orthodontic archwire. All materials were initially investigated by scanning electron microscopy / x-ray energy dispersive spectroscopy (SEM/EDX) while wires were also tested by x-ray diffraction spectroscopy (XRD). All bracket-wire combinations were immersed in acidic 0.1M NaCl 0.1M lactic acid and neutral NaF 0.3% (wt) electrolyte, and the potential differences were continuously recorded for 48 hours.

**Results:** The SEM/EDX analysis revealed that INC is a single-unit bracket made of a high gold (Au) alloy while IOV and STB are two-piece appliances in which the base and wing are made of SS alloys. The SS wire demonstrated austenite and martensite iron phase, while NiTi wire illustrated an intense austenite crystallographic structure with limited martensite. All bracket wire combinations showed potential differences below the threshold of galvanic corrosion (200 mV) except for INC and STB coupled with NiTi wire in NaF media.

**Conclusions:** The electrochemical results indicate that all brackets tested demonstrated galvanic compatibility with SS wire, but fluoride treatment should be used cautiously with NiTi wires coupled with Au and SS brackets. (*Angle Orthod.* 2018;88:450–457.)

**KEY WORDS:** Galvanic corrosion; Brackets; Electrochemistry

## INTRODUCTION

Corrosion of orthodontic appliances and the biological consequences are a primary concern of clinical orthodontists, researchers, academics and manufacturers. Therefore, a lot of research has been focused on in vivo phenomena, material characterization, and development of new products involving orthodontic brackets and wires.[1–6] Primary testing of electrochemical properties of orthodontic alloys used in manufacturing orthodontic devices is of paramount importance. In addition, galvanic coupling between dissimilar alloys, such as brackets and wires, is also a hot topic in orthodontic research as it may trigger galvanic corrosion under clinical conditions, increasing ionic release and degrading the functionality of orthodontic devices.[7–14]

Lingual orthodontic brackets were introduced in clinical practice in the late 1970s[15] to satisfy the demand for invisible treatment. However, the position-associated patient intolerance,[16–18] and the in-

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creased shape variability of the anterior tooth lingual surfaces[19] partially undermined their usability. Therefore, an effort was made to overcome these two major drawbacks by manufacturing low-profile brackets and customizing them for each patient, respectively. Recently, gold (Au) base brackets have been introduced with big differences in mechanical properties compared with conventional lingual brackets, which are still made of stainless steel (SS) alloys.[20] In particular, Au alloy brackets are advertised as highly anticorrosive and the first choice for patients allergic to nickel (Ni). A recent retrieval analysis study pointed out that Au base brackets demonstrated elemental and mechanical stability over the course of orthodontic treatment.[21] However concerns have arisen related to the big difference in electronegativity between Au alloy and orthodontic wire made of SS and nickel-titanium (NiTi).

The aim of this study was to investigate the galvanic potential of lingual orthodontic brackets combined with representative types of orthodontic wires in different electrolyte media containing chlorides and fluorides.

## MATERIALS AND METHODS

### Materials Tested

Three types of orthodontic central incisor lingual brackets of 0.022″ slot size were included in this study: Incognito (INC) (3M Unitek, Monrovia, Calif, USA), InOvation L (IOV) (Dentsply GAC, Bohemia, NY, USA). and STb (STB) (Light Lingual System, Ormco, Orange, Calif, USA). One rectangular 0.017 × 0.025″ stainless steel (SS) orthodontic archwire (SAW) (Steel Arch Wires, Forestadent, Bernhard Forster, Germany), and a Ni-Ti wire of similar dimensions (NSE) (Neo Sentalloy, Dentsply GAC) were also tested.

