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RESEARCH ARTICLE

Corrosion Analysis of Orthodontic Brackets and Arch Wires – An *in vitro* Study

D.M.L. Wijesinghe, W.S.S. Gunathilake*, W.B.M.C.R.D. Weerasekera and U.J.M.A.L. Jayasinghe

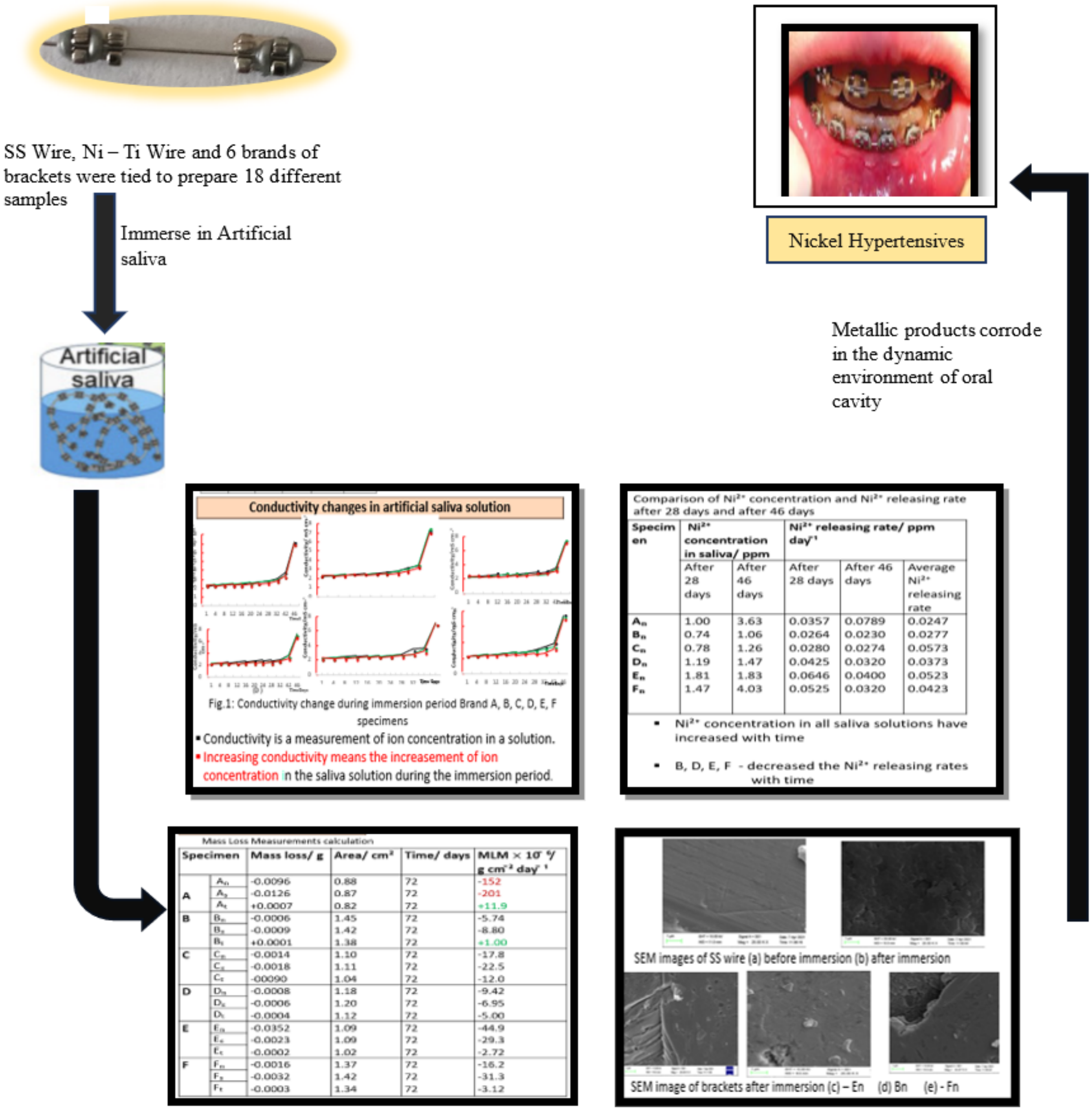

Fig.1: Conductivity change during immersion period Brand A, B, C, D, E, F specimens

- Conductivity is a measurement of ion concentration in a solution.
- Increasing conductivity means the increasement of ion concentration in the saliva solution during the immersion period.

Comparison of Ni^{2+} concentration and Ni^{2+} releasing rate after 28 days and after 46 days

Specimen	Ni^{2+} concentration in saliva/ ppm		Ni^{2+} releasing rate/ ppm day^{-1}		
	After 28 days	After 46 days	After 28 days	After 46 days	Average Ni^{2+} releasing rate
A_n	1.00	3.63	0.0357	0.0789	0.0247
B_n	0.74	1.06	0.0264	0.0230	0.0277
C_n	0.78	1.26	0.0280	0.0274	0.0573
D_n	1.19	1.47	0.0425	0.0320	0.0373
E_n	1.81	1.83	0.0646	0.0400	0.0523
F_n	1.47	4.03	0.0525	0.0320	0.0423

- Ni^{2+} concentration in all saliva solutions have increased with time
- B, D, E, F - decreased the Ni^{2+} releasing rates with time

Mass Loss Measurements calculation

Specimen		Mass loss/ g	Area/ cm^2	Time/ days	MLM $\times 10^{-5}$/ g cm^{-2} day^{-1}
A	A_n	-0.0096	0.88	72	-152
	A_s	-0.0126	0.87	72	-201
	A_t	+0.0007	0.82	72	+11.9
B	B_n	-0.0006	1.45	72	-5.74
	B_s	-0.0009	1.42	72	-8.80
	B_t	+0.0001	1.38	72	+1.00
C	C_n	-0.0014	1.10	72	-17.8
	C_s	-0.0018	1.11	72	-22.5
	C_t	-00090	1.04	72	-12.0
D	D_n	-0.0008	1.18	72	-9.42
	D_s	-0.0006	1.20	72	-6.95
	D_t	-0.0004	1.12	72	-5.00
E	E_n	-0.0352	1.09	72	-44.9
	E_s	-0.0023	1.09	72	-29.3
	E_t	-0.0002	1.02	72	-2.72
F	F_n	-0.0016	1.37	72	-16.2
	F_s	-0.0032	1.42	72	-31.3
	F_t	-0.0003	1.34	72	-3.12

Highlights

- In all saliva samples, Ni^{2+} concentration has increased with time, while in some Ni^{2+} releasing rates declined with time.
- All specimens prepared using Ni -Ti wires release Ni^{2+} in the range between 9 – 20 ppm during the one-year study period.
- The study confirms that all brands of brackets used in this study were able to develop nickel hypersensitivity with time.

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Corrosion Analysis of Orthodontic Brackets and Arch Wires – An *in vitro* Study

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Abstract: Orthodontic plates are fixed onto the teeth in a dynamic environment in the oral cavity. The Orthodontic appliances, which includes both the brackets and the arch wires, are exposed to different pH fluctuations in the mouth. These appliances are manufactured using metal alloys that made out from nickel, iron, cadmium and titanium. These are commercially available in Sri Lanka and in the international market in different prices covering a large price range. Recent studies are investigating on the biocompatibility of these materials with the aim of determining the upper limit of the biological tolerance and to find methods to maintain ion release within acceptable limits. According to the previous studies there are evidences that the Ni and Cr ions release from Ni-Cr alloy in the presence of different acidity of artificial saliva. In this research *in vitro* corrosion process of selected orthodontic wires in artificial saliva solutions were evaluated with the aim of identifying a relationship between the quality and the price of selected orthodontic appliances available in Sri Lankan market. Eighteen specimens from different brands were selected and immersed in each of different types of artificial saliva at different pH, for different storage periods. All the sample tubes were incubated at 37 °C. The release of metal ions from specimens with time were studied by conductivity, Atomic Absorption Spectroscopic (AAS) and mass loss measurements. According to the results, all specimens prepared using Ni -Ti wires release Ni^{2+} in the range between 9 ppm – 20 ppm during one year study period. Ni^{2+} concentration in all saliva solutions has increased with time and in specimens B, D, E, F the Ni^{2+} releasing rates were decreased with time. According to this study, all brands of brackets which were used in this study may lead to develop nickel hypersensitivity with time.

Keywords: Orthodontic appliances; corrosion; nickel; ion release; chromium

INTRODUCTION

The fixed orthodontic appliance is an appliance fitted on to the crowns of teeth of orthodontic patients who are adolescents and adults. The duration of treatment ranges from approximately one year to 3 years. The appliance is fixed onto the teeth in a dynamic environment in the oral cavity (House et al., 2008). The metallic components currently used in orthodontic treatment differ widely depending on them with composition and characteristics, reflecting the physical and mechanical properties required (Hwang, 2001). The deterioration of dental materials caused by the aggressive action of the environment is how orthodontic appliances corrode, and the oral environment encourages corrosion (Turpin, 2011). Potential cause of corrosion are the quantity, quality and pH value of secreted saliva (which are affected by the diet and intake of medicines or drugs), intake of organic acids commonly found in foods and beverages (such as lactic, acetic, malic, oxalic, tartaric, and carbonic acids), and accumulation of dental plaque (Rimsdottir et al., 1982). Orthodontic brackets and arch wires are manufactured with metal alloys such as nickel, iron, cadmium and titanium (Schiff, 2005; Coiffi et al., 2005). These ions on the other hand are claimed to be toxic to the human being. The commonest problem is allergies to Ni (Dunlap, 1989). Further, Ni and Cd are toxic metals to kidneys and prolonged exposure and accumulation of these ions can contribute to kidney disease which is endemic to many parts of the world (Lindsten & Kurol, 1997).

The orthodontic market is flooded with various products with different standards. Therefore, orthodontic clinician can be tempted to choose any product regardless of the quality of the product. It is not only the bio mechanics that has to be taken into consideration when selecting the brackets and arch wires for the patient but also the heavy metal ion content and potential accumulation (Genelhu et al., 2005; Kim et al., 1999). There is an increasing awareness of the biocompatibility of the materials used for orthodontic treatment (House et al., 2008). Clinicians need to have a thorough insight into the biocompatibility of the products when they are used on the patients.

The aim of this study was to identify and quantitatively estimate the heavy metal ions released from a set of selected orthodontic brackets commercially available in the Sri Lankan market with the duration of usage.

MATERIALS AND METHODS

Materials

Commonly used six different brands of brackets (A, B, C, D, E, F) and two types of arch wires (Ni- Ti, and Stainless

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steel) which have different prices in the Sri Lankan market were selected.

Urea (U5128-500G, Sigma Aldrich, Germany), $NaH_2PO_4.2H_2O$ (12054-85-2, HiMedia, India), (1073-4405, DAEJUNG), NaF (HIMEDIA, India) and KCl (KOSDAQ, India) were used in preparing artificial saliva. Purified water (0.55 µS/cm, TKA Smart pure, Germany) was used throughout. The pH of the solution was adjusted using dilute NaOH (Research lab fine chem, India) and dilute nitric acid (0.6 % HNO_3 v/v, 7647-01-0, HIMEDIA, India).

$NiCl_2$. $6H_2O$ (97%, HIMEDIA, India), $CrCl_3$. $6H_2O$ (93%, 807180217, research lab fine chem, India) and $FeCl_3$ (98% ,7705-08-0, SRLCHEM) were used for prepare standard solutions.

Instrumentation

For the determination of the relative composition of metallic elements present in the specimen, Xray Fluorescence Spectrometer (XRF) (Fischerscope - Model – DF500FG – 456) was used. Mass loss measurements were recorded using analytical balance (AS 220/C/2). Area measurements were done using PDFTRON software. Incubator (Hightec Sri Lanka) was used to maintain the temperature at 37℃. A digital magnetic stirrer and a hot plate (VELF sciencetifica, Malaysia) were used to control stirring and temperature. Ultrasonic cleaner (Thomas scientific, MA – 1823, Germany) was used to clean the surfaces of specimens. 10 – 100 µl and 100 – 1000 µl micropipettes (CE-IVD – HT, 98/79/EC) were used to measure microliter volumes. For the measurement of pH of the saliva solutions, pH meter (420A, ORION) was used. Conductivity meter (585129, EZODO, Taiwan) was used to measure conductance. Ion chromatography (METROHM, Switzerland) was used for the determination of anions present in the artificial saliva solutions. Scanning Electron Microscopy (SEM), (ZEISS) was used to analyze the surface of brackets and arch wires before and after the immersion.

Methods

Six brackets from one brand were selected and Ni – Ti wire and SS wire were selected to prepare samples. Two brackets were tied to SS wire and another two brackets were tied to Ni – Ti wire. Remaining two brackets were not bound to a wire and these two were used for the comparison of the effect of the wire. This procedure was followed for each brand of brackets. All the tested materials were brand new parts of the orthodontic appliances and these brackets and arch wires were ultrasonically cleaned using Ethanol solution for 15 minutes. Then, the relative metal composition of samples was determined using X ray fluorescence Spectroscopy (XRF) test.

The artificial saliva solution was prepared by the following method (Wendl et al., 2017). Urea, $NaH_2PO_4.2H_2O$, NaF and KCl was used in preparing artificial saliva. Purified water was used throughout. The pH of the solution was adjusted using dilute NaOH and dilute nitric acid.

The anion composition of the prepared artificial saliva was compared with the normal human saliva using Ion Chromatography (IC) before starting the experiments.

The study was carried out in a specially designed incubator. The system consisted of a filament bulb (40 W) to generate heat. The bulb was turned off automatically using electronic temperature controlling system, when temperature exceeds 37℃. Stainless steel water bath was used to evenly distribute the heat. 12 ml of artificial saliva solution was withdrawn from stock solution for each test tubes and samples were immersed and were incubated at 37℃ which is the standard normal human body temperature.

The initial masses of each purified specimen were measured before immersing in each test solution with an accuracy of ± 0.0001 g. Specimens were withdrawn from each test solution after immersion period (72 days) and the masses were measured. From Mass Loss Measurements (MLM), mass loss per unit area per day and percentage mass loss per unit area per day were calculated. PDFTRON software was used to measure the surface areas of brackets.

Conductivity changes in the sample solution were measured in four days intervals and graphs were drawn using MS excel.

After 28 days from immersion, 0.5 ml from each test samples were withdrawn and the metal composition (Ni, Cr, Fe) was determined using Atomic Absorption Spectroscopy (AAS). For the AAS analysis, standard addition method was used. In standard addition method, 100 ppm Ni^{2+} standard solution was prepared using $NiCl_2$. $6H_2O$, 100 ppm Cr^{3+} standard solution was prepared using $CrCl_3$. $6H_2O$ (93%) and 100 ppm Fe^{3+} standard solution was prepared using $FeCl_3$ (98%). 0.5 ml from each solution were withdrawn after 28 days, 42 days, 56 days, 70 days from the immersion day for analysis using AAS. Then, the following procedure was followed for 0.5 ml which was withdrawn from sample A_s. 20 µl parts were withdrawn from 0.5 ml volume, using micropipette and standard addition method was followed.

SEM images were obtained for specimens before and after immersion in saliva solutions to analyze the morphological changes that take place during the process.

RESULTS AND DISCUSSION

In this research, the influence of different oral environmental conditions on the corrosion behavior of orthodontic appliance specimens was studied. To evaluate the corrosion behavior of alloys, anion concentration (Cl^-, F^-) in saliva is very important. The corrosive effect of the artificial saliva-based solutions is due to the presence of chloride ions (Milosev et al., 2013; Anwar et al., 2011). If the environment contains certain amount of chloride ions, it would lead to the formation of pitting corrosion. It is a form of symmetrical localized corrosion in which pits are formed on the metal surface (Taher & Jabab, 2003; Perez, 2014). Also, the presence of fluoride ions significantly affects the corrosion behavior of Ti metal (Strietzel, 1993; Lee et al., 2009). The presence of anions significantly affects the corrosion behavior of metals (Park & Shearer, 2004). All the alloys in acidified saliva show an active behavior due to the presence of significant concentrations of HCl, HNO_3,

HF, HF^{2-} species that dissolve the spontaneous air formed oxide film giving rise to surface activation. (Chelariu, 2014). Due to these reasons, characterization of saliva is a very important step. Ion Chromatography (IC) was used for characterization of anion composition in artificial saliva. Figure 1 shows the ion chromatogram for artificial saliva at pH 7.3. Table 1 shows the concentrations of each anion. Accordingly, artificial saliva contains 633.68 ppm Cl^-, 23.948 ppm NO_3^-, 18.7 ppm phosphate. The concentration of chloride ions in the normal human saliva varied between 355 – 1500 ppm (Thaysen, 2015).

Table 2 shows the relative metal percentages of each metal present in specimens. Accordingly, the most detectable metals present in the specimen are Fe, Cr, Ni. In addition to these metals, Cu, Co, Mo and Mn are present in trace quantities.

PDFTRON software was used to measure the surface areas of brackets. Table 3 shows the mass loss per square centimeter per day. The immersion period studied was 72 days.

According to mass loss measurements it is clear that the specimens which were prepared using brand A brackets lose high amount of mass during the immersion period. However, the specimens, A_t and B_t which were prepared without a wire have increased their masses. The reasons for mass increase can be due to the deposition of metal oxides and microbial growth such as Algae in laboratory conditions.

Passivation is a chemical process that create a thin layer of oxide on the surface of the metal and loss of chemical reactivity experienced by certain metal alloys under particular environmental conditions. The material becomes self-protective against corrosion by means of a protective film formation on the surface. The layers are observed to be multilayered with the composition depending on the electrochemical potential, electrolyte composition, temperature, type of metal or metal alloy, etc. The following metals or metal alloys containing them exhibit passivity: iron, nickel, silicon, chromium, and titanium. Under typical conditions, zinc, cadmium, tin, uranium, and thallium only show a limited passivity (Keun-Teak et al., 2005).

An assumed half-cell reaction might occur during the passivation of chromium in acidic medium as follows:

$$2\,Cr + 3\,H_2 0 \rightarrow Cr_2 0_3 + 6e^- \tag{1}$$

The iron, cobalt – chromium, titanium alloys used in orthodontic appliances rely on the formation of the passive oxide film to prevent corrosion (Maijer & Smith, 1986). This protective layer is not infallible. It is vulnerable to both mechanical and chemical damage. A and B brackets

Table 1: Concentrations of anions present in artificial saliva

Retention Time/ Min.	Area/µ S cm⁻¹) min.	Height/ µ S cm⁻¹	Concentration/ ppm	Anion
3.423	0.345	1.156	Invalid	
8.145	126.242	341.819	633.680	Chloride
11.563	0.069	0.105	1.024	Bromide
13.027	2.329	5.342	23.948	Nitrate
18.772	32.927	47.317	697.803	Phosphate

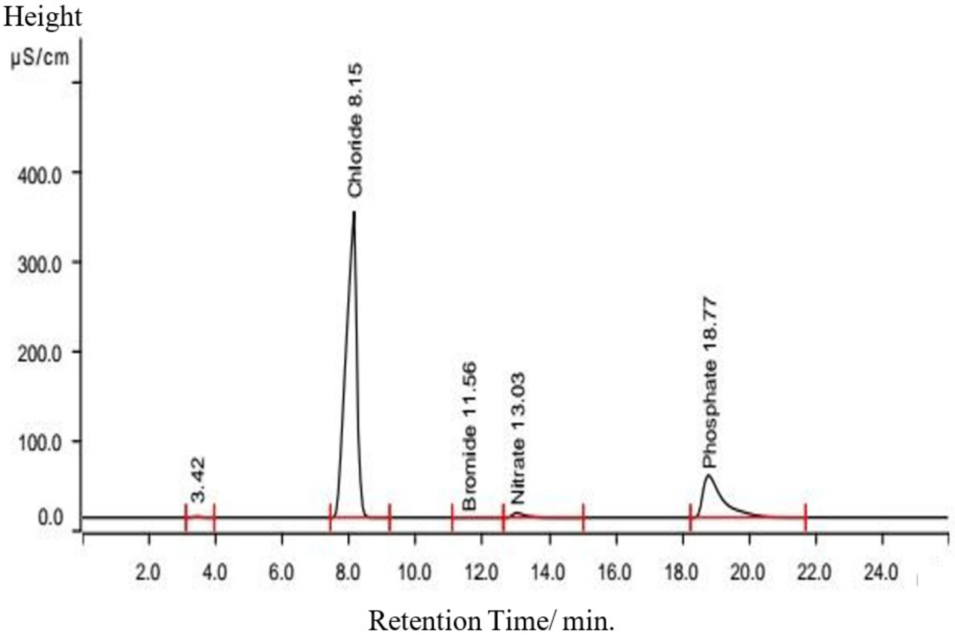


Figure 1: Ionic chromatogram for artificial saliva

Table 2: Relative metal percentages in brackets and arch wires.

Brand	Fe %	Cr %	Ni %	Cu %	Mn %	Mo %	Co %	Ti %
A	76.42	15.41	4.97	3.20	-	-	-	-
B	74.29	18.20	3.83	3.68	-	-	-	-
C	72.18	19.12	8.70	-	-	-	-	-
D	69.92	17.94	12.13	-	-	-	-	-
E	74.30	17.53	4.55	3.63	-	-	-	-
F	-	32.26	-		0.93	6.08	-	-
SS	71.52	19.29	8.47	-	0.73	-	-	-
Ni – Ti	-	-	55.04	-	-	-	60.73	44.96

Table 3: Mass loss measurements of specimens.

Brand	{(Average mass of SS wires + two brackets) ±0.0001} /g			{(Average mass of Ni-Ti wires + two brackets) ± 0.0001}/ g			(Average mass of two brackets alone ± 0.0001) /g		
	Initial	Final	Mass difference	Initial	Final	Mass difference	Initial	Final	Mass difference
A	0.1321	0.1195	-0.0126	0.1347	0.1251	- 0.0096	0.0787	0.0794	+ 0.0007
B	0.1783	0.1774	-0.0009	0.1773	0.1767	-0.0006	0.1321	0.1322	+0.0001
C	0.1589	0.1571	-0.0018	0.1550	0.1536	-0.0014	0.1440	0.1350	-0.0090
D	0.1674	0.1668	-0.0006	0.1591	0.1583	-0.0008	0.1398	0.1394	-0.0004
E	0.1615	0.1592	-0.0023	0.1645	0.1293	-0.0352	0.1310	0.1308	-0.0002
F	0.1700	0.1666	-0.0032	0.1644	0.1628	-0.0016	0.1322	0.1319	-0.0003

Table 4: Calculations of Mass Loss Measurements (MLM).

Specimen		Mass loss/ g	Area/ cm²	Time/ days	MLM × 10^{-6}/ g cm^{-2}/ day
A	A_n	-0.0096	0.88	72	-152
	A_s	-0.0126	0.87	72	-201
	A_t	+0.0007	0.82	72	+11.9
B	B_n	-0.0006	1.45	72	-5.74
	B_s	-0.0009	1.42	72	-8.80
	B_t	+0.0001	1.38	72	+1.00
C	C_n	-0.0014	1.10	72	-17.8
	C_s	-0.0018	1.11	72	-22.5
	C_t	-00090	1.04	72	-12.0
D	D_n	-0.0008	1.18	72	-9.42
	D_s	-0.0006	1.20	72	-6.95
	D_t	-0.0004	1.12	72	-5.00
E	E_n	-0.0352	1.09	72	-44.9
	E_s	-0.0023	1.09	72	-29.3
	E_t	-0.0002	1.02	72	-2.72
F	F_n	-0.0016	1.37	72	-16.2
	F_s	-0.0032	1.42	72	-31.3
	F_t	-0.0003	1.34	72	-3.12

(-) – Mass loss; (+) – Mass increase

contain Fe and Cr. Their mass increment can be due to the formation of an oxide layer (Strietzel, 1993).

The saliva contains about 99 % of water and also, pH 6.75 is a suitable pH for algae growth (Michael et al., 2017). More than 700 bacterial species have already been identified in the human oral cavity, with up to 500 species in an individual oral cavity. The oral microbiota of adult humans holds a variety of viruses, fungi, protozoa, archaea, and bacteria. The oral epithelium, tongue, soft and hard palate, and teeth surfaces, and also dental restorations and prosthesis, orthodontic brackets and arch wires, are all colonized by different biofilms with varied bacterial species. Significant corrosion is caused by sulfate-reducing bacteria and different dental materials exhibit varied resistance to biocorrosion (Wang et al., 2022; Huang, 2003; Huang et al., 2003; Huang et al., 2001).

According to MLM calculations, most of the specimen lose their mass at ppb level per day. High percentage of this mass loss occur due to the corrosion of iron as shown in the following reactions 1 and 2. Iron in a weak acid like lactic acid, the oxidation reaction results in dissolution of the iron and ferrous ion is produced. Hydrogen ions are converted to hydrogen gas during reduction at the cathode (Maia, 2014). This corrosion process continues until the metal is completely consumed, unless the metal can form a protective surface layer (passivation).

$$Fe\,(S) \rightarrow Fe^{2+}\,(S) + 2e \tag{1}$$

$$2H^{+}\,(aq) + 2e \rightarrow H_2\,(aq) \tag{2}$$

All specimens which were prepared using Ni – Ti wire lose their mass. Many studies have demonstrated that, in a fluoridated, acidic environment, the corrosion susceptibility of Ti is increased. In these circumstances, the highly protective TiO_2 layer is breached, permitting corrosive attack of the underlying alloy (House, 2008). The artificial saliva which was used in this study have low concentration of fluoride and low acidity. Due to that reason, it is possible to form a TiO_2 layer on the specimens, which helps to retain without breaching the TiO_2 layer. Most of the specimens which were prepared using SS wire lose more mass than the specimens which were prepared using Ni – Ti wire. SS wire contain high percentage of Fe. Fe has a higher ability to corrode than Ni, Ti. The brand C brackets have a higher MLM value than other brackets.

Two brackets were used without binding to arch wires to evaluate the mass loss from wire alone. Table 5 shows the mass losses only from arch wires. Accordingly, same type of wire loses different amounts of masses when bind to different brackets. Sometimes it can be due to the galvanic corrosion. Arch wires and brackets made from different metals (Cr, Co, Ni, Ti) and were immersed in a common electrolyte and in contact with each other physically, galvanic corrosion is possible to take place. There can be a galvanic coupling which leads to a galvanic cell. The anode of the galvanic cell has the lower corrosion resistance than the cathode, and therefore, the anode undergoes corrosion (Müller, 2004). When the galvanic couple is changed, corrosion rate of the wire can be changed (Matasa, 1995).

Ni^{2+} ion concentration was determined using AAS. Due to the low concentration of Ni^{2+} ions in the solution, standard addition method was applied to calculate the unknown Ni^{2+} concentrations.

Table 5: Mass loss from only arch wires.

Brand	**Mass loss from only Ni – Ti wire $\times 10^{-6}$ / mg cm^{-2} day^{-1}**	**Mass loss from only SS wire $\times 10^{-6}$ / mg cm^{-2} day^{-1}**
A	-	-
B	-	-
C	5.80	10.5
D	4.42	2.47
E	42.18	26.58
F	13.08	28.18

Table 6: Comparison of Ni^{2+} concentration and Ni^{2+} releasing rate after 28 days and after 46 days.

Specimen	**Ni^{2+} concentration in saliva/ ppm**		**Ni^{2+} releasing rate/ ppm day^{-1}**		
	After 28 days	**After 46 days**	**After 28 days**	**After 46 days**	**Average Ni^{2+} releasing rate**
A_n	1.00	3.63	0.0357	0.0789	0.0247
B_n	0.74	1.06	0.0264	0.0230	0.0277
C_n	0.78	1.26	0.0280	0.0274	0.0573
D_n	1.19	1.47	0.0425	0.0320	0.0373
E_n	1.81	1.83	0.0646	0.0400	0.0523
F_n	1.47	4.03	0.0525	0.0320	0.0423

According to calculations, the solution with the specimen E_n have the highest concentration of Ni^{2+} ion and the lowest is the solution with B_n specimen. Ni^{2+} concentration in saliva solution after 46 days from immersion was measured and Table 6 shows the comparison of Ni^{2+} releasing rates. According to Table 6, Ni^{2+} concentration in all saliva solutions have increased with time and in specimen B, D, E, F the Ni^{2+} releasing rates were decreased with time. Specimen F_n releases the highest amount of Ni^{2+}. Then, specimen A_n have high corrosion rate. Specimen B_n have the lowest corrosion rate. Table 8 shows the conductivity measurements of saliva solutions during the immersion period.

Conductivity is a measurement of the ability of an aqueous solution to convey an electrical current. The current is carried by ions, and therefore the conductivity rises with the concentration of ions present in the solution. In this study, conductivity is rapidly increased after 42 days from the immersion. It can be due to the metal release from specimens. Specimen D_n showed a higher conductivity than all other specimens after 4 days from immersion. This specimen contained higher percentage of nickel than all other specimens. Other specimens contained higher percentage of iron. The passivation rate of iron is higher than nickel and iron form protective layers that reduce the ion releasing (Wang, et al., 2021) But nickel has lower passivation rate. Because of this, the rate of oxide film formation is slow (Eliadas & Brantley, 2016). As a result of this, nickel containing metals and metal alloys are corroded easily and release ions. It can be the reason for higher conductivity of D_n specimen than the others after 4 days. Figure 2 to 7 show the conductivity change during the time period.

Table 8: Conductivity change measurements of artificial saliva during immersion period.

Day	**1**	**4**	**8**	**12**	**16**	**20**	**24**	**30**	**34**	**42**	**46**
An	2.36	2.39	2.43	2.44	2.49	2.64	2.72	2.83	3.07	3.79	7.19
As	2.36	2.42	2.49	2.55	2.61	2.65	2.67	2.8	2.94	3.38	7.12
At	2.36	2.36	2.39	2.42	2.48	2.51	2.58	2.6	2.81	3.39	7.03
Bn	2.36	2.37	2.43	2.47	2.51	2.58	2.69	2.78	3.12	3.34	7.34
Bs	2.36	2.36	2.4	2.43	2.46	2.51	2.57	2.74	3.08	3.46	7.43
Bt	2.36	2.36	2.38	2.39	2.44	2.49	2.54	2.61	2.79	3.16	7.02
Cn	2.36	2.43	2.5	2.62	2.64	2.68	2.87	2.94	3.01	3.63	7.28
Cs	2.36	2.37	2.43	2.54	2.61	2.67	2.68	2.7	2.73	3.45	7.21
Ct	2.36	2.36	2.38	2.4	2.43	2.48	2.51	2.64	2.77	3.2	6.96
Dn	2.36	2.45	2.59	2.64	2.71	2.77	2.83	2.85	3	3.63	7.31
Ds	2.36	2.36	2.37	2.4	2.44	2.47	2.51	2.55	2.72	3.58	7.3
Dt	2.36	2.39	2.39	2.41	2.42	2.49	2.54	2.58	2.66	3.06	6.97
En	2.36	2.41	2.53	2.57	2.63	2.68	2.71	2.82	3.46	3.72	7.17
Es	2.36	2.39	2.42	2.46	2.53	2.6	2.68	2.75	2.86	3.47	7.07
Et	2.36	2.34	2.37	2.39	2.43	2.48	2.55	2.64	2.78	3.28	7.09
Fn	2.36	2.41	2.53	2.57	2.63	2.68	2.71	2.82	3.46	3.72	7.17
Fs	2.36	2.39	2.42	2.46	2.53	2.6	2.68	2.75	2.86	3.47	7.07
Ft	2.36	2.34	2.37	2.39	2.43	2.48	2.55	2.64	2.78	3.28	7.09

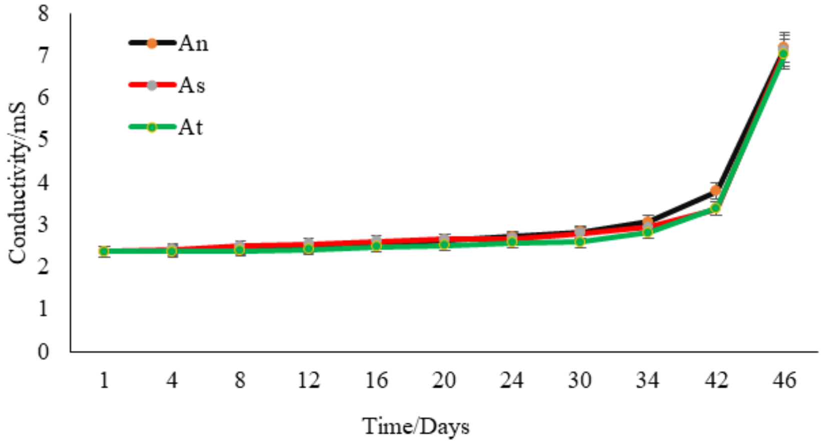


Figure 2: Conductivity change during immersion period for Brand A specimens

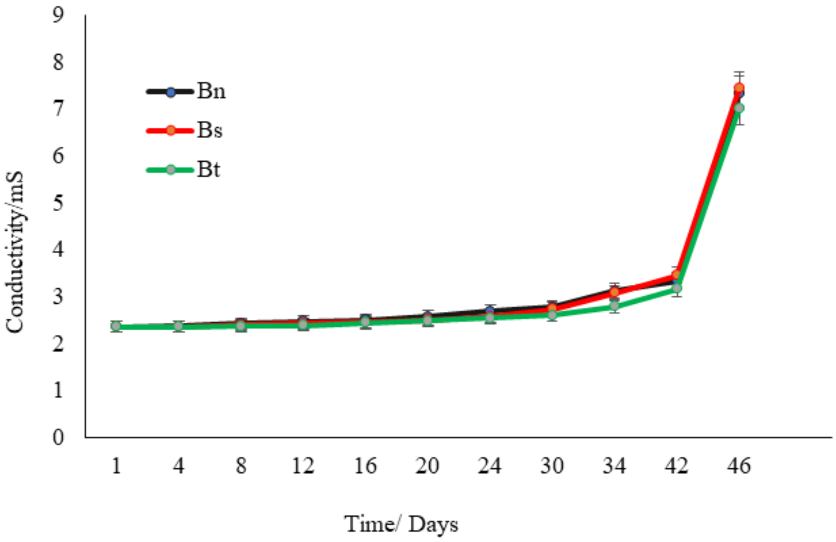


Figure 3: Conductivity change during immersion period Brand B specimens.

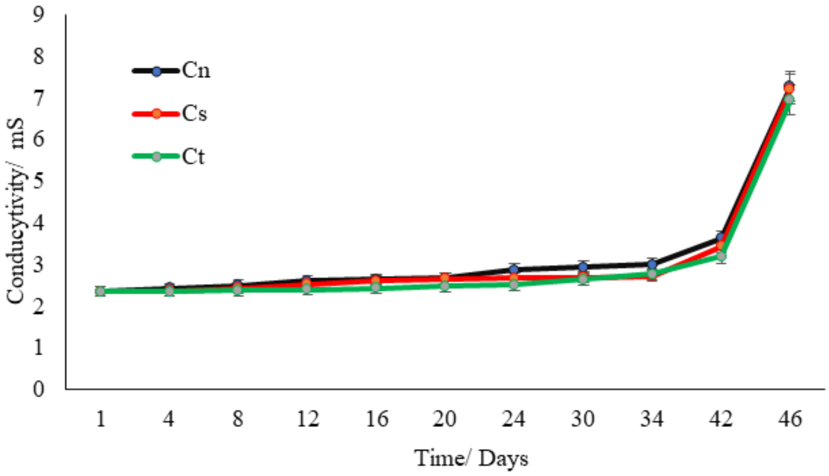


Figure 4: Conductivity change during immersion period Brand C specimens.

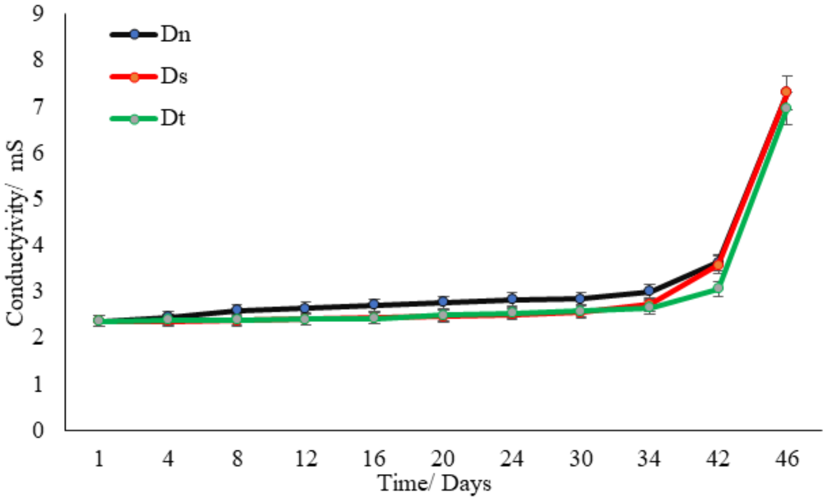


Figure 5: Conductivity change during immersion period Brand D. specimens

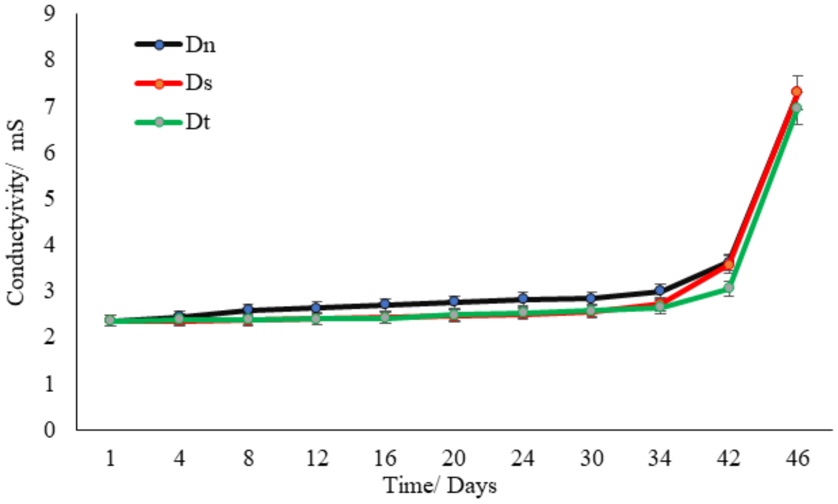


Figure 6: Conductivity change during immersion period Brand E specimens

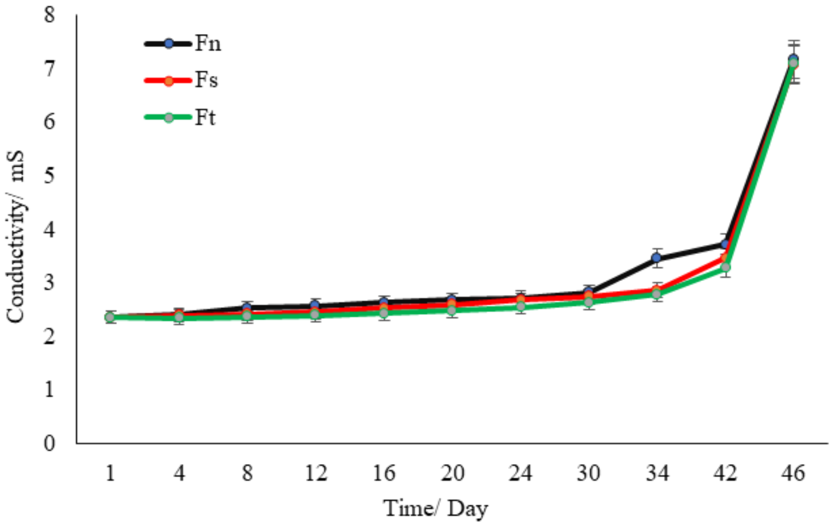


Figure 7: Conductivity change during immersion period Brand F specimens.

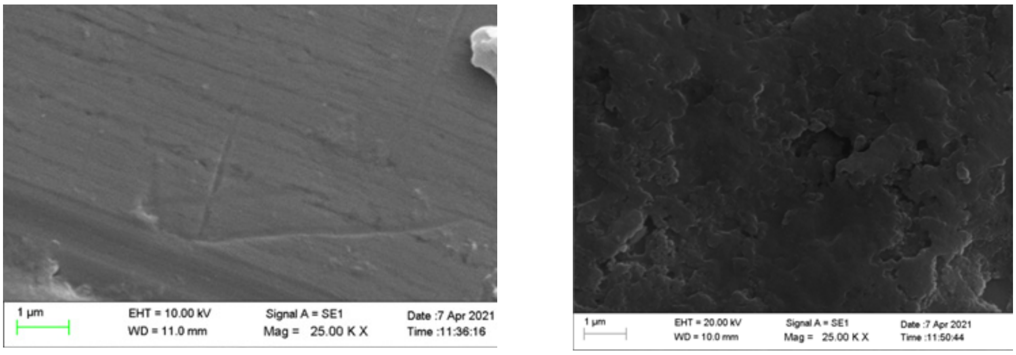
In this study, three different techniques were used to investigate the metal release from orthodontic brackets and arch wires. The results indicate that the investigations from the conductivity measurements and concentration calculation values follow the same trend. Mass loss can be occurred due to the release of Fe, Cr, Ni, Cu, Ti. Some oxide layers can be deposited on the metal surface, and it can be the cause to increase the mass loss.

