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Assessment of Metal Ions Released from Orthodontic Mini-Implants in Fluoridated Mouthwashes

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ABSTRACT

Objective: *The current in vitro study was performed to evaluate the effect of fluoridated mouthwashes and immersion time on the amount of the metal ions released from titanium orthodontic mini-implants.* ***Methods:*** *Total 15 titanium mini-implants were used in the current study, which were divided equally into 3 groups (5 mini-implants in each group) and were immersed separately in (artificial saliva, Lacalut white and Kin B5 mouthwashes) for 28 days as following immersion intervals (1-7), (8-14) and (15-28) days. All mini-implants were assessed for metal ions release after immersion in the storage media. The mini-implants were used in as-received condition without any additional treatment.* ***Results:*** *The results of the Atomic Absorption Spectroscopy (AAS) showed that the release of total ions was highest in Lacalut White followed by Kin-B5 fluoridated MWs being higher than that released in artificial saliva, this was related to the pH of immersion media as well as the fluoride ion effect on the pattern of metal ions released from dental alloys.* ***Conclusion:*** *The factors of exposure time, alloy type and the type of the storage medium (pH and fluoride) influenced the pattern of metal ions released from MIs.*

Keywords: Orthodontic, Lacalut white, Cobalt-chromium, Spectrophotometer

INTRODUCTION

Anchorage can be defined as the resistance to undesirable tooth movement. The success of orthodontic treatment has been frequently determined by proper anchorage control in all 3 planes of space and most practitioners realize such a challenging factor in establishing the orthodontic treatment planning [1]. The introduction of orthodontic Mini-Implants (MIs) via Kanomi in 1997, has demonstrated a revolution in the anchorage discipline by serving as an absolute source of stability [2]. In apposition to prosthodontic implants, MIs are metal devices which are temporarily fixed to the bone and have been utilized to achieve a variety of orthodontic tooth movements [3,4].

Although there is a huge number of metals and alloys in the industry of materials, only a considerable number of metals and alloys could be suitable for the use as bio-implants. The widespread utilization of metallic biomaterials lies in (Ti) and its alloys and to a little degree the 316L Austenitic Stainless Steel (ASS) and Cobalt-chromium (Co-Cr) alloys [5].

Despite the effective role of MIs in orthodontic anchorage, they are considered to be a potential source of human exposure to metallic ions due to different elements used in the manufacturing of these devices and because of the corrosion of titanium alloys in different body fluids [6,7].

In the oral environment, the metal ions release has been broadly estimated with regards to orthodontic brackets, fixed appliances and other devices employed in the oral cavity during the course of orthodontic treatment [8,9].

It has been reported that the metal dental alloys used in the oral cavity are subjected to the effect of chemical, mechanical, biological, thermal and electrical forces which could result in the biodegradation of their composing biomaterials and may have a negative effect on the major dental practice or on the adjacent tissue [10].

Variety of electrochemical approaches had been utilized to evaluate the influence of F- on the corrosion potential of Ti and Ti6-Al-4V implant alloys, in artificial saliva and other storage media when being combined with either metal/ceramic or all ceramic frameworks. Actually, it can be concluded that with increased fluoride concentration, the corrosion resistance of Ti and its Ti6-A1-4V alloy has been reduced, and the oxide layer consequently gets weakened because of the complex formation of metal F- molecules on the alloy surface [11,12].

In orthodontics, the fluoridated mouthwashes are recommended by the clinicians since most patients are adolescents who do not always follow an adequate oral hygiene regimen, in addition to its effectiveness in the reduction of dental caries and white spot lesion [13]. The aim of the current study is to evaluate the metal ion released from orthodontic mini-implants after immersion in different storage media (artificial saliva, Kin-B5 mouthwash (MW) and Lacalut-White Mw.

PATIENTS AND METHODS

Atomic Absorption Spectrometry (AAS) was performed to obtain a descriptive analysis of the amounts of the metal ions released from Ti (MIs). The estimation of ions concentration involved Ti, Al and V, and was achieved by using Graphite Furnace Atomic Absorption Spectrophotometer (GFAAS), following standardized procedure, which is an analytical method for detection of elements and is appropriate for the evaluation of concentrations ranging from trace up to the large ones [14] (Figure 1).