### Scanning Electron Microscopy/X-Ray Energy Dispersive Spectroscopy

Five brackets and five 10-mm segments from the central part of the orthodontic wires were imaged by a scanning electron microscope (QUANTA 200, FEI, Hillsboro, Ore, USA). Secondary electron images were recorded from the surfaces of brackets and wires under the following operational conditions: $10^{-6}$ Torr chamber pressure (high vacuum mode), 20 kV accelerating voltage, 103 μA beam current, and ×100 nominal magnification. The elemental composition of the devices tested was determined using x-ray energy dispersive spectroscopy (EDX) with an X Flash 6|10 Silicon Drift Detector (Bruker, Berlin, Germany). One spectrum was collected from different locations on bracket surfaces (ie, base, soldering alloy, wing) and orthodontic wire using 20 KV accelerating voltage 107 μA beam current and spot analysis mode.

### X-Ray Diffraction Spectroscopy

Ten segments (about 2 mm in length) from each orthodontic wire were retained together along their long axis and embedded in epoxy resin (Epofix, Struers, Belarup, Denmark). Then, the samples were ground up to 4000 grit SiC paper under water cooling and polished with diamond pastes up to 1 μm in a grinding/polishing machine (Dap-V, Struers). Their crystallographic structure was determined using x-ray diffraction spectroscopy (XRD) analysis (D8 Advance; Bruker, Billerica, Mass, USA). Spectra were recorded employing 40 kV accelerating voltage, 40 mA beam current, 30°–100° 2theta angle scan range, 0.02 °/s scanning speed, 0.02° scan step and 1-second preset time.

### Electrochemical Testing

Adequate length SS metallic rods were laser welded (R102915, LaserStar Technologies, Riverside, RI, USA) to the bases of the lingual orthodontic brackets. The orthodontic archwires, the bases of the brackets and a portion of the welded rods were insulated with nonconducting epoxy resin and an elastic rubber tube on top. The electrical connection between the two ends (bracket and wire) was verified by a multimeter. The galvanic cell apparatus consisted of a glass container for the electrolyte, a Plexiglas top permitting the entrance of an orthodontic bracket-archwire couple and preventing evaporation of electrolyte, a voltometer (P903, Consort, Turnhout, Belgium) and a personal computer. The construction of the electrochemical cell and the procedure for measuring galvanic potential difference followed the ASTM G71-81 standard.[22] The ratio of exposed surfaces to the electrolytes corresponded as much as possible to the clinical conditions (8 mm length for orthodontic archwires[7] and the total lingual surface area for the bracket). The volume of electrolyte was selected according to the proposed ratio of 40 mL/cm$^2$ metal surface area (≈55 mL). Measurement of potential difference was conducted at room temperature (25°C) three times for each bracket–wire pair using new specimens each time. Data regarding time and potential were collected continuously for 48 hours every 10 seconds since pilot studies showed that the plateau phase was reached much earlier. The galvanic potential at 48 hours was averaged. Before each measurement, the exposed surfaces were cleaned with acetone to prevent organic contamination. The measurement of galvanic potential difference was measured using Consort nv Software

(2002), and the data were graphically represented accounting for the noise as well.

Two electrolytes were used containing chloride and fluoride ions, respectively. The first electrolyte was an acidic (pH = 2.3) water-based solution of lactic acid 0.1M and NaCl 0.1M according to ISO 10271.[23] The second electrolyte was a water-based solution of NaF 0.3% that corresponded to 1394 parts per million (ppm) fluoride ion with a pH = 6.5. Deionized water was used to prepare both electrolytes.

## RESULTS

### Scanning Electron Microscopy/X-Ray Energy Dispersive Spectroscopy

Figure 1 demonstrates representative SEM images and EDX spectra from the surfaces of the brackets and wires tested. The elemental content of material tested after EDX analysis is presented in Table 1. Figure 1A shows the INC brackets as a single-unit appliance made by a precious alloy (Au-Cu-Pt-Ag) (Figure 1B, Table 1). The IOV consists of a base and wing joined together by an intermediate zone with successive overlapping laser spots (Figure 1C). The EDX analysis (Figure 1D) illustrated that the base and wing were made of different SS alloys. The STB was also a two-piece structure made by a base and wing of different SS alloys joined together by a high Au soldering alloy (Table 1). SAW (Figure 1G) and NSE (Figure 1I) were typical orthodontic wires made of SS and NiTi, respectively (Table 1), with the latter showing a rougher surface compared with the former.