Figure 8 to 12 Show the surface changes that take place during the immersion period.

The original morphology of the wires (the presence of flaws or highly rough) can also affect their corrosion performance (Perez, 2014). Figure 8(a) and Figure 9 presents the surface morphology of the as-received commercial SS and Ni-Ti wires. It is feasible to observe that both wires present smooth surfaces, without many defects. Nevertheless, the Ni-Ti wire (Figure 9) present small cracks and pores. Since the presence of manufacturing defects may accelerate the corrosion process (Perez, 2014), these small defects in Ni-Ti wires may influence their performances in aggressive environments. According to the Figure 8(b) SS wire present many defects, on the surface after immersion. And also, B_n, E_n, F_n brackets present many defects due to the corrosion.

CONCLUSION

According to all measurements taken, it can be concluded that the orthodontic appliances release metals in the corrosive environment of the oral cavity. According to the mass loss measurements, specimen which was prepared using brand "B" brackets and Ni – Ti wires show the highest resistivity for the corrosion. The specimen "A_s" (brand A brackets + SS wire) has a higher mass loss rate than other specimens. Considering specimens which were prepared using only brackets, brand "E" has the lowest mass loss rate than other brackets. SS and Ni – Ti wires lose different masses when brackets bind with different brands of brackets. Mass loss occur due to the release of Fe, Cr, Ni, Cu, Ti. ions. According to Ni^{2+} concentrations



(a) (b)

Figure 8: SEM images of SS wire (a) before immersion (b) after immersion.

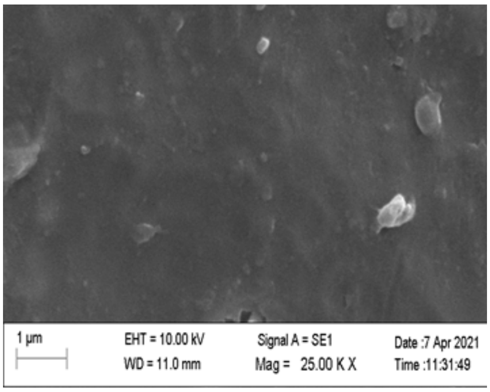


Figure 9: SEM image of Ni – Ti wire before immersion.

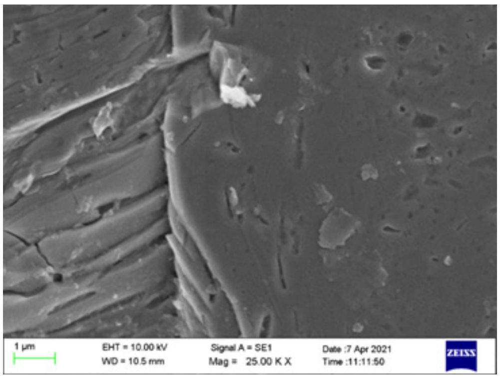


Figure 10: SEM image of bracket in specimen E_n after immersion.

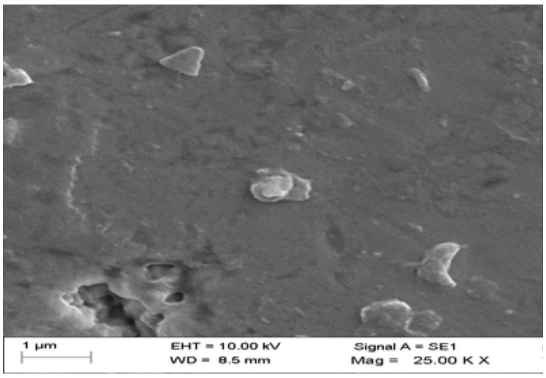
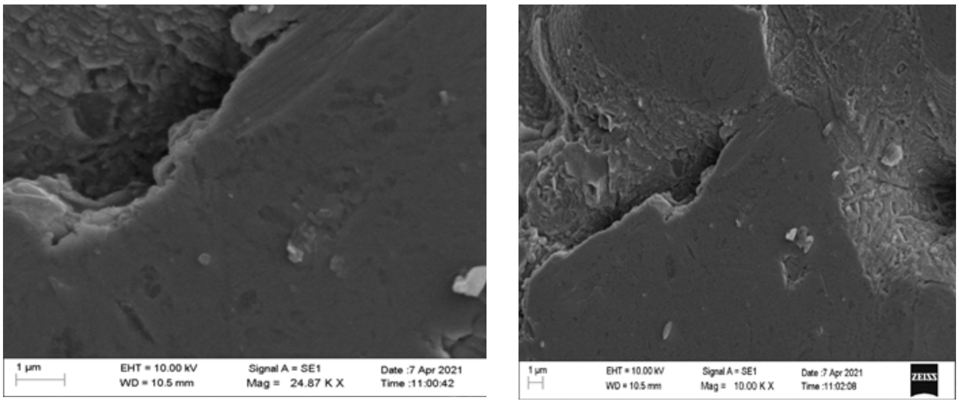


Figure 11: SEM image of bracket in specimen B_n after immersion.



(a) (b)

Figure 12: SEM image of bracket in specimen F_n after immersion (a) 25000 × (b) 10000 ×

in the saliva, the specimen which was prepared using brand F brackets and Ni – Ti wire releases the highest amount of Ni^{2+} and specimen which were prepared using brand "B" brackets and Ni – Ti wire releases the lowest amount of Ni^{2+}. Therefore, considering Ni^{2+} release, the specimen B_n (Brand "B" brackets + Ni – Ti wire) is the safest orthodontic appliance among these brands. All specimens which were prepared using Ni -Ti wires release Ni^{2+} in the range between 9 ppm – 20 ppm during one-year treatment period. The daily amount of Ni^{2+} released was insignificant when compared with the daily dietary intake. However, even such a small amount of release might produce sensitivity when the orthodontic appliances place for 2 to 3 years. Because symptoms can be developed several years later, nickel hypersensitivity should be observed on a long-term basis. Further, these values can be changed according to the oral environment conditions. According to this study, all brands of brackets which were used in this study could lead to develop nickel hypersensitivity with time.

DECLARTION OF CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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