# In vitro release of nickel and chromium from different types of simulated orthodontic appliances

**Heidi Kerosuo, Dr. Odont; Grete Moe; Erik Kleven**

Most of the steel-based alloys used in orthodontics contain nickel and chromium. These elements give stainless steel its ductility and corrosion resistance. But both nickel and chromium can cause hypersensitivity in some people, particularly nickel, which is the most common contact allergen in women.[1-3] Allergic reactions to metallic orthodontic appliances have been documented in several case reports.[4-6] However, patients with confirmed nickel sensitivity are often able to use nickel-based prosthetic or orthodontic appliances without symptoms.[7-9]

Concomitant increases in the prevalence of nickel hypersensitivity and the demand and availability of orthodontic treatment have created growing interest in the composition of alloys and the release of metals during treatment. Grimsdottir et al.[10] analyzed the composition of facebows, bands, brackets, and archwires from different manufacturers and found that most components contained 8% to 12% nickel and 17% to 21% chromium.

Some corrosion of metallic devices is almost inevitable in the oral environment.[11-12] Park and Shearer[13] reported an average release of 40 μg nickel and 36 μg chromium per day from a simulated full-mouth, fixed appliance. The release of nickel is not necessarily proportional to the alloy's nickel content.[10] Heat treatment and silver soldering of the archwires accelerate corrosion in vitro.[14-16]

**Abstract**

Five identical samples, each consisting of a fixed appliance, a headgear and a quad-helix for one-half of a dental arch, were immersed in 0.9% sodium chloride for 2 hours, 24 hours and 7 days. A control appliance was subjected to dynamic test conditions in a specially built "oral simulator" under similar test conditions. A significant release of nickel was detected from the quad-helix during the first two hours in static conditions, whereas during the following two periods significantly less nickel was released from the quad-helix than from the other appliances. The fixed appliance with simulated function showed a significantly higher cumulative release of nickel than the similar appliance in static conditions, 44.2 μg (SD 22.8) and 17.1 μg (SD 3.4). The total amounts of chromium released from the fixed appliance were significantly lower than those of nickel. No difference in the release of chromium was seen between the static and dynamic conditions. The results indicate certain differences in the amount and pattern of nickel release from different stainless steel orthodontic appliances in vitro. The release rate of nickel from dynamically loaded fixed appliances was found to be accelerated compared with that released under static conditions. Caution should be exercised when applying the results to the in vivo situation.

**Key words**

Nickel • Chromium • Corrosion • Orthodontic appliances

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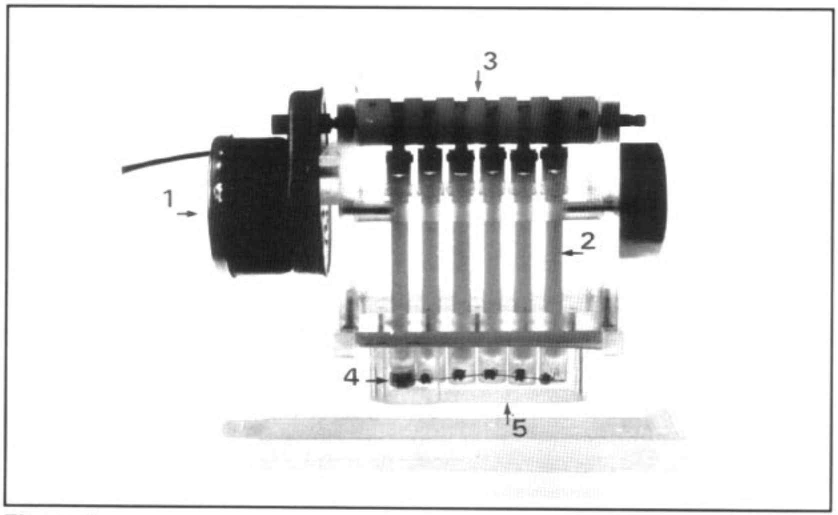