### X-Ray Diffraction Spectroscopy

The XRD analysis (Figure 2) showed that SAW consisted of austenite ($\gamma$ phase) and martensite ($\alpha'$ phase) iron structures. NSE exhibited predominately an austenitic NiTi structure with limited content of martensite.

### Electrochemical Testing

The potential differences over time for all bracket-archwire combinations tested are presented in Figure 3. Table 2 demonstrates the mean values and standard deviations of the final potential differences after 48 hours. In all cases, the potential difference seemed to reach a plateau during the first hours after immersion except for STB-NiTi in NaCl/lactic acid and for all bracket-NiTi combinations in NaF, where a constant value was reached at a later stage of recording (Figure 3D). INC coupled with SS wire (SAW) showed the lowest potential difference (-19mV) in the acidic conditions of NaCl/lactic acid solution followed by IOV (–24 mV) and STB (–58 mV), while the potential differences were eliminated in the NaF media (Table 2). INC and IOV showed minimal differences (4 and -9 mV respectively) when coupled with NiTi wire (NSE) in NaCl/lactic acid solution, while STB showed a higher value (–95 mV). In NaF solution, IOV showed the lowest difference (55 mV) followed by STB (203 mV) and INC (319 mV).

## DISCUSSION

Both ferrous brackets (IOV and STB) are two-piece structures that consist of different alloys in the base and wing parts. However, both brackets share similar compositions for base and wing components. The elemental composition for the base fits well with the nominal composition of austenitic SS AISI 316 alloy (%wt: Fe balance, Cr: 16–18, Ni: 10–14, Mo: 2–3, Mn: 2.0),[14] while the wings correspond to the nominal composition of precipitation hardening SS alloy PH 17-4 (%wt: Fe balance, Cr: 15–17, Ni: 3–5, Cu: 3–5, Si: 1, Mn: 1, and traces of P, S, and C).[13] However, the base and wing are joined by laser welding for IOV, while for STB they are soldered by a high Au soldering alloy. Both technologies (laser welding and soldering) have been extensively used in bracket technology, with the latter always raising concerns for galvanic actions of dissimilar alloys.[1,13,24] In contrast, INC is a single-piece appliance made of a high Au-Cu-Pt-Ag alloy (Table 1). The XRD analysis of orthodontic wires was essential, especially for Ni-Ti wires as their electrochemical properties are dominated by the presence of different phases.[25] The results of XRD analysis in accordance with previously reported XRD results,[26] where NSE consisted mainly of an austenitic phase. SAW showed a smoother surface, a finding that is analogous to previously published data.[27]

Two solutions were used in this study. The first solution was acidic with a pH of 2.3 and is proposed by ISO 10271 for screening testing of electrochemical properties of dental materials.[23] The susceptibility of orthodontic brackets and wires to F ion is concentration-related and has been tested many times in NaF solutions with similar concentrations (0.1$\sim$0.5 %wt).[28–31] Furthermore, the concentration of 0.3% NaF used corresponds to 1394 ppm F ion, which is below the upper limit of 1450 ppm present in child toothpastes.[32]

In the presence of acidic NaCl/lactic acid electrolyte, INC brackets exhibited the lowest galvanic values independent of the archwire type (Table 1). Therefore, it seems that the nobility difference between the orthodontic alloys is not the main factor affecting the results, but rather, the passivation dynamics are more important. This involves the formation of chromium[33,34] and titanium oxide[35–38] protective layers as well as the tendency to dissolve by the electrolyte constituents

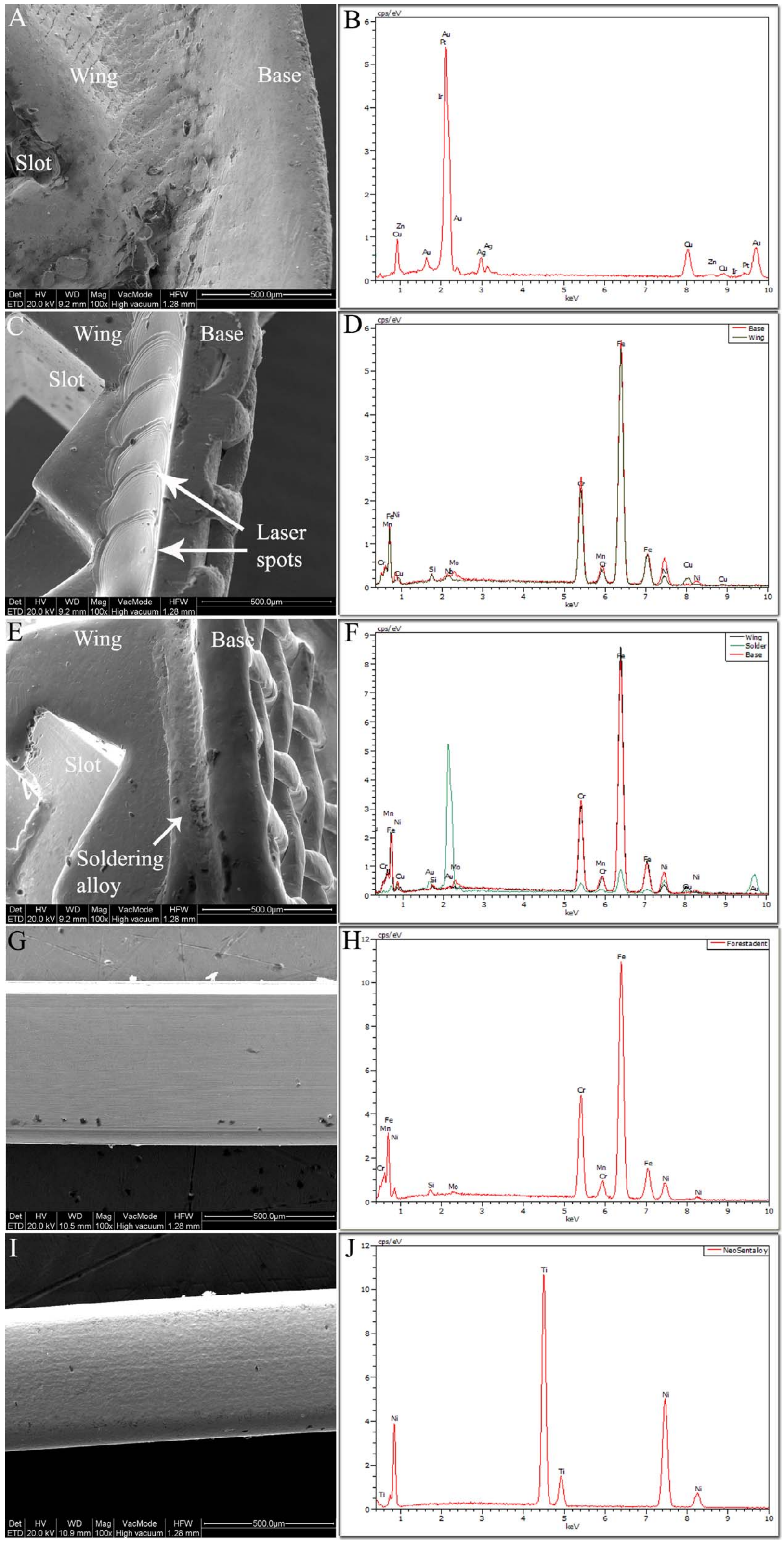


**Figure 1.** Representative secondary electron images (SEI) and EDX spectra from the surfaces of brackets and wires tested. INC is a single-unit bracket (A), while IOV(C) and STB(E) demonstrate an intermediate zone with successive laser spots and soldering alloy, respectively. EDX spectra show that, for both brackets, bases and wings are made of different SS alloys (D and F). SAW (G) illustrates a smoother surface compared with NSE (I) orthodontic wire. Nominal magnification 100×, scale 500 μm.

**Table 1.** Mean Values of Elemental Content of All Material Tested After X-Ray Energy Dispersive Spectroscopy Analysis (n = 5)[a,b]

| | | IOV | | STB | | | | |
|---|---|---|---|---|---|---|---|---|
| Elements | INC | Base | Wing | Base | Soldering | Wing | SAW | NSE |
| Fe | | 67.5 | 73.2 | 71.1 | 12.2 | 76.9 | 72.2 | |
| Cr | | 17.3 | 16.3 | 16.4 | 3.5 | 15.5 | 18.2 | |
| Ni | | 11.3 | 3.8 | 9.9 | 7.8 | 4.1 | 7.6 | 52.5 |
| Cu | 13.2 | | 4 | | 1.7 | 3.5 | | |
| Mo | | 2.5 | | 2.1 | | | 0.4 | |
| Mn | | 1 | 0.8 | 0.6 | 0.5 | 0.4 | 0.8 | |
| Si | | 0.7 | 0.7 | 0.4 | 0.3 | 0.5 | 0.6 | |
| Au | 69.6 | | | | 73.8 | | | |
| Ag | 7.4 | | | | | | | |
| Pt | 8.3 | | | | | | | |
| Zn | 1.2 | | | | | | | |
| Ti | | | | | | | | 47.5 |
| Ir | 0.6 | | | | | | | |
| Nb | | | 1.0 | | | | | |

[a] Standard deviations are less than 0.6 for all elements tested and have been omitted for the sake of clarity.
[b] INC indicates Incognito bracket (3M Unitek, Monrovia, Calif); IOV, InOvation L bracket (Dentsply GAC, Bohemia, NY); NSE, nickel-titanium archwire (Neo Sentalloy, Dentsply GAC); SAW, stainless steel archwire (Steel Arch Wires, Forestadent, Bernhard Forster, Germany); STB, STb bracket (Light Lingual System, Ormco, Orange, Calif).

and acidity. In general, SS alloys are more susceptible to chloride ion attack than titanium,[30] and acidity acts in a deleterious way synergistically.[39] Although the base and wing of IOV and STB are made of the same alloy, they showed different galvanic potentials. The latter showed higher galvanic potential (Table 1) with both wires tested, a finding that should be attributed to the Au-base soldering alloy. Previous studies have reported the development of an intermediate diffusion zone depleted from Au, and thus, it is of questionable corrosion resistance.[24] From a clinical point of view, an opposite relationship might be more favorable since brackets remain intraorally throughout treatment, whereas archwires can be replaced monthly or sooner. Nevertheless, the potential difference of all bracket-archwire couples did not surpass 200 mV, which is considered the threshold for galvanic action between dissimilar alloys. Thus, galvanic corrosion is not anticipated to occur at this particular corrosive environment.

In contrast to NaCl/lactic acid electrolyte, INC brackets were characterized by the worst behavior in combination with NiTi alloy archwires in NaF solution. In a similar manner, the STB bracket, due to its Au brazing, exhibited potential difference close to the limit of 200 mV. Clinically, the ability of the orthodontist to change the NiTi archwires monthly minimizes the alterations to their mechanical properties, but this is not true for the biocompatibility consequences. The concentration of electrolyte fluoride ions used was close to the upper limit of 1450 ppm present in toothpastes for children. Nevertheless, possible fluo-

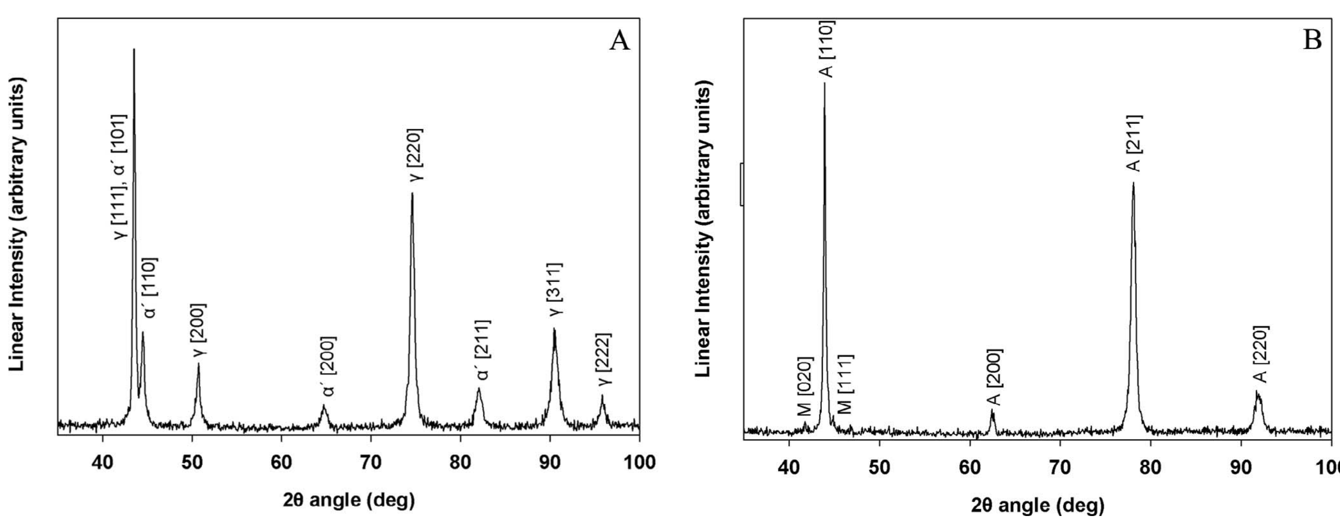


**Figure 2.** XRD spectra of SAW (A) and NSE (B) wires tested. (A) SAW consists of austenite (γ phase) and martensite (α′ phase) iron structure. (B) NEO shows the presence of NiTi austenite (A) structure with limited presence of martensite (M).

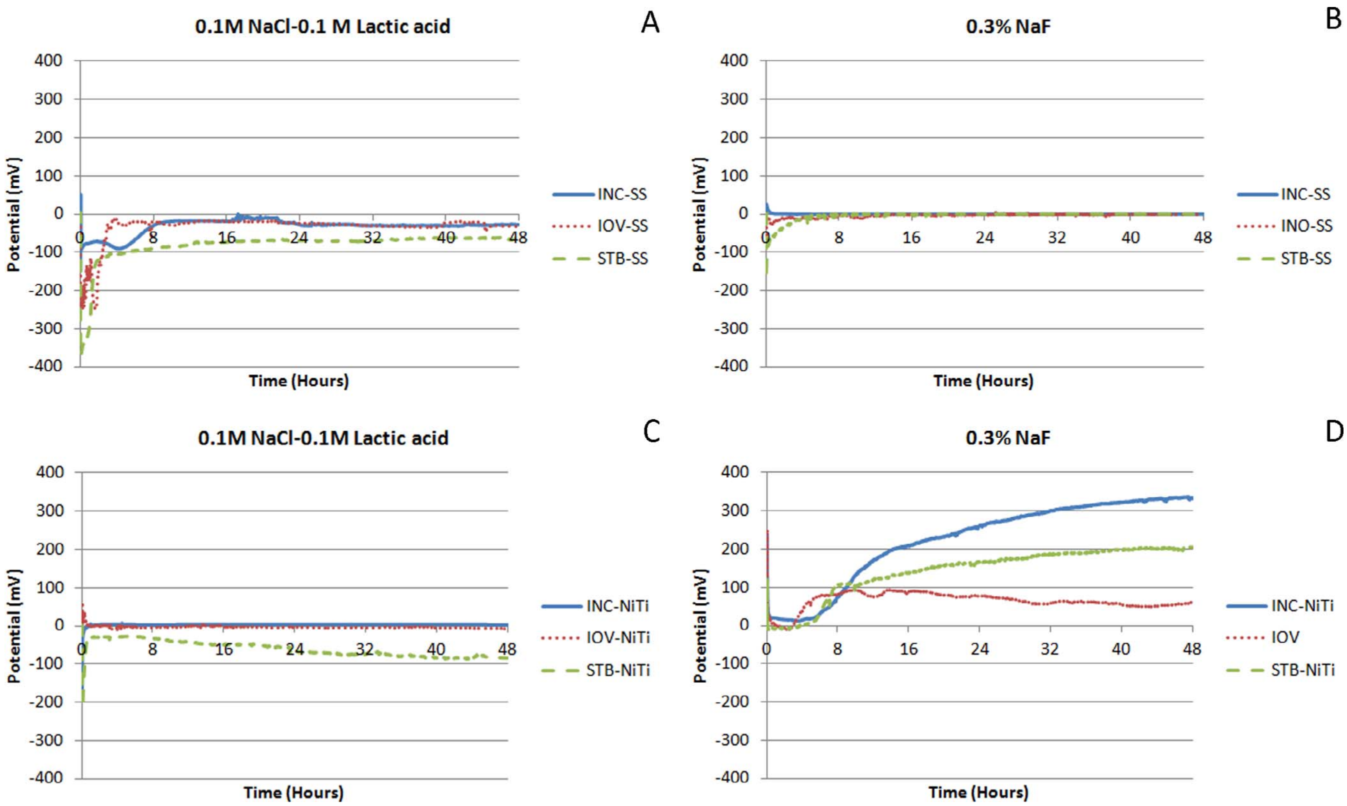


**Figure 3.** Graphic representation of galvanic potential difference changes recorded for 48 hours in different electrolytic environments. Lingual orthodontic brackets coupled with SS archwire (SAW) in NaCl/lactic acid (A) and NF (B) media. Lingual brackets coupled with NiTi archwire in NaCl/lactic acid (C) and NaF (D).

ride gel topical therapy, where fluoride concentrations may reach up to 12500 ppm, should be postponed in the presence of NiTi orthodontic archwires, or the wires should be temporarily removed during the process and replaced at the end by the clinician. In any case, low-concentration fluoride dentifrices and toothpastes should be preferred.

A limitation of this study was that the galvanic potentials cannot be extrapolated directly to intraoral conditions because of the multiplicity of factors that could alter the reactivity of materials in the oral environment. These factors include the adsorption of integuments and formation of biofilm, temperature and pH fluctuations, as well as enzymatic and microbial activity. Contrary to other electrochemical phenomena, such as ionic release in which saliva samples could be obtained and analyzed, experimental testing is the only way to measure the intensity of galvanic coupling between dissimilar alloys. Although the experimental results might differ from what happens under clinical conditions, the ranking of different combinations is indicative of the most vulnerable pairs of materials.

## CONCLUSIONS

- The electrochemical results indicate that all brackets tested demonstrated galvanic compatibility with SS

**Table 2.** Galvanic Coupling Potential Difference Results Recorded After 48 Hours: Mean (SD) of Three Measurements[a,b]

| | Galvanic Potential (mV) | | | |
|---|---|---|---|---|
| | SAW | | NSE | |
| | NaCl/Lactic Acid | NaF | NaCl/Lactic Acid | NaF |
| INC | –19 (16) | 0 (2) | 4 (2) | 319 (44) |
| IOV | –24 (12) | –1 (1) | –9 (1) | 55 (42) |
| STB | –58 (13) | 0 (2) | –95 (23) | 203 (2) |

[a] Positive values correspond to archwire oxidation and bracket reduction while negative to the opposite effect.
[b] INC indicates Incognito bracket (3M Unitek, Monrovia, Calif); IOV, InOvation L bracket (Dentsply GAC, Bohemia, NY); NSE, nickel-titanium archwire (Neo Sentalloy, Dentsply GAC); SAW, stainless steel archwire (Steel Arch Wires, Forestadent, Bernhard Forster, Germany); STB, STb bracket (Light Lingual System, Ormco, Orange, Calif).

wire, but caution is suggested in performing fluoride treatment in the case of NiTi wires coupled with Au and SS brackets.

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