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Overview of Metal Ions Released from Fixed Orthodontic Appliance: In Vitro Studies

Maha Mohammed[1], Riyam Haleem[1*], Zaid Abdulhussein[1], Mohammed Abbood Al-Maliky[1], Noor Musa[1], Mustafa Wathiq Abdul Kareem[1], Hind H. Enad1[1], Maher M.jwaid[1], Hanady Abbas Jaafar Al Alalaq[2], Mayyadah Hasan Rhaif Al-Sahlanee[3]

[1] Department of dentistry, Al-Hadi University College, Baghdad-10011, Iraq
[2] Ministry of Health/Al Imamein Al Kadhimein Medical city, Baghdad, Iraq
[3] Department of Physiology, College of Medicine, Mustansiriyah University, Baghdad, Iraq

Abstract: Intraoral fixed orthodontic appliances are frequently used in the clinical practice of dentistry. They are made from alloys containing different metals at various percentages. The use of these appliances leads to the long-term exposure of patients to these materials, and the potential toxic effects of this exposure raises concerns about patient safety. Thus, the biocompatibility (corrosion behaviour and toxicity) of these materials has to be evaluated prior to clinical use. In the present report, the most recent studies in the scientific literature examining metal ion release from orthodontic appliances and the toxic effects of these ions have been reviewed with a special focus on cytotoxicity and genotoxicity. Previous studies suggest that a case-by-case safety evaluation is required to take into account the increasing variability of materials, their composition and the manufacturing processes. Moreover, in vitro toxicity studies in regard to metal release, cytotoxicity and genotoxicity are still scarce. Therefore, in vitro monitoring studies are needed to establish cause-effect relationships between metal ion release and biomarkers of cytotoxicity and genotoxicity. Further investigations could be performed to elucidate the toxic mechanisms involved in the observed effects with a special emphasis on oxidative damage.

1. Introduction

Orthodontic history, beginning with Kingsley, indicates that the use of metal alloys is an essential part of orthodontic therapy (Heravi *et al.*, 2013). Orthodontic care provides malocclusion correction and inharmonious jaw location with the advantage of improved functioning and teeth protection.

While receiving the orthodontic treatment the patients are exposed to a noticeable amount of metal alloys. There is release of metallic ions from orthodontic appliance into oral fluids of patients undergoing fixed orthodontic treatment (Heravi *et al.*, 2013). Thermal, microbiological and aqueous properties of the oral environment are responsible for the metallic ions release from orthodontic appliance. Beside these pH fluctuations in oral cavity due to intake of food, various drinks and mouthwash also facilitate the corrosion of orthodontic appliance and lead to release of metallic ions (Heravi *et al.*, 2013). Many oral diseases, dentition appearance, malocclusion, and the treatment for these disorders on function and aesthetic bases received a broad focus from researchers.

Once the patient is referred to an orthodontist, in order to assess the prognosis and location of teeth orthodontist takes radiographs (OPG) and sometimes lateral cephalograms are adjunct with conebeam computed tomography (CBCT). Beside these, the orthodontist must obtain the patient's teeth impression for construction of study model.

2. Materials and Methods

The available literature from the Google Scholar was referred using search terms led by Boolean operators "AND" and "OR" with the keywords "cytotoxicity," "orthodontics," "genotoxicity," "in vitro," "corrosion", " and "metal release" using a methodological framework fashioned by Arksey and O'Malley,[4] which consisted of five steps, namely (a) identification of the research question, (b) identification of relevant studies, (c) selection of study, (d) data charting, and (e) collating, summarizing, and data reporting.

Result

In vitro studies concerning metallic ions released from orthodontic appliances, Among the 49 in vitro study articles, 18 emphasized on different types of archwires,21 on different types of brackets, , 1 on molar bands, and 1 on mini implants, 1Removable appliance (Table 1). In the present work, Table 1 summarizes more recent in vitro studies on released metals from fixed orthodontic appliances from the last 6 years, including information on the orthodontic material employed, the solutions used, the duration of treatment, the method of sample collection, the instrumental technique chosen for measuring metal ions, the median or mean concentrations of trace metals investigated and the main findings.

Table 1: Summary of type of samples and incubation medium used in *in vitro* studies

Study (year)	Type of samples	Type of incubation medium	Methods	Duration of study	Key findings
(Azizi *et al.*, 2016)	▪ 40 round NiTi archwire ▪ 40 rectangular NiTi archwire	Artificial saliva	Inductively coupled plasma-optical emission spectroscopy	21 days	▪ In the rectangular wire community, the nickel and titanium amounts were substantially higher Within the first hour of immersion, the most significant release of all metal was measured.
(H. D. Hussain *et al.*, 2016)	▪ SS archwires NiTi archwires	Artificial saliva at 37°C, pH6.75±0.15	Inductively coupled plasma-optical emission spectroscopy	1 and 7 days,1,2 and 3 months	▪ Significant release of nickel was seen in all groups up to the end of first month.
(S. Hussain *et al.*, 2016)	▪ SS brackets masel/Conventional bracket	▪ Potassium Ferrocyanide and distilled water/water based for control group Potassium Ferrocyanide /oil based for experiment group	Field Emission Scanning Electron Microscope	2h	▪ All types of brackets prove signs of corrosion. ▪ self-ligating brackets were more susceptible to corrosion than the conventional ones. ▪ Masel was the most corroded brackets for conventional brackets The oil-based salad dressing illustrated the most extensive corrosion in all brackets
(Behroozi *et al.*, 2016)	▪ Five SS wires ▪ Five different brackets (Dentaurum, 3M, Ortho Organizer, Cobas and O.R.G)	Artificial saliva at 37°C, pH 7.2	inductively coupled plasma (ICP)		Ortho Organizer and ORG brackets are suggested in terms of resistance to corrosion
(Brigitte Wendl *et al.*, 2017)	▪ Bands, brackets and wire made of ▪ SS ▪ Cr Ni NiTi	Artificial saliva	Inductively coupled plasma-optical emission spectroscopy	44 days	▪ Bands released the largest quantities of Co, Cr, Mn, and Ni, followed by brackets and wires ▪ Three separate profiles of temporal metal release were observed: A)continuous, though not inherently linear release, B) saturation (metal release stopped after a certain time, and C) an intermediate release profile showing signs of saturation without reaching saturation
(Shruthi *et al.*, 2017)	brackets and archwires	Mouthwash	inductively coupled plasma-optical emission spectrometer	45 days	Mean ion release in the bonded bracket group was less than that of nonbonded bracket group. Ion release in control subgroup of both

					groups was 0.18 ± 0.08 µg/dl (A1) and 0.17 ± 0.06 µg/dl (B1); in Phos-Flur mouthwash subgroup was 0.12 ± 0.06 µg/dl (A2) and 0.13 ± 0.05 µg/dl (B2); in chlohex mouthwash subgroup was 0.13 ± 0.06 µg/dl (A3) and 0.14 ± 0.06 µg/dl (B3); in Hiora mouthwash subgroup was 0.10 ± 0.06 µg/dl (A4) and 0.12 ± 0.05 µg/dl (B4).
(Mihardjanti *et al.*, 2017)	stainless steel bracket	Mouthwash	ICP-MS (Inductively Coupled Plasma-Mass Spectrometer)	30 days	The results showed differences among the four groups in the nickel ions released ($p < 0.05$) and the chromium ions released ($p < 0.5$). In conclusion, the ions released as a result of mouthwash immersion have a small value that is below the limit of daily intake recommended by the World Health Organization.
(Kosayadiloka *et al.*, 2017)	MU orthodontic miniscrews as well as two other brands of orthodontic miniscrews over time.		(ICP-MS)	30 days	The results indicated that there were no statistical differences between the self-made orthodontic miniscrews and those from two commercial groups (p<0.05). Throughout the testing period, the quantity of ions increased from T1 to T3. After 24 h, vanadium was the first to appear on the surface in small quantities in other two commercial groups. The self-made orthodontic miniscrews exhibited no toxic effects on living cells.
(A. Mirhashemi *et al.*, 2018)	Archwires 60 SS and 60 NiTi Brackets SS Bands SS	Mouthwashes Oral B and Oral B 3D White Luxe Chlorhexidine Listerine Advanced White Distilled deionized water	Atomic absorption spectroscopy	1, 6, 24 and 168 hours	Nickel ions were released. from both wires at all timepoints; the highest amount was in Listerine and the lowest in Oral B mouthwashes The remaining two solutions. were in-between this range Similar process for chromium. release from SS wires as seen in Ni release
(Furlan *et al.*, 2018)	Archwires 10 different types . of archwires from commercial brand NiTi American . Orthodontics Flexy NiTi Copper . Tanzo Copper . Nickel Titanium Wire Damon OptimalForce Copper NiTi Copper nickel–titanium (CuNiTi)	Natural or acid solutions	Graphite Furnace Atomic Absorption Spectrometry, inductively coupled plasma-optical emission spectroscopy	7 days	Higher mean Ni concentration ♣ release from NiTi Memory Wire and Flexy NiTi Cu archwires compared to other archwires Higher detectable Cu ♣ concentration in Tanzo Cu NiTi and Flexy NiTi Cu archwires in neutral solution compared to other groups in acid solution
(Jamshidi *et al.*, 2018)	NiTi archwires SS archwires	24 orthodontic patients 28 control Scalp hair	Atomic absorption spectrometry	After one year treated	Levels of Ni and Cr in two groups showed significant differences (0.086 ± 0.007 and 0.258 ± 0.009 mg/g for control group and 0.149 ± 0.010 and 0.339 ± 0.013 mg/g for patient groupAfter 1 year of treatment, baseline levels of Ni and C between two groups were significant
(Małkiewicz *et al.*, 2018)	SS archwires ▪ Beta titanium ▪ ArchwiresNickel titanium ▪ archwires	Artificial saliva solution at 37 C°	Autolab PGSTAT100	6 month	The average corrosion current density was thelowest for nickel–titanium archwires The highest corrosion was observed in the steel wires
(Jurela *et al.*, 2018)	nickel (Ni), titanium (Ti), chromium (Cr), cobalt (Co), copper (Cu) and zinc (Zn) were measured in 42 patients with ceramic brackets and in 42 patients with metal conventional brackets	Artificial saliva	inductive coupled plasma/mass spectrometry.	Six months	-No difference in baseline salivary concentrations of any of the studied electrolyte between patients with metallic and non-metallic braces was found -Salivary concentrations of titanium were significantly higher after the treatment in patients with metallic and non-metallic braces, respectively.

(Quadras *et al.*, 2018)	nickel (Ni), chromium (Cr), and zinc (Zn)	Human saliva	atomic absorption spectrometry and comet assay to assess the amount of metal ions and DNA damage	1.5 years	**Ni ions increased to 62.85 ± 4.81 ppb at the end of 1.5 years from 22 ± 2.3 ppb at baseline before the insertion of appliance, Cr ion levels reached 58.3 ± 5.1 ppb from 20 ± 3.8 ppb, and Zn ion levels reached 562.8 ± 66.5 ppb from 197.4 ± 68.5 ppb, respectively. This result was significant with P < 0.01. A decrease in cell viability and an increase in head diameter, % DNA in tail, and tail length were found at the end of 1.5 years as compared to baseline with P < 0.05.**
(A. H. Mirhashemi *et al.*, 2018)	nickel titanium (NiTi) and stainless steel (SS) orthodontic wires	**Oral B, Oral B 3D White Luxe, Listerine, and Listerine Advance White**	Atomic absorption spectroscopy served to quantify the amount of released ions.	168h	The process of release of chromium from the SS wire was the same as that of nickel. However, the release trend in NiTi wires was not uniform
(Yanisarapan *et al.*, 2018)	stainless steel, nickel-titanium, and beta-titanium	solutions of fluoride toothpaste, 1.23% acidulated phosphate fluoride (APF), or artificial saliva without fluoride as a control group.	SEM	3 months	The SEM results showed that the brackets and wires in the APF groups demonstrated more lines and grooves compared with the other groups.
(A. Mirhashemi *et al.*, 2018)	nickel and chromium ions from nickel titanium (NiTi) and stainless steel (SS) orthodontic wires	use of four common mouthwashes available on the market Oral B, Oral B 3D White Luxe, Listerine,	Atomic absorption spectroscopy served to quantify the amount of released ions	for 1, 6, 24, and 168 h	Nickel ions were released from both wires at all time-points; the highest amount was in Listerine and the lowest in Oral B mouthwashes. The remaining two solutions were in-between this range.
(Polychronis *et al.*, 2018)	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	acidic 0.1M NaCl 0.1M lactic acid and neutral NaF 0.3% (wt) electrolyte	x-ray energy dispersive spectroscopy	48 hours.	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
(Furlan *et al.*, 2018)	Ni titanium (Ti) Memory Wire (American Orthodontics), Damon Optimal-Force Cu Ni-Ti (Ormco), Tanzo Cu NiTi (American Orthodontics), and Flexy NiTi Cu (Orthometric)	Neutral and acid media	Graphite Furnace Atomic Absorption Spectrometry	7 days	Metal ion release by archwires is dependent on the commercial brand and the immersion solution
(Hamad & Hassan, 2018)	fixed orthodontic appliances are made of stainless steel and Nickel-Titanium alloys,	Saliva samples from 18 patients (9 males and 9 females) between 15-25 years	Inductively Coupled Plasma/ Optical EmissionSpectrometr	1 month	Nickel, Chromium and Iron levels in saliva were increased after the placement of fixed orthodontic appliance.
(Jamshidi *et al.*, 2018)	fixed orthodontic appliances, including bands, brackets and wires Nickel (Ni) and chromium (Cr)	the scalp hair	atomic absorption spectrophotometer by graphite furnace method	1 year	Due to the slightly elevated levels of Ni and Cr ions in the scalp hair of patients treated with fixed orthodontic appliances and considering the cytotoxic and allergic effects of these ions,
(Soni *et al.*, 2018)	standard orthodontic brackets	artificial saliva	Inductively Coupled Plasma/ Optical EmissionSpectrometr	1 hour, 7 days and 1 month respectively.	Acidic pH was found to increase the amount of nickel release in the artificial saliva.
(Małkiewicz *et al.*, 2018)	orthodontic archwires made of stainless steel, titanium–molybdenum and nickel–titanium alloys	artificial saliva	potentiodynamic tests	28 days	the highest corrosion resistance is observed for NiTi arches (3M, USA), while the lowest resistance for SS arches (3M, USA
(Mortazavi *et al.*, 2018)	orthodontic brackets:	artificial saliva	Inductively Coupled Plasma/ Optical	6 months	The mean nickel levels in the exposed and non-exposed groups

			EmissionSpectrometr		were 11.95 and 2.89 µg/l
(Amini *et al.*, 2019)	Metal orthodontic appliances	oral environment (Saliva)	inductively coupled plasma mass spectrometry (ICP-MS)	2 months	The t test showed a significant difference between nickel values of orthodontic patients with and without periodontitis.
(Chitra *et al.*, 2019)	Metal orthodontic appliances	gingival crevicular fluid	inductively coupled plasma mass spectrometry.	6-month	No changes in metal levels at any time were observed in the untreated control group. Nickel levels were elevated to 101.78 µg/L in the fluoridated group at 30 days posttreatment, indicating heavy leaching from nickel-titanium archwires (Friedman *P* < 0.001). Results returned to baseline in both groups at 6 months. Mean differences for chromium, titanium, and manganese ion release were not statistically significant at 30 days. Titanium showed elevated levels at 30 days in both tested groups, but levels were lesser than nickel.
(Moghadam *et al.*, 2019)	Fixed orthodontic appliances Ni,Cr,Zn,Cu,Fe,Mn	in the serum of patients	Plasma mass spectrometry (ICP-MS).	1 month to 6 months, 6 months to 12 months, 12 months to 18 months, and finally, over 18 months of treatment	The results of the SEM-EDS showed a high variation in the level of metal ions in the brackets and wires. In conclusion, fixed orthodontic appliances increased serum levels of Ni, Zn, Mn, Fe, and Cu but did not change Cr levels.
(Mudjari *et al.*, 2019)	Fixed orthodontic appliances Ni, Cr	hair and GCF gingival crevicular fluid	atomic absorption spectroscopy	4, 8, and 16 months	After 16 months, compared with the baseline, average hair nickel level changed from 0.125 µg/g to 0.956 µg/g with statistically significant difference (p=0.00); average chromium level changed from 0.090 µg/g to 0.295 µg/g but no significant difference (p>0.05); average GCF nickel level changed from 3.335 µg/g to 10.410 µg/g; average chromium level changed from 1.859 µg/g to 9.818 µg/g. Both of these increases were significant (p=0.000). SEM examinations showed that the corrosion on brackets was seen in the fourth month, and more severely visible after 8 and 16 months of uses.
(Quadras *et al.*, 2019)	Fixed orthodontic appliances Ni, Cr, Zn	Saliva and blood samples	atomic absorption spectrophotometry	1 week, 3 months, 1 year, and 1.5 years	Orthodontic appliances do release considerable amounts of metal ions such as nickel, chromium, and zinc in saliva and serum. However, it was within permissible levels and did not reach toxic levels.
(Arun & Mahesh, 2019)	Four brands of orthodontic brackets ▪ Gemini (3M Unitek) ▪ Ecoplus (Chirpans Orthodontics) ▪ Monalisa (JJ Orthodontics) ▪ Sapphire (Modern Orthodontics)	Artificial saliva	Inductively couple plasma mass spectrometry.	24 hours	Gemini brackets offered better corrosion resistance and showed the least nickel release among all the groups
(Hameed *et al.*, 2019)	stainless steel brackets	artificial saliva	atomic absorption spectrophotometer	28 days	all brands showed significant increase in Cr ion release concomitant with an increase in the polishing time. Damon® Q ™ show the greatest amount of Cr ion release
(Al-Nassar *et al.*, 2019)	60 lingual retainer wires of two types ▪ 3 braided strands ▪ 6 coaxial strands	Dental bleaching gel (carbamide peroxide) ▪ 35% carbamide peroxide/opalescence PF/ultradent ▪ 16% carbamide peroxide/polanight SDI	Flameless atomic absorption spectrophotometer	7 days	▪ There were no significant variations between two groups of wires and between 30% carbamide peroxide and control group ▪ 16% carbamide peroxide displayed slightly less release of nickel relative to control group. ▪ 35% carbamide peroxide group.
(Tahmasbi *et*	24 brackets of	artificial saliva	atomic absorption	28 days	The mean amount of ions released

al., 2019)	4 (Dentaurum, American Orthodontics, Shinye and ORJ) with NiTi wires or SS wires		method		was not significantly different between groups.(The potential difference of Shinye brackets coupled to SS wire was significantly lower than that of other combinations and was negative throughout the study. The potential difference of Dentaurum bracket-NiTi wire, ORJ bracket-NiTi wire, Shinye bracket-SS wire and ORJ bracket-SS wire combinations at the end of experiment was negative as well.
(Jafari *et al.*, 2019)	Ni–Cr disk	Mouthwashes Listerine and Oral B	ICP-MS	45days	the amount of ion release was within the safe limits in the two experimental groups. However, it is recommended that prescribe Listerine mouthwash should not be prescribed for the patients with a history of Ni allergy.
(Currò & Bilello, 2020)	Fixed orthodontic appliance	Human saliva	atomic absorption spectrophotometer instrument.	24 months	Absolute values of the salivary metal ions in the subjects with fixed orthodontic appliances are more than the values observed in the control group, but these values are within the normal range.
(de Souza Schacher & de Menezes, 2020)	orthodontic appliances with soldered or welded parts	Human saliva	ICP-MS	One year	Results For Cr, Fe, Cu, and Sn ion concentrations among groups, there was no difference along collections and no statistically significant difference throughout collections for any group ($P > 0.05$, with release values between 3.3 and 4.2 µg/L for Cr, 201 and 314.8 µg/L for Fe, 23.1 and 40.7 µg/L for Cu, and 13 and 27.7 µg/L for Sn). For Ni, G4 showed an increased ion release at T2 (14.3 µg/L) and T4 (34.5 µg/L), values with an interaction effect ($P < 0.001$) comparing the groups and the points of collection. For Zn, Ag, and Cd ions there was no difference along the points in time ($P > 0.05$).
(Wajahat *et al.*, 2020)	NiTi archwires	▪ 3 types of mouthwashes artificial saliva	Field Emission Scanning Electron Microscope (FESEM)	28 days	▪ NiTi wires tested in mouthwash containing HCl in 0.15% w/v of Benzydamine Hydrochloride (EnziclorTM) produced greatest corrosion (16.2300+4.405 MPY) ▪ Dexapanthenol + permethol containing mouthwash (Hi-ParaentTM) showed minimum corrosion of the NiTi wires The rate of corrosion was found to be insignificant in artificial saliva, the control medium
(Moeen, 2020)	NiTi Archwires	3 types of mouthwashes artificial saliva	Field Emission Scanning electron microscope (FESEM)	6 months	NiTiwires tested in mouthwash containing HCl in 0.15% w/v of Benzydamine Hydrochloride (EnziclorTM) produced greatest corrosion (16.2300+4.405 MPY) ▪ Dexapanthenol + permethol containing mouthwash (Hi-ParaentTM) showed minimum corrosion of the NiTi wires▪ The rate of corrosion was found to be insignificant in artificial saliva, the control medium
(Velasco-Ibáñez *et al.*, 2020)	fixed appliances and stainless steel archs	urine and saliva	Using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)	between 3 and 6 months	There are differences in the concentration of Ni in saliva were found between 3 and 6 months of intervention and Ti in urine was found 3 and 6 months
(Habar *et al.*, 2020)	(NiTi) archwire and NiTi archwire with additional cooper (NiTi-Cu)	artificial saliva	Using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)	The ratio of the archwire and the saliva was 0.02 gr: 1 ml during 1 day, 33days and 66 days.	Corrosion resistances reviewed by average saliva artificial contained ion Ni after immersed 1 day of NiTi archwires and NiTi-Cu were 0.033 ± 0.000, and after immersed 33 days were 0.053 ± 0.022 and 0.101 ± 0.050, and after 66 days immersed were 0.101 ± 0.050 and 8.052 ±

					3.4667.
(Faleh *et al.*, 2020)	two brands of orthodontic bondable molar tubes	Mouthwashes	AtomicAbsorption Spectrophotometer and comparisons	45 days	The results showed statistically significant differences in ions released among different types of mouthwashes for both brands; The number of ions released in herbal mouthwashes was higher than in chemical one, so prolonged use of these mouthwashes is not recommended.
(Butt *et al.*, 2020)	fixed orthodontic appliances	Human saliva	Using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)	6 months	The mean age of candidates was 15.95 ± 3.63 years in arch wire group and 17.25 ± 3.91 in control group. There were 5 (25%) males and 15 (75%) females in arch wire group and 4 (20%) males and 16 (80%) females in control group. In this study, mean nickel concentration was 15.83 ± 12.96ng/ml in arch wire group while 10.21 ± 9.56ng/ml in control group. The difference was insignificant ($p>0.05$).
(Kovač *et al.*, 2021)	fixed orthodontic appliances SS brackets, 2 SS sterile archwires	Artificial saliva	ICP-MS,	90 days	The metal compositions of each sample derived by ICP-MS evidenced that brackets and archwires that were, according to the manufacturer declaration, made of stainless steel had roughly the same composition. The Fe content was 55.4 wt.% and 58.3 wt.%, while the Cr content was 24.9 wt.% and 27.1 wt.%, respectively, for SS brackets and SS archwires. Ni content was 17.8 wt.% in brackets and 14.6 wt.% in SS archwires, whereas Ti and Co were found in less than 0.1 wt.% for both brackets and SS archwires.
(Wepner *et al.*, 2021)	Removable appliance	Artificial saliva	Inductively coupled plasma mass spectrometry (ICP-MS)	7 days	The statistical analysis showed that there was no significant difference of Al release in reference to the colour of the test specimens. Generally, Al concentration of the glitter-free groups was in the range of the reference solution (770 µg/L), while Al concentration of the glitter-containing samples was clearly increased. Remanium® wires in combination with blue resin and glitter released 3764 µg/L on average, while colourless ones with glitter released 5511 µg/L. Conversely, Menzanium® released more aluminium with the colourless resin (6270 µg/L), while the blue ones released 9164 µg/L.
(Haleem *et al.*, 2021)	brackets and archwires	body fluid	inductively coupled plasma atomic emission spectroscopy	days 7, 14 and 28	All 23 elements under investigation except Si ions were detected from the control samples and fake braces. There were significant increased K ions and reduced levels of Mg ions from the fake archwires and brackets. Most ions released were less than 10 mg/L (Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Cd, Pb, Al) or 1 mg/L (Li, Ba) into the SBF medium.
(Shetti *et al.*, 2022)	32 of molar bands. 60 samples were silver soldered to stainless steel (SS) wire 16 were laser welded to SS wire.	Chlorhexidine (CHX), and artificial saliva (AS).	Spectrometry	24 h	Level of metal ions released from the samples of silver soldering was higher than from laser welding. The lowest amounts of metal ions were released in CHX while highest in NaF + alcohol. The SEM images were in accordance with these findings
(Mobeen *et al.*, 2022)	Thirty-six metal brackets were coated with copper oxide	artificial saliva at pH of 6.5	atomic absorption spectrometer	21 days	The highest concentration of zinc ion released from the zinc oxide and copper oxide nano coated brackets in

	(group A) and zinc oxide (group B)				the artificial saliva was on the 7th day and the quantity of zinc ion released was well below the levels that are toxic to humans throughout the study period.
(Ganidis *et al.*, 2022)	Metal orthodontic appliances	artificial saliva	inductively coupled plasma-optical emission spectrometer (ICP-OES)	30 days	the leachates were mainly enriched with Cr and Ni ions by decreasing the saliva pH, while most of the archwires released the highest amounts of Ni, Mn and Cr ions after 30 days aging at pH=3.5. Independent of the material type or the aging conditions, the total release of Niand Cr ions was within the considered average dietary intake levels.
(Natarajan & ., 2022)	orthodontic brackets and wires	oral fluids	Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES)	24 hours	The highest mean value of nickel release was noted in group C (0.32±0.020156 µg/mL) at the 24 hrs peak time followed by group B (0.24±0.014338 µg/mL). Statistical analysis showed a significant difference between the two experimental groups at all time periods except 1 hour (p-value <0.05). Conclusion: The amount of nickel ion release did not exceed the permissible limit in any of the study groups. However, it can be inferred that Amflor mouthwash can be prefered over Zero sense mouthwash for Orthodontic patients considering the lower nickel ion release.
(Kovac *et al.*, 2022)	SS brackets NiTi sterile archwires	artificial saliva	inductively coupled plasma mass spectrometry (ICP-MS)	90 days	concentrations of released metal ions from all tested alloys were below the upper recommended limit of daily intake.
(Fróis *et al.*, 2022)	Metal orthodontic appliances	Saliva	inductively coupled plasma optical emission spectroscopy	12-week	Mean salivary metallic ions were below toxic levels, and no adverse clinical reactions were registered. The intraoral surface degradation of the fixed components was corroborated by optical microscopy, scanning electron microscopy, and energy dispersive spectrometry. Microstructural analysis after complete orthodontic procedure confirmed different corrosion types, from pitting to biocorrosion.
(Kovac *et al.*, 2022)	SS brackets NiTi sterile archwires	intraoral exposure (Saliva)	Inductively coupled plasma-mass spectrometry (ICP-MS).Plasmamass spectrometry	90 days	concentrations of released metal ions from all tested alloys were below the upper recommended limit of daily intake.
(Natarajan & ., 2022)	orthodontic brackets and wires	oral fluids	Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES)	24 hours	The highest mean value of nickel release was noted in group C (0.32±0.020156 µg/mL) at the 24 hrs peak time followed by group B (0.24±0.014338 µg/mL). Statistical analysis showed a significant difference between the two experimental groups at all time periods except 1 hour (p-value <0.05). Conclusion: The amount of nickel ion release did not exceed the permissible limit in any of the study groups. However, it can be inferred that Amflor mouthwash can be prefered over Zero sense mouthwash for Orthodontic patients considering the lower nickel ion release.
(Almasry *et al.*, 2022)	Ni archwires	oral fluids	atomic absorption spectrophotometer (ASS)	1-2 months	There were no statistically significant differences in concentration of (Ni) ions in first two months of treatment. However, in (25 %) of samples taken from

					patients in 1-2 months after the beginning of treatment a small increase in concentration of Ni ions (by 7,5 %) was observed.

4. Discussion

Corrosion is defined as an electrochemical reaction on the metallic surface, leading to a reduction in material properties. In the context of orthodontic appliance corrosion in the oral environment, the emphasis is on two areas: (a) internal corrosive issues stemming from the metal composition and structure of the orthodontic appliance, and (b) external issues associated to the biological surroundings, which includes the pH value, media composition, and strain (B. Wendl *et al.*, 2017). Corrosion products can be absorbed into the body and lead to systemic or localized effects. Corrosion stems from the draining of metal ions into a solution, or the progressive dissolution of a surface layer, typically a sulfide or an oxide. The internal corrosive factors, which contribute toward metal ion leaching from orthodontic appliances, is determined by the type and structure of the material; as well as the alloy composition used for the fabrication of the appliances. Fixed orthodontic appliances with similar kinds of alloys (SS and NiTi alloys), produced by different companies, can differ in alloy composition from one company to another. This can be attributed to differences in production technologies and electrolytic coatings. Different ionic releases were observed from dissimilar types of wires and brackets, as well as from dissimilar types of incubation mediums. The different metal ions released by dissimilar archwire mediums may be attributed to the oxidation treatment, during the fabrication of the archwires (Zhang *et al.*, 2014). The neutral and acid media solutions used during these studies also play a role in determining the amount of metal ions leached into the incubating medium. The different analytical methods adopted for assessing metal ion leaching resulted in dissimilar sensitivity and detection limits (Riyam Haleem, Maha Mohammed, 2023).

5. Conclusion

Ni was the common ions investigated during last few years followed by Cr, mostly in the cytotoxicity. Studies of orthodontic appliance. the trends and needs in wearing orthodontic appliance should receive a different perspective with regards to metal leaching, which may give rise to adverse effects in long term application.

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