Figure 1 Graphite furnace atomic absorption spectrophotometer (GFAAS) (Shimadzu AA-6800 series)

In this study, 15 Ti (MIs) were used, which was divided equally into 3 groups which contained 5 MIs according to immersion media (artificial saliva, Lacalut-white, and Kin-B5 mouthwashes) (Figure 2,3). Furthermore, MIs in each group were stored individually in a glass tube (Figure 4). All MIs were used as-received condition with no additional treatment.

Figure 2 Ti (MI) (Morelli, Brazil)

Figure 3 Chemical reagents

Figure 4 Tube contained single

Each capped-glass test tube was filled with 10 ml of either one of the two different MWs and artificial saliva using measuring glass cylinder, then all the test tubes were incubated in an incubator set at a constant temperature of 37°C for 28 days which were divided into 3 separated immersion intervals as follows: (1-7) days, (8-14) days, (15-28) days. At the end of each incubation period, the samples were made ready for estimation of ions concentration. The resulting amount of metal ions release after each immersion interval was recorded separately, and the overall quantity of release was assessed at the finishing of incubation period of 28 days by adding the amounts of ions released after each immersion interval (1-7) days, (8-14) days, (15-28) days, and the final result was calculated as a cumulative value of the total assessment and measurement of metal ions released from orthodontic MIs.

RESULTS

The Total Amount of the Ions Released from MIs

Table 1 and Figure 5 showed that the Ti, Al and V ions were released throughout the whole study; the highest amount of release was in Lacalut-White MW, followed by Kin-B5 MW and with the least amount of release was in artificial saliva.

Table 1 The effect of different storage media on accumulative ions release levels (ug/l) from Ti (MIs), I=artificial saliva, II=Kin-B5, III=Lacalut-white MWs

Ions	Storage Media	Descriptive statistics				Comparison		Storage Media	Tukey's HSD test	
		Mean	S.D.	Min.	Max.	F-test	p-value		Mean Difference	p-value
Ti	I	3.264	0.316	2.97	3.66	64.463	0.000	I-II	-2.092	0.000
	II	5.356	0.813	4.25	6.15			I-III	-4.182	0.000
	III	7.446	0.506	6.93	7.97			II-III	-2.09	0.000

Al	I	10.246	0.972	9.05	11.56	60.167	0.000	I-II	-2.76	0.000
	II	13.006	0.659	12.19	13.84			I-III	-5.056	0.000
	III	15.302	0.468	14.77	15.8			II-III	-2.296	0.001
V	I	1.388	0.505	0.95	1.94	2.578	0.117	-	-	-
	II	1.992	0.432	1.35	2.51			-	-	-
	III	2.406	1.041	0.59	3.14			-	-	-

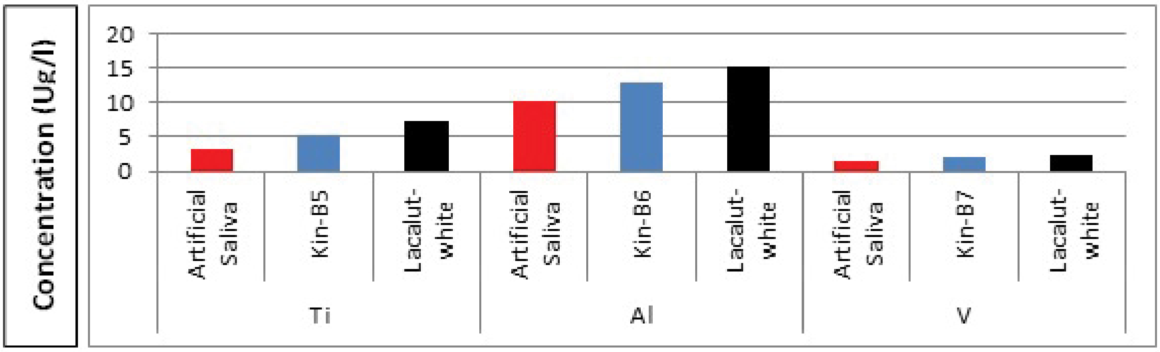

Figure 5 The effect of different storage media on the accumulative ions release concentrations (ug/l) from Ti (MIs)

Regarding the amount of the ions released in all the studied groups, obviously, Al ion was the highest, followed by Ti ion while V was the least ion released.

The Effect of Storage Media and Immersion Time on Ions Release

Table 2 and Figure 6-8, illustrated that, regarding the storage media, there was an apparent marked effect of different storage media on the total ions released from Ti (MIs) used in this study over the storage periods. The highest amount was released in Lacalut-white MW (III) followed by Kin-B5 MW (II) and the least amount was in artificial saliva (I).

Table 2 The effect of storage media on ions release levels (Ug/l) from Ti (MIs) at different time intervals (T1, T2, and T3), I=Artificial Saliva, II=Kin-B5 and III=Lacalut-white MWs

Durations	Ions	Storage Media	Descriptive statistics				Comparison		Storage Media	Tukey's HSD test	
			Mean	S.D.	Min.	Max.	F-test	p-value		Mean Difference	p-value
T1 (1-7 days)	Ti	I	1.268	0.074	1.160	1.350	35.657	0.000	I-II	-1.184	0.007
		II	2.452	0.740	1.480	3.230			I-III	-2.672	0.000
		III	3.94	0.449	3.450	4.360			II-III	-1.488	0.001
	Al	I	2.784	0.485	1.950	3.170	14.062	0.001	I-II	-0.942	0.034
		II	3.726	0.550	2.880	4.400			I-III	-1.724	0.001
		III	4.508	0.508	4.060	5.100			II-III	-0.782	0.079
	V	I	0.49	0.258	0.190	0.800	1.53	0.256	-	-	-
		II	0.848	0.226	0.600	1.200			-	-	-
		III	0.930	0.647	0.150	1.740			-	-	-
T2 (8-14 days)	Ti	I	1.074	0.160	0.880	1.270	18.282	0.000	I-II	-0.618	0.008
		II	1.692	0.323	1.160	2.030			I-III	-1.000	0.000
		III	2.074	0.281	1.720	2.420			II-III	-0.382	0.096
	Al	I	4.038	0.538	3.380	4.720	17.705	0.000	I-II	-0.910	0.031
		II	4.948	0.644	3.930	5.580			I-III	-1.846	0.000
		III	5.884	0.132	5.750	6.070			II-III	-0.936	0.027
	V	I	0.364	0.381	0.060	1.010	0.537	0.598	-	-	-
		II	0.460	0.367	0.160	0.940			-	-	-
		III	0.654	0.574	0.100	1.300			-	-	-

T3 (15-28 days)	Ti	I	0.922	0.238	0.640	1.210	3.018	0.087	-	-	-
		II	1.212	0.351	0.860	1.760			-	-	-
		III	1.432	0.381	1.140	2.080			-	-	-
	Al	I	3.424	0.662	2.700	4.300	13.071	0.001	I-II	-0.908	0.023
		II	4.332	0.415	3.810	4.790			I-III	-1.486	0.001
		III	4.910	0.183	4.710	5.190			II-III	-0.578	0.161
	V	I	0.534	0.299	0.220	1.030	0.342	0.717	-	-	-
		II	0.684	0.470	0.250	1.240			-	-	-
		III	0.822	0.775	0.090	2.000			-	-	-

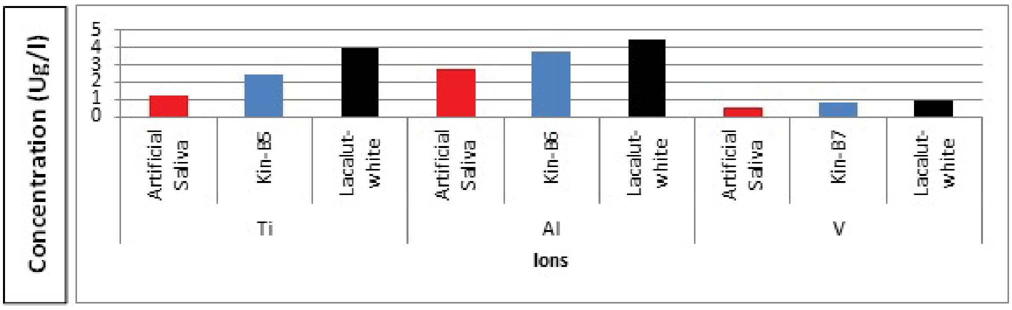

Figure 6 The effect of different storage media on the ions release concentrations (Ug/l) from Ti (MIs) at (T1:1-7 days)

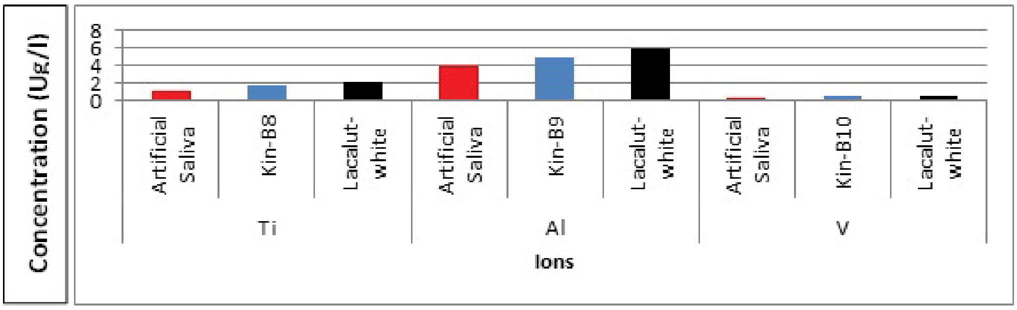

Figure 7 The effect of different storage media on the ions release concentrations (Ug/l) from Ti (MIs) at (T2: 8-14 days)

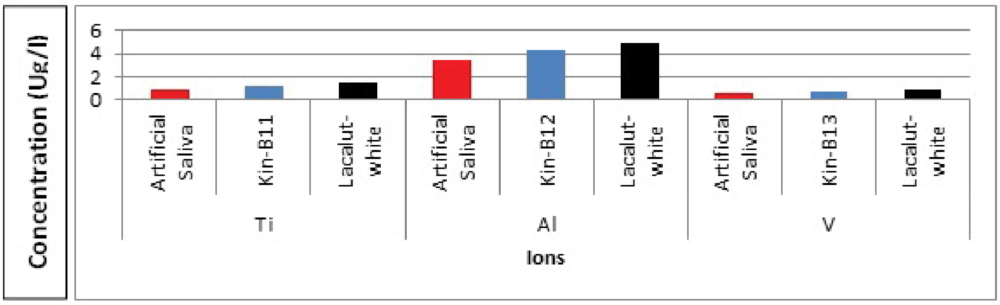

Figure 8 The effect of different storage media on the ions release concentrations (Ug/l) from Ti (MIs) at (T3: 15-28 days)

Regarding the effect of different duration of immersion on the ions released from Ti (MIs), Table 3 and Figure 9-11 showed the following:

(Ti) Ion: The Ti ion released in all the studied groups (artificial saliva, Kin-B5 MW and Lacalut-White MW) was the maximum at the 1st interval (T1), decreased at the 2nd interval (T2), and then continuously decreased to reach the minimum level in the last interval (T3).

(Al) Ion: The Al ion released in all the studied groups was the minimum at the (T1) interval, increased in (T2) interval to the maximum level, and then decreased at the last study interval (T3).

(V) Ion: In artificial saliva, the level of V ion which was released in (T1) interval showed a decrease in (T2) interval, and then increased to reach the maximum in (T3) interval. However, in Kin-B5 and Lacalut-White MWs, the level released at (T1) interval was the maximum, decreased to the minimum at (T2), then increased in (T3) study interval.

Table 3 The effect of different duration of immersion on the ions release levels (ug/l) from Ti (MIs) in different storage media, T1=(1-7 days), T2=(8-14 days), T3=(15-28 days)

Storage Media Groups	Ions	Durations	Descriptive statistics				Comparison		Duration	Tukey's HSD test	
			Mean	S.D.	Min.	Max.	F-test	p-value		Mean Difference	p-value
1-Artificial Saliva	Ti	T1	1.268	0.074	1.16	1.35	5.149	0.024	T1-T2	0.194	0.213
		T2	1.074	0.16	0.88	1.27			T1-T3	0.346	0.019
		T3	0.922	0.238	0.64	1.21			T2-T3	0.152	0.369
	Al	T1	2.784	0.485	1.95	3.17	6.126	0.015	T1-T2	-1.254	0.011
		T2	4.038	0.538	3.38	4.72			T1-T3	-0.64	0.215
		T3	3.424	0.662	2.7	4.3			T2-T3	0.614	0.24
	V	T1	0.49	0.258	0.19	0.8	0.387	0.687	-	-	-
		T2	0.364	0.381	0.06	1.01			-	-	-
		T3	0.534	0.299	0.22	1.03			-	-	-
2-Kin-B5 MW	Ti	T1	2.452	0.74	1.48	3.23	7.567	0.007	T1-T2	0.76	0.085
		T2	1.692	0.323	1.16	2.03			T1-T3	1.24	0.006
		T3	1.212	0.351	0.86	1.76			T2-T3	0.48	0.328
	Al	T1	3.726	0.55	2.88	4.4	6.295	0.014	T1-T2	-1.222	0.01
		T2	4.948	0.644	3.93	5.58			T1-T3	-0.606	0.224
		T3	4.332	0.415	3.81	4.79			T2-T3	0.616	0.215
	V	T1	0.848	0.226	0.6	1.2	1.401	0.284	-	-	-
		T2	0.46	0.367	0.16	0.94			-	-	-
		T3	0.684	0.47	0.25	1.24			-	-	-
3-Lacalut-White MW	Ti	T1	3.94	0.449	3.45	4.36	59.808	0	T1-T2	1.866	0
		T2	2.074	0.281	1.72	2.42			T1-T3	2.508	0
		T3	1.432	0.381	1.14	2.08			T2-T3	0.642	0.048
	Al	T1	4.508	0.508	4.06	5.1	24.349	0	T1-T2	-1.376	0
		T2	5.884	0.132	5.75	6.07			T1-T3	-0.402	0.159
		T3	4.91	0.183	4.71	5.19			T2-T3	0.974	0.001
	V	T1	0.93	0.647	0.15	1.74	0.215	0.81	-	-	-
		T2	0.654	0.574	0.1	1.3			-	-	-
		T3	0.822	0.775	0.09	2			-	-	-

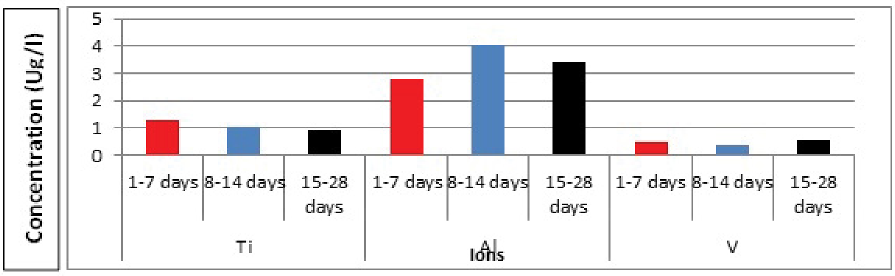

Figure 9 Concentrations of ions release at different time intervals in group A1: (Ti, Al and V ions in artificial saliva)

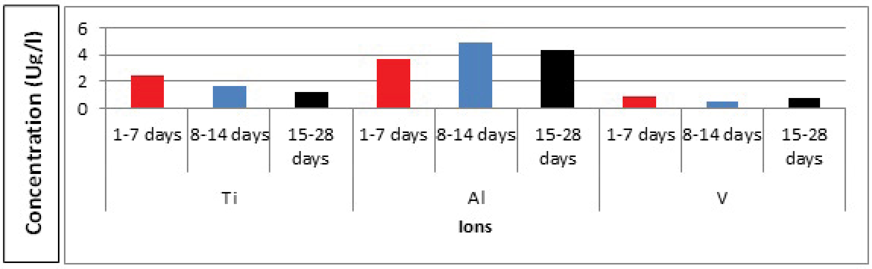

Figure 10 Concentrations of ions release at different time intervals in group A2: (Ti, Al and V ions in Kin-B5 MW)

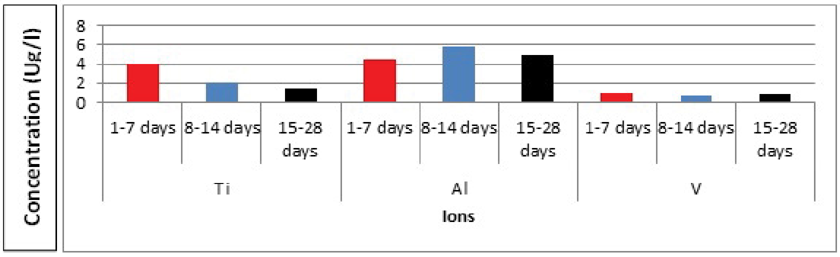

Figure 11 Concentrations of ions release at different time intervals in group A3: (Ti, Al and V ions in Lacalut-white MW)

DISCUSSION

The ions that were measured in the current study involved (Ti, Al, and V) as the major composing elements of (Ti-6Al-4V) alloy used in the manufacturing of Ti (MIs) [15,16]. The existing variations in the obtained results throughout the whole period of the current study as compared with other corrosion studies involving metal ions release could be explained by various analytical methods and variables such as interferences, sensitivities and detection limits, an additional reason could be the variations in the composition of alloys, the employed techniques for material construction, and the galvanic coatings [17].

Regarding the ions released from Ti (MIs) in all the tested groups throughout the total intervals of the present study, apparently Al ion showed the highest amount of release, followed by Ti ion while the least amount was V ion, which may be related to the mechanical and electrochemical behavior of the passive oxide surface layer (TiO_2) on Ti-6Al-4V alloy which was detected to comprise a little amount of bound water, Al_2O_3 and hydroxyl groups, thus Ti and Al ions were expected to be the main released ions, while V is not an essential ion in the producing of the passive oxide film on the surface of Ti-6Al-4V alloy [18,19].

Concerning the storage media used in the present study, there was an apparent effect of the testing solutions of different compositions and acidic values on the metal ions release and corrosion of MIs, the highest amounts of ions release and corrosion defects were seen in the more acidic media (Lacalut-White followed by Kin-B5 MWs) as compared with artificial saliva of neutral pH, indicating that the corrosion resistance of dental alloys could be influenced by differences in the acidity and compositions of various immersion solutions [20,21]. Regarding the time factor, the possibility of metal ions released from orthodontic alloys is a time-related object, hence, the over-time metal ion release in the saliva might be altered [22].

The maximum levels for Ti and V ions release in all tested groups were noticed at the end of the T1 interval (7 days), then the amounts showed a decrease with increased intervals until reaching the minimum level at T3 interval (28 days) in all storage media, such a reduction in the rate of ions release could be clarified by the normal capacity of the passivation layer of the alloy to form a protective stable oxide film that inhibits the corrosion process in various environments, thus the rate of corrosion will be diminished [23,24].

In contrast to Ti and V, the Al ion released in a minimum level in T1 then increases to the maximum amount at the end of the T2 interval. The pattern of Al release could be related to different storage media of various pH and the aggressive effect of fluoride ion on corrosion behavior of Ti alloy [25].

The levels of released ions were increased with decreasing the pH value of the solution when MIs placed in the more acidic environment, which may be related to the ability of the acidic media to create a reducing environment capable of decreasing the stability of protective oxide layer necessary for corrosion resistance [26,27].

The maximum level the of ions released from Lacalut-White MW of pH 5.5 followed by Kin-B5 MW of pH 6.5 in the current study might be attributed to the electrochemical features of Ti alloy as revealed by Schiff, et al., who compared the pure Ti and various Ti alloys (NiTi, TiAl6V4 and NiTiCo) depending on the pH value and F- concentration of the saliva, and detected that the resulting polarization curve assays demonstrated the increased corrosion rate of pure Ti and TiAl6V4 alloy in the case of more acidic storage medium, followed by the fluoridated and finally fluoridated acidified media [25].

Furthermore, Kin-B5 and Lacalut-White MWs exhibited highly significant differences in the amounts of ions release; this may be due to the composition of MW itself since the amount of corrosion of any metal relies on the chemical situation of the immersion solvents used as storage media [28].

Based on the findings of the present study, it can be stated that the amounts of metal ions released from MIs are not directly proportional to the composition of metal elements within the alloy [29,30].

CONCLUSION

The factors of exposure time, alloy type, and type of the storage medium have influenced the pattern of metal ions released from orthodontic MIs. The release of the total metal ions examined in the present study was highest in Lacalut-white followed by Kin-B5 fluoridated MWs being higher than that released in artificial saliva, this was related to the pH of immersion media as well as the fluoride ion effect on the pattern of metal ions released from dental alloys. The amounts of total released ions were lower than the recommended daily doses and below the toxicity limits and did not result in the signs and symptoms of allergy, hypersensitivity, and carcinogenicity.

DECLARATIONS

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

[1] Daskalogiannakis, John, and A. Ammann. *Glossary of orthodontic terms*. Chicago: Quintessence Books, 2000.

[2] Kanomi, R.. "Mini-implant for orthodontic anchorage." *Journal of Clinical Orthodontics,* Vol. 31, 1997, pp. 763-67.

[3] Hong, Ryoon-Ki, Jung-Min Heo, and Young-Ki Ha. "Lever-arm and mini-implant system for anterior torque control during retraction in lingual orthodontic treatment." *The Angle Orthodontist,* Vol. 75, No. 1, 2005, pp. 129-41.

[4] Herman, Robert J., G. Frans Currier, and Alan Miyake. "Mini-implant anchorage for maxillary canine retraction: a pilot study." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 130, No. 2, 2006, pp. 228-35.

[5] Muley, Sachin Vijay, et al. "An assessment of ultra-fine grained 316L stainless steel for implant applications." *Acta Biomaterialia,* Vol. 30, 2016, pp. 408-19.

[6] Rodríguez-Mercado, Juan José, Elia Roldán-Reyes, and Mario Altamirano-Lozano. "Genotoxic effects of vanadium (IV) in human peripheral blood cells." *Toxicology Letters,* Vol. 144, No. 3, 2003, pp. 359-69.

[7] de Morais, Liliane Siqueira, et al. "Systemic levels of metallic ions released from orthodontic mini-implants." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 135, No. 4, 2009, pp. 522-29.

[8] Danaei, Shahla Momeni, et al. "Ion release from orthodontic brackets in 3 mouthwashes: an *in-vitro* study." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 139, No. 6, 2011, pp. 730-34.

[9] Natarajan, Madhumitha, et al. "Evaluation of the genotoxic effects of fixed appliances on oral mucosal cells and the relationship to nickel and chromium concentrations: an in-vivo study." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 140, No. 3, 2011, pp. 383-88.

[10] Manivasagam, Geetha, Durgalakshmi Dhinasekaran, and Asokamani Rajamanickam. "Biomedical implants: corrosion and its prevention-a review." *Recent Patents on Corrosion Science,* 2010.

[11] Anwar, Eman M., Lamia S. Kheiralla, and Riham H. Tammam. "Effect of fluoride on the corrosion behavior of Ti and Ti6Al4V dental implants coupled with different superstructures." *Journal of Oral Implantology,* Vol. 37, No. 3, 2011, pp. 309-17.

[12] Kocijan, Aleksandra, Darja Kek Merl, and Monika Jenko. "The corrosion behavior of austenitic and duplex stainless steels in artificial saliva with the addition of fluoride." *Corrosion Science,* Vol. 53, No. 2, 2011, pp. 776-83.

[13] Ananthanarayanan, Venkateswaran, Sridevi Padmanabhan, and Arun B. Chitharanjan. "A comparative evaluation of ion release from different commercially-available orthodontic mini-implants-an in-vitro study." *Australian Orthodontic Journal,* Vol. 32, No. 2, 2016, p. 165.

[14] Khamees, Asmaa M., and Sami K. Al-Joubori. "Comparison of metal ions release and corrosion potential from different bracket archwire combinations (An in vitro study)." *Journal of Baghdad College of Dentistry,* Vol. 26, No. 1, 2014, pp. 171-79.

[15] Milošev, Ingrid, Barbara Kapun, and Vid Simon Šelih. "The effect of fluoride ions on the corrosion behavior of Ti metal, and Ti6-Al-7Nb and Ti-6Al-4V alloys in artificial saliva." *Acta Chimica Slovenica,* Vol. 60, No. 3, 2013, pp. 543-55.

[16] Morais, Liliane S., et al. "In vivo metal ion release from Ti-6AL-4V orthodontic mini-implants." *Matéria (Rio de Janeiro),* Vol. 12, No. 2, 2007, pp. 290-97.

[17] Mikulewicz, Marcin, and Katarzyna Chojnacka. "Trace metal release from orthodontic appliances by in vivo studies: a systematic literature review." *Biological Trace Element Research,* Vol. 137, No. 2, 2010, pp. 127-38.

[18] Chawla, Krishan Kumar, and M. A. Meyers. *Mechanical behavior of materials*. Upper Saddle River: Prentice Hall, 1999.

[19] Hanawa, Takao. "Metal ion release from metal implants." *Materials Science and Engineering,* Vol. 24, No. 6-8, 2004, pp. 745-52.

[20] Kedici, S. P., et al. "Corrosion behavior of dental metals and alloys in different media." *Journal of Oral Rehabilitation,* Vol. 25, No. 10, 1998, pp. 800-08.

[21] House, Kate, et al. "Corrosion of orthodontic appliances-should we care?." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 133, No. 4, 2008, pp. 584-92.

[22] Eliades, Theodore, et al. "Salivary metal levels of orthodontic patients: a novel methodological and analytical approach." *The European Journal of Orthodontics,* Vol. 25, No. 1, 2003, pp. 103-06.

[23] López, M. F., A. Gutiérrez, and José Antonio Jiménez. "*In vitro* corrosion behavior of titanium alloys without vanadium." *Electrochimica Acta* 47.9 (2002): 1359-1364.

[24] Juraga, Ivan, Vinko Šimunović, and Đ. Šipaniček. "Contribution to the study of effects of surface state of welded joints in stainless steel upon resistance towards pitting corrosion." *Metalurgija,* Vol. 46, No. 3, 2007, pp. 185-89.

[25] Schiff, Nicolas, et al. "Influence of fluoride content and pH on the corrosion resistance of titanium and its alloys." *Biomaterials,* Vol. 23, No. 9, 2002, pp. 1995-2002.

[26] Sfondrini, Maria Francesca, et al. "Chromium release from new stainless steel, recycled and nickel-free orthodontic brackets." *The Angle Orthodontist,* Vol. 79, No. 2, 2009, pp. 361-67.

[27] Elshahawy, Waleed, Ikuya Watanabe, and Mari Koike. "Elemental ion release from four different fixed prosthodontic materials." *Dental Materials,* Vol. 25, No. 8, 2009, pp. 976-81.

[28] Okazaki, Yoshimitsu, and Emiko Gotoh. "Comparison of metal release from various metallic biomaterials in vitro." *Biomaterials,* Vol. 26, No. 1, 2005, pp. 11-21.

[29] Grimsdottir, Margret Rosa, Nils R. Gjerdet, and Arne Hensten-Pettersen. "Composition and in vitro corrosion of orthodontic appliances." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 101, No. 6, 1992, pp. 525-32.

[30] Hwang, Chung-Ju, Ji-Soo Shin, and Jung-Yul Cha. "Metal release from simulated fixed orthodontic appliances." *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol. 120, No. 4, 2001, pp. 383-91.