Figure 1

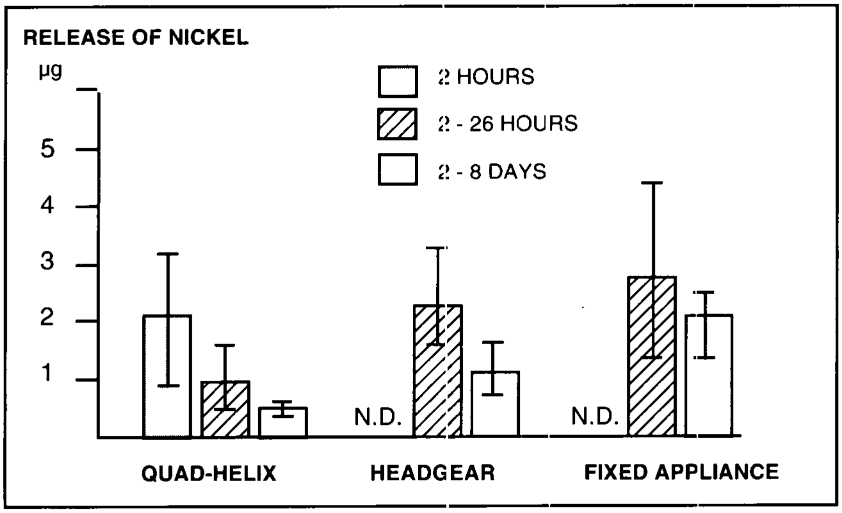

Figure 2

**Figure 1**
**Construction of the 'oral functioning simulator.' (1) electric motor; (2) Delrin rods; (3) camshaft; (4) acrylic caps with a fixed appliance; and (5) basin.**

**Figure 2**
**Mean release (+ S.D.) of nickel in 0.9% NaCl from orthodontic appliances during consecutive periods of 2 hours, 24 hours and 7 days. N.D., not detected.**

Little information is available about the amount of nickel and other metals released by different types of orthodontic appliances. In addition, in vitro experiments lack a functional component, even though friction and abrasion may affect the release of metals.

The aim of the present study was to investigate the amounts of nickel and chromium released from different types of orthodontic appliances, especially from a fixed appliance in a simulated oral environment under both static and dynamic test conditions.

## Material and methods

Three types of simulated orthodontic appliances were used for this experiment: fixed appliance, headgear and quad-helix. The appliances were constructed for half of a simulated dental arch, excluding second molars.

The fixed appliance consisted of five brackets, from mandibular second premolar to central incisor (Mini twin, nos. 350-0025, -0725, -0423, and -0625, Ormco, Glendora, Calif), and a molar band with double tube (GAC, International, Inc., Commack, NY). An 0.014-inch diameter Ni-Ti (Ormco) archwire was fastened to the brackets with metal ligatures. To simulate bonding and cementing, the bracket bases and the inner surface of the molar band were covered with autopolymerizing methylmethacrylate (Pro-base, Ivoclar AG, Schaan, Liechtenstein).

The headgear consisted of a molar band with double tube (GAC) and a facebow (GAC no. 08-420-00), with the outer bow removed and cut into two equal parts at the middle of the solder joint.

The quad-helix was fabricated by bending an 0.036-inch diameter stainless steel wire (Rocky Mountain Orthodontics, Inc., Denver, Colo) and cutting into equal halves. A half-helix was soldered to a molar band (GAC) using soldering flux and a silver plate (RMO).

### Static conditions

Five identical samples of quad-helix, headgear, and fixed appliance were constructed and immersed in 15 ml of 0.9% sodium chloride in acid-cleaned plastic tubes and held at room temperature for three periods: 2 hours, 24 hours and 7 days. Acid cleaning was performed with 3 N HCl (Suprapur, Merck, Germany). After each period the appliance was removed and immersed in a new tube with fresh solution of sodium chloride. The bands and the bases of the brackets were filled with autopolymerizing methylmethacrylate to simulate bonding and cementing of the appliance. The amounts of nickel and chromium released into sodium chloride were analyzed by flameless atomic absorption spectrophotometry.

### Dynamic conditions

A fixed appliance was mounted to the "oral functioning simulator" apparatus (OFS, Figure 1) to study the effect of movement on the release of nickel and chromium from the appliance. The OFS was composed of a 20-ml covered basin and six Delrin rods connected to a camshaft which was kept in motion by an electric motor. The rods were covered with acrylic caps to simulate the teeth in half a dental arch. Brackets were bonded to the caps with autopolymerizing methylmethacrylate and the bands cemented with glass ionomer cement (Ketac, ESPE GmbH, Seefeld/Oberbayern, Germany). The appliance was immersed in 15 ml of 0.9% sodium chloride in the basin at room temperature (23°C). The apparatus was connected to an electric timer which allowed movement; movement and rest periods were alternated every other hour to simulate an oral environment where periods of rest and functional activity interchange. Each rod moved vertically in sequence six times per minute. Each appliance was immersed in the saline solution for three periods: 2 hours (no pause in movement), 24 hours and 7 days (1 hour on; 1 hour off). After each period the saline was transferred to acid-cleaned plastic tubes for analysis and 15 ml fresh saline was added. After the last period, any precipitate was transferred together with an extra 4 ml of saline to a separate tube. The same experiment was run five times using a new appliance each time.

### Nickel and chromium analyses

The solutions from the simulated orthodontic appliances were prepared by adding 1 ml $HNO_3$ (Suprapur, Merck, Germany) to each sample. Chemicals were analyzed by electrothermal atomic absorption spectrophotometry (Model 372, Perkin Elmer Corp., USA,HGA 76B Grafite furnace, Bodenseewerk Perkin Elmer & Co. GmbH, Germany). Nickel and chromium standard solutions of 0.01 µg/ml - 0.50 µg/ml were used, 50 µl(Ni) and 10 µl(Cr) of the sample was injected directly into the graphite tube (Perkin Elmer B00810871, uncoated). The graphite tube temperature program consisted of drying at 150°C for 30 seconds, ashing at 1200°C for 20 seconds, and atomizing at 2700°C for 8 seconds.

After measurement of the peak height, the concentration of metal ions in the test solution was calculated from the standard curve. The analytical lines used were 357.9 nm for chromium and 232.0 for nickel. Unspecific absorption was corrected by a deuterium background corrector.

### Statistics

The student's t-test was used to compare the quantities of nickel and chromium released in different experiments.

## Results

The mean release of nickel into saline from the different simulated orthodontic appliances after periods of 2 hours, 24 hours, and 7 days is shown in Figure 2. Only the quad-helix released significant amounts of nickel within the first 2 hours. During the two longer periods, significantly less nickel was released from the quad-helix than from the fixed appliance ($p<0.025$) or headgear ($p<0.01$).

The amount of nickel released in 8 days from the fixed appliance under dynamic loading was significantly higher ($p< 0.05$) than from the fixed appliance in the static state, 44.3 µg (SD 22.8) and 17.1 µg (SD 3.4) respectively (Figure 3).

The amount of chromium released from the fixed appliance under the same conditions was significantly lower ($p< 0.01$), 2.5 µg (SD 0.7) and 4.5 µg (SD 2.0) respectively, and there was no significant difference between the static and dynamic experiments. The amounts of chromium released from quad-helix and headgear were also low (Figure 4).

Different degrees of brownish discoloration in the solutions were seen among the parallels. The bulk of the chromium released from the fixed appliance in the oral simulator was detected in the precipitate, whereas only trace amounts of nickel were found there.

## Discussion

Several electrochemical and physical factors, such as temperature, concentration of the liquid, surface area, stress, and loading, affect the corrosion of metals in vitro. One of the main objectives of this study was to test the effect of dynamic loading on the release of metals from the orthodontic appliances. An oral functional simulator was created for this purpose. The fixed

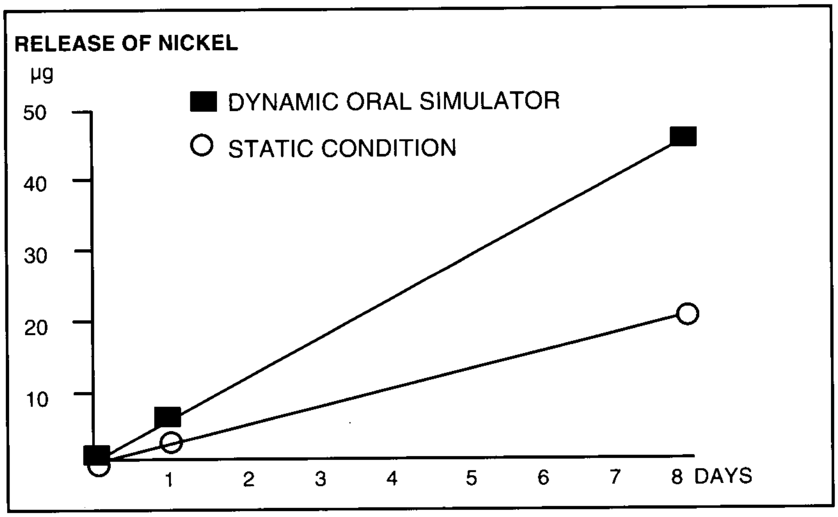

**Figure 3**

**Figure 3**
**Cumulative release of nickel from the fixed appliance as a function of time. Statistical differences: after 2 h $p< 0.05$, one day n.s., 8 days $p< 0.05$.**

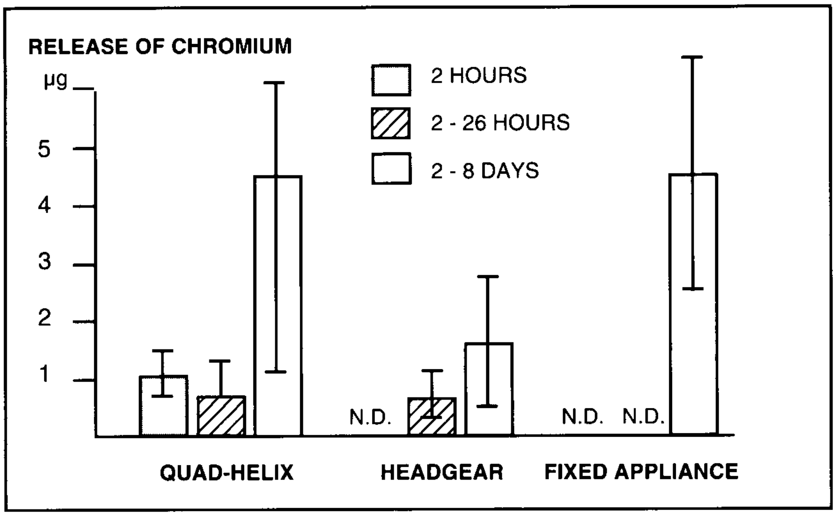

**Figure 4**

**Figure 4**
**Mean release (+ S.D.) of chromium in 0.9% NaCl from orthodontic appliances during consecutive periods of 2 hours, 24 hours, and 7 days. N.D., not detected.**

appliance was found to be most suitable for the dynamic setup because a load could be created by mounting the appliance to the rods simulating teeth, and then moving them in relation to each other. Both the quad-helix and headgear, being fixed to the first molars only, would not have been exposed to dynamic stress in this setting.

The tests were performed at room temperature instead of 37°C to avoid overheating of the electric motor of the oral simulator, which was a problem in initial experiments (unpublished). However, in relation to the high temperatures, which are needed to change the behavior and consistency of metals in general, the difference between room temperature and the more clinically-relevant temperature of 37°C, is small and not likely to significantly affect the release of metals.

Surface area is a relevant factor in the corrosion of metals, but determining the surface area of orthodontic bands and brackets of complex geometry was beyond the scope of this study, which aimed more at investigating the overall release of nickel and chromium from commonly-used orthodontic appliances.

For practical reasons the static and dynamic tests were not performed in the same apparatus; instead, blank samples were run together with both experiments to control contamination from instruments, test tubes, fixing materials, or the apparatus. Also, the exposed surface areas of the fixed appliances were identical in both tests due to the covering of the bracket bases and the inside of the molar bands with autopolymerizing methylmetacrylate in the static experiment. Cementing the bands with glass ionomer might theoretically have promoted metal release from the surface of bands tested in the oral simulator in comparison with those in the static test, but this theory needs more investigation.

The present results indicate a detectable release of nickel from simulated stainless steel fixed appliances in 0.9% sodium chloride, while the release of chromium was only slight and mostly in the form of precipitate. Several authors[10,13-14,16-17] have reported corrosion of orthodontic appliances in vitro, but variation in study designs and different electrochemical factors make comparisons between the studies somewhat difficult. The preparation and analytical procedure, including dissolving the precipitate, are technique-sensitive and may be a source of variation. Also, some of the corrosion products might adhere to the metal surface and would not be available for the instrumental analysis of the solutes and thus remain undetected.

The amounts of nickel released in the present study during 7 days from a simulated fixed appliance (16.7μg) and from headgear (7.5μg) are in good accordance with the results of Grimsdottir et al.,[10] who studied nickel release in vitro in 0.9% sodium chloride from different components of orthodontic appliances made by different manufacturers. Park and Shearer[13] reported roughly five-times-higher release of nickel per day from a simulated fixed appliance for half of a mandibular arch compared with the present study. This difference might be due to the larger surface area of the fixed appliance in their study. Also, differences have been found in the metal release between corresponding products made by different manufacturers.[10]

The amounts of chromium detected in the present study were considerably smaller than those reported earlier.[10,13] The precipitate was analyzed separately only in the oral simulator experiment, and this analysis confirmed the earlier findings[13,18] that chromium is released primarily in an insoluble form from orthodontic appliances. Only the quad-helix, with its "handmade" solder, showed similar release values for both nickel and chromium.

Silver-soldered stainless steel has been reported to be prone to corrosion.[14] In the present study, silver soldering might have been important in the earlier onset of metal release from the quad-helix than from the other appliances, but did not seem to affect the amounts of nickel and chromium released during 8 days.

Orthodontic appliances in the oral environment are exposed to rubbing, stress, and friction due to masticatory function, and these factors may affect the release of metals from the appliances. In this study we tested the effect of stress in vitro by comparing metal release from similar fixed orthodontic appliances both when immersed in saline in test tubes and by exposing the appliance to dynamic loading in the oral simulator. The test revealed that nickel release increased under dynamic loading. Whether this was due to an increased corrosion process or mechanical attrition cannot be determined on the basis of this study setup.

Physiological conditions in the oral cavity differ from in vitro arrangements. However, there is no reason to believe that functional stress, such as chewing, would not have the same increasing effect on corrosion/attrition of orthodontic appliances in vivo, even though the actual values of nickel release may differ. Loading of orthodontic appliances is likely to be greater in a real environment than that which could be constructed in the laboratory setting.

The present in vitro experiments were carried out with simulated appliances for one jaw quadrant. These data indicate a release of 22 μg of nickel per day from a full-mouth fixed appliance under functional stress. The dietary intake of nickel varies, with mean values reported from 130 μg to 165 μg per day.[19-22] This amount is considerably greater than the amount of nickel released from orthodontic appliances; however, the amounts are not directly comparable because the nickel ions released from orthodontic appliances have a higher local concentration and may thus play a more active role in local nickel hypersensitivity reactions.

The amount of nickel required to create a contact hypersensitivity reaction depends on the individual;[23] a minimun threshold has not been determined. A higher provocation threshold has been found for allergic symptoms of the oral mucosa than for the skin.[24] However, several case reports show allergic reactions in connection with orthodontic treatment.[4-5,25] In spite of individual variation, according to most recent studies, nickel-containing prosthetic and orthodontic appliances are generally quite well tