The Effect of Acidity Level on Ions Released and Corrosion of Metal Orthodontic Appliances at Different Time Intervals (An *In vitro* Study)

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ABSTRACT

Background: This study measured the effects of three parameters pH value, length of immersion and type of archwire on metal ions released from orthodontic appliances.
Materials and Methods: Ninety maxillary halves simulated fixed orthodontic appliances that were immersed in artificial saliva of different pH values (6.75, 5 and 3.5) during 28 day period. Three types of archwires were used: stainless steel, nickel titanium and thermal activated nickel titanium. The quantity of nickel and chromium ions was determined with the use of atomic force spectrophotometer while iron ions by spectrophotometer. Each orthodontic set was weighted two times, before the ligation and immersion in the artificial saliva and after 28 days at the end of immersion period using analytic balance device.
Results: The release different metal ions was observed: nickel (Ni), chromium (Cr) and iron (Fe)). Statistically analysis of variance (ANOVA) and t-test were used. Results showed that (1) the appliances released measurable quantities ofall ions examined; (2) the change in pH had a very strong effect on the release of ions; (3) the release of ions was dependent on wire composition, but it was not proportionalto the content of metal in the wire and (4) orthodontic samples showed decreases in the weight at the end of the study.
Conclusion: Levels of released ions are sufficient to cause delayed allergic reactions. This must be taken into account when type of archwire is selected, especially in patients with hypersensitivityor compromised oral hygiene.
Key words: Orthodontic appliances, ions released, pH. (J Bagh Coll Dentistry 2015; 27(4):168-174).

INTRODUCTION

There is increasing concern about the biocompatibility of dental materials and, therefore, this topic has been widely investigated during recent years [(1)]. Fixed orthodontic appliances usually include brackets, bands, and archwires made of stainless steel (containing approximately 18% chromium and 8% nickel) or nickel-titanium (where nickel content exceeds 50%). These alloys have to be fully biocompatible and must elicit an appropriate biological response within a host [(2)]. Since orthodontic fixed appliances have become popular, the question about the quantity and potential cytotoxicity of released metal ions is still valid [(3)].

"Warning: This product contains nickel and/or chromium. A small percentage of the population is known to be allergic to nickel and/or chromium. If an allergic reaction occurs, direct the patient to consult a physician". This common information on orthodontic product labels makes research on the biocompatibility of orthodontic appliances a timely issue [(4)].

Several methods can be used to evaluate the release of metal ions from dental alloys: in vitro (e.g., in the environment of artificial saliva or tissue culture [(6,7)] and in vivo experiments with the application of invasive (e.g., blood) [(8)] or non-invasive matrices (e.g., saliva, hair, urine) [(9-13)]. None of the abovementioned methods is able to reflect the real, changeable, complex environment of the human oral cavity.

Electrochemical reactions during which the surface of a metal is deteriorated via ion release are called corrosion. Internal corrosive factors are determined by metal composition and structure; external factors depend on biological surroundings (e.g., media composition, pH, temperature, strain, illumination) [(12)].

The oral environment is conducive to biodegradation and corrosion of dental materials caused by constant chemical, mechanical, thermal, microbiological, and enzymatic changes[(14)]. The mouth is moist and has a fluctuations in temperature. The liquids and food ingested have wide ranges of pH. Acids are released during breakdown of food stuffs. This food debris adheres strongly to the metals providing a condition that is highly conducive to the accelerated reaction between the oral media and the metal or alloy [(15,16)].

Nickel is the most common cause of contact allergy [(17)]. Orthodontic brackets, bands, and archwires are universally made with an alloy, which contains approximately 6% to 12% nickel and 15% to 22% chromium [(6)]. In addition to the allergic issue, carcinogenic, mutagenic, and cytotoxic effects have been assigned to nickel and, to a lesser extent, chromium.

The introduction of metal ions into the human body is an additional risk to health since these

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ions may be released in different places and at different levels, depending on the characteristics and solubility of the products containing them [18]. Consequently, biological functions are affected, which may lead to systemic and local effects [19].

Several studies have demonstrated that metal ions from fixed orthodontic appliances, primarily nickel and chromium, can cause allergic reactions[20-22].

Other reports have indicated that 4.5% to 28.5% of the population is nickel hypersensitive, and this condition is more prevalent among females. This might be so because women could have been sensitized by wearing jewelry that contains nickel [23,24]. Besides allergic reactions, metal ions released from orthodontic appliances could have carcinogenic, mutagenic, and cytotoxic effects [25].

The purpose of the present study was to determine the quantities of three metal ions (nickel, chromium and iron) released from three different metal orthodontic appliances of three types of archwires (stainless steel [SS], nickel-titanium [NiTi] and thermal activated nickel-titanium in artificial saliva of three different pH values (to simulate saliva and conditions in the presence of dental plaque). Furthermore, the effects of change in pH and time of exposure on release of metal ions from these different alloys were evaluated.

MATERIALS AND METHODS

The samples used in the present study represents half fixed orthodontic appliances and consisted of first molar band of similar sizes, five orthodontic stainless steel brackets from second premolar to central incisor and archwire tied to the brackets using elastomeric ligature all orthodontic materials made by Orthotechnology, USA.

The ninety orthodontic samples were divided into three groups according to the type of orthodontic archwires used: A- stainless steel, B- nickel titanium and C- thermal activated nickel titanium. The 0.016 × 0.022 inch archwires were cut into 6 cm long and were shaped to an ideal arch form according to ideal study model (Apexion, India). Each groups were subdivided again into three subgroups according to the pH of artificial saliva that were immersed in it, so each subgroup has ten sets.

The artificial saliva which is used in this study consisted of 0.7g NaCl , 1.2g KCl , 0.26g Na2HPO4 , 0.2g K2HPO4 , 1.5g NaHCO3 , 0.33g KSCN , 0.13g urea and 1000 ml deionized water, this formula is named modified Carter's solution which is a modification to the old one used by Gerdet and Hero [15].

To simulate changing conditions in the oral cavity, artificial saliva of different pH values was used; selection was based on average pH in the oral cavity (6.75) [26], lowest pH (3.5) found under mature dental plaque [27] and pH 5 was selected in between them [28]. Lactic acid was used to adjust the pH of artificial saliva using the pH-meter (JENWAY, model 3320, Cyprus) and maintained in 37°C using incubator after filtering using filter paper to get rid of any insoluble salts and impurities.

Each orthodontic set was cleaned ultrasonically and washed in deionized water using ultrasonic cleaner, immersed in 70% ethanol for 4-5 seconds, then immersed in deionized water and finally in acetone (which act as volatile organic solvent) for 8-10 seconds, dried in hot air and finally stored in closely packed plastic bags which contain silica gel particles to avoid any oxidation and contamination of the alloy. This method of cleaning used to remove any contaminants or oxide layer formed on the alloy during storage. This method used according to American society for Metals and Alloys [29].

Neither the inner surface of the bands nor the mesh of the brackets were covered by any material. The exposed surface area of the appliance components was approximately equal to the exposed surface area of the bonded and banded full arch fixed orthodontic appliance [29].

Each set was ligated by dental floss mesial to molar band and placed in a glass container contain 35ml of artificial saliva according to its group in such a way that the sample was fully immersed in the artificial saliva without touching the walls of the container. Each container was closed by parafilm to control evaporation. The glass containers were placed in the incubator at 37°C for 28 days [29].

Collection of solutions was done by aspiration 1ml of artificial saliva using mechanical micro pipette at 1, 7, 14, 28 days and directly read for ions concentrations.

The artificial saliva was prepared for estimation of ions concentration included nickel and chromium using atomic absorption spectrophotometer (analytikjena, novAA 300, Germany) and iron concentration using spectrophotometer (Cecil, model 1011, France). Atomic absorption spectrophotometer is an analytical method for determination of elements and it is applicable for the analysis of concentrations ranging from trace up to large concentration following standardized procedure.

Each orthodontic set was weighted two times, the first time was before the ligation and immersion in the artificial saliva and the other

after 28 days at the end of immersion period using analytic balance device (Precisa, model XB220A, Switzerland).

The analysis of variance (ANOVA) used to test statistically significant difference between the amounts of ions released according to the periods, medium acidity and the samples composition. t-test used for weight comparison before and after immersion.

RESULTS AND DISCUSSION

Effects of Different pH of Artificial Saliva on Ions Released:

The effects of different acidity on the ions released from the orthodontic sets used in this study appeared to be marked over the storage periods. The larger amount of chromium, nickel and iron ions were released in the artificial saliva with highest acidity pH 3.5 then followed by the one with pH 5 and finally in the one with neutral pH 6.75.

In table 1, the results of (ANOVA) test showed very highly significant difference on the nickel ions released. In the (Table 2) the results (ANOVA) has demonstrated a very highly significant difference on the chromium ions released in the all acidity of artificial saliva in any periods of any orthodontic sets group. By inspecting the result of (ANOVA) test in table 3, it can be seen that there were very highly significant difference on the iron ion release in all acidity in any group.

This study demonstrate the importance of many factors that can affect the release of metal ions from fixed orthodontic appliances such as the type of alloy, immersion period and the pH of the solution. The appliance consisted of the brackets and wires, and it is likely that the brackets contributed to the quantities of released ions. However, because the brackets consisted of the same material in all samples, their contribution was constant and did not influence relative comparisons of ions released from wires.

The present study showed that the release of Ni, Cr and Fe ions depended not only on the pH value of the solution, but also on the length of exposure and, to a smaller degree, on the material that made up the archwire used. Although the quantities of released metal ions measured in this and similar studies cannot be directly applied to in vivo conditions, they are useful for relative comparisons and for determination of the effect of each individual variable (e.g., pH) on ion release without the influence of external factors. Other studies have suggested that the quantity of released metal ions is not proportional to the content.

It is important to note that the oral environment is extremely conducive to the corrosion products formation, because the mouth is moist and always subjected to changes in temperature. Saliva acts as an electrolyte, which can cause corrosion. Foods and drinks cause transitory, but important and wide, variations in the chemistry of the environment, as the ingested food and liquids have wide ranges of pH. During breakdown of foodstuffs, acids are liberated. This food debris often adheres strongly to the metals in the mouth providing a localized condition that is highly conducive to the reaction between the oral media and the metal or alloy [16,30].

The higher levels of ions were released in artificial saliva of pH 3.5 followed by artificial saliva of pH 5 and the least amount of ions was released in neutral artificial saliva of pH 6.75 in the different groups, so the levels of released ions were gradually increased with decreasing solution pH. These results confirm the hypothesis that low pH values reduce the resistance of dental alloys to corrosion [14].The metal ions released was more when the brackets were placed in an acidic environment [12]. These results agree with the finding of [31]. While our findings disagree with the result of Duffó and Farina [16] who showed that the aggressiveness of the different liquids is independent on the pH of the solution. This finding may be due to the decrease in the stability of titanium dioxide (TiO2) of NiTi based alloy surfaces, and so decreasing their corrosion resistance with the increase of H^+ concentration[32,33]. For stainless steel alloy this occurred also because the acidic condition provide a reducing environment in which the stainless steel oxide film required for corrosion resistance is less stable [9].

The results in figure 1 showed that all orthodontic appliances groups of different archwires decreased in weight after immersion in different acidity of artificial saliva at the end of the study when compared to zero line (specimens weight before immersion in artificial saliva).

The reduction in the weight of the appliances might occur because of the released of some ions in artificial saliva in acidic condition provide a reducing environment in which the metal oxide film required for corrosion resistance is less stable[9].

To sum up;

1. The effects of acidity of the medium were significantly influenced ions released. The release of ions was increased with decreasing the pH of the solutions, this indicating the breakdown of protective metals film by low pH of acids

2. The measurable amounts of metal ions released in artificial saliva was clearly below the average dietary intake and far from the toxic concentrations, but it might be enough to cause delayed allergic reactions.
3. The findings of this study indicated that in nickel-sensitive patients, use of thermal activated NiTi wires should be preferred to nickel-titanium archwires.
4. Weighing the orthodontic samples revealed that there were decreases in the weight of the orthodontic appliances in all studied groups at the end of the study.

Table 1: Descriptive Statistics and Effect of pH on the Ni release

Groups	Duration	pH	Descriptive statistics				pH difference	
			Mean	S.D.	Min.	Max.	F-test	p-value
A	1 day	3.5	566.30	7.99	557	578	42657.987	0.000
		5	37.59	1.05	35.7	39.1		
		6.75	24.34	1.52	22.7	26.7		
	7 days	3.5	1321.40	7.85	1310	1334	234426.012	0.000
		5	54.00	1.82	50.9	56.7		
		6.75	38.75	2.11	36.8	41.7		
	14 days	3.5	1537.00	5.89	1527	1547	522371.102	0.000
		5	59.70	1.92	57.2	63.1		
		6.75	42.50	1.98	39.6	45.2		
	28 days	3.5	2136.00	7.42	2126	2147	654565.192	0.000
		5	71.07	2.61	66.6	75.5		
		6.75	55.20	1.93	52.3	58.2		
B	1 day	3.5	458.70	7.51	450	468	31184.830	0.000
		5	33.40	1.55	30.9	35.3		
		6.75	22.59	0.82	20.7	23.6		
	7 days	3.5	1146.50	11.36	1130	1159	91650.258	0.000
		5	47.95	1.50	46.1	50.9		
		6.75	34.16	1.47	32.02	36.5		
	14 days	3.5	1461.70	6.77	1451	1471	404408.068	0.000
		5	55.14	1.47	52.6	58.2		
		6.75	40.85	1.21	38.7	43.1		
	28 days	3.5	1855.07	7.26	1844	1868	506530.719	0.000
		5	65.96	2.04	62.1	69.1		
		6.75	47.19	2.64	43.2	51.3		
C	1 day	3.5	428.05	6.73	420.5	438	33643.712	0.000
		5	32.79	1.39	30.4	35.2		
		6.75	21.94	0.68	20.9	23.2		
	7 days	3.5	1036.60	9.37	1020	1048	106975.254	0.000
		5	40.68	1.91	37.21	43.8		
		6.75	31.84	1.44	29.9	34.4		
	14 days	3.5	1256.80	6.86	1243	1265	279175.531	0.000
		5	47.41	1.89	44.9	50.8		
		6.75	35.15	1.51	32.6	37.9		
	28 days	3.5	1353.44	9.17	1343.4	1368	167952.067	0.000
		5	56.20	2.55	52.4	59.6		
		6.75	45.45	3.24	40.9	51.5		

Highly Significant P ≤ 0.01

Table (2): Descriptive Statistics and Effect of pH on the Cr Release

Groups	Duration	pH	Descriptive statistics				pH difference	
			Mean	S.D.	Min.	Max.	F-test	p-value
A	**1 day**	3.5	130.51	1.21	128.7	132.3	56280.714	0.000
		5	28.2	0.97	26.2	29.4		
		6.75	3.312	0.10	3.16	3.44		
	7 days	3.5	201.7	1.50	199.2	203.8	88723.375	0.000
		5	47.055	1.15	45.55	48.8		
		6.75	6.054	0.11	5.88	6.21		
	14 days	3.5	238.34	2.85	232.4	241.7	40897.491	0.000
		5	55.635	1.58	53.1	57.5		
		6.75	8.015	0.44	7.45	8.79		
	28 days	3.5	283	3.62	278	288	43468.858	0.000
		5	63.5	1.13	62	65		
		6.75	9.89	0.25	9.4	10.3		
B	**1 day**	3.5	86.15	2.40	82.4	89.8	9222.245	0.000
		5	24.695	0.49	24.05	25.4		
		6.75	3.37	0.13	3.1	3.5		
	7 days	3.5	140.02	1.14	138.6	141.9	43272.016	0.000
		5	40.13	1.44	37.7	42.1		
		6.75	5.52	0.13	5.32	5.74		
	14 days	3.5	170.82	2.02	167.1	173.4	32196.971	0.000
		5	52.865	1.54	51.15	55.6		
		6.75	7.651	0.39	7.11	8.04		
	28 days	3.5	203.6	5.40	196	209	9918.405	0.000
		5	56.8	1.40	54.5	59		
		6.75	8.55	0.32	8.1	9.1		
C	**1 day**	3.5	81.38	1.71	79.3	84.1	15902.460	0.000
		5	25.165	0.46	24.25	25.75		
		6.75	1.988	0.09	1.88	2.12		
	7 days	3.5	126.62	2.69	123.4	130.5	14387.964	0.000
		5	38.975	1.00	37.1	40.25		
		6.75	4.356	0.15	4.13	4.57		
	14 days	3.5	165.67	1.66	163.2	168.2	48302.264	0.000
		5	45.56	1.21	43.7	47.65		
		6.75	5.742	0.28	5.32	6.12		
	28 days	3.5	202.6	3.34	197	206	24718.958	0.000
		5	51.05	1.21	49.5	53		
		6.75	7.05	0.38	6.4	7.6		

Highly Significant $P \leq 0.01$

Table (3): Descriptive Statistics and Effect of pH on the Fe Release

Groups	Duration	pH	Descriptive statistics				pH difference	
			Mean	S.D.	Min.	Max.	F-test	p-value
A	1 day	3.5	174.81	6.82	166.78	186.05	1408.298	0.000
		5	74.60	4.46	65.78	81.06		
		6.75	67.56	3.20	62.46	71.10		
	7 days	3.5	484.44	6.17	478.18	494.55	23363.22	0.000
		5	78.96	3.82	72.50	84.34		
		6.75	85.90	4.06	80.00	93.33		
	14 days	3.5	845.36	5.94	838.06	852.69	65370.98	0.000
		5	126.37	3.35	122.39	132.09		
		6.75	119.55	5.78	111.19	128.36		
	28 days	3.5	1060.37	5.24	1053.76	1069.23	108445.7	0.000
		5	179.13	3.98	171.74	184.06		
		6.75	163.13	5.44	154.68	170.50		
B	1 day	3.5	168.09	5.36	160.13	178.07	1376.332	0.000
		5	75.72	4.15	70.43	81.73		
		6.75	63.59	5.03	58.47	71.76		
	7 days	3.5	459.88	5.88	452.97	469.01	22312.31	0.000
		5	77.30	4.83	68.81	82.96		
		6.75	79.39	2.71	75.51	83.67		
	14 days	3.5	802.92	4.94	796.26	810.49	85401.68	0.000
		5	119.57	3.60	114.39	125.18		
		6.75	108.61	4.27	100.79	114.96		
	28 days	3.5	1019.76	5.98	1011.72	1027.62	79588.67	0.000
		5	175.04	4.61	169.13	182.52		
		6.75	152.55	5.92	143.93	159.83		
C	1 day	3.5	168.99	4.83	160.80	176.74	1599.978	0.000
		5	70.60	4.25	65.12	77.74		
		6.75	63.65	4.87	57.81	70.43		
	7 days	3.5	428.47	5.37	421.81	437.36	19043.62	0.000
		5	76.96	4.30	71.35	83.04		
		6.75	78.10	4.16	72.38	85.71		
	14 days	3.5	766.42	5.65	761.08	779.14	65081.9	0.000
		5	108.51	4.65	100.00	113.39		
		6.75	102.25	3.69	97.76	108.21		
	28 days	3.5	914.22	3.39	909.45	919.69	156983.5	0.000
		5	161.24	3.69	155.81	167.44		
		6.75	139.83	3.47	132.22	145.61		

Highly Significant P ≤ 0.01

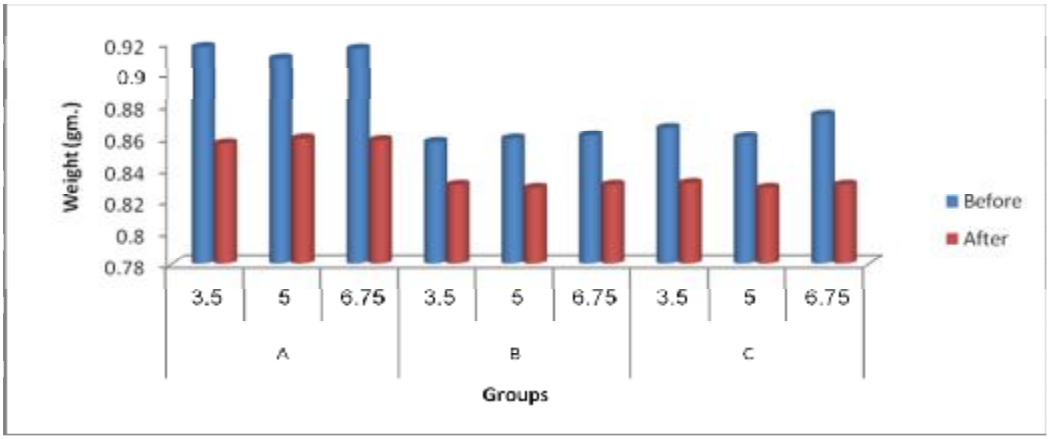

Figure (1): Mean Distribution of Weight of Different Studied Groups Before and After Immersion in Different Acidity of Artificial Saliva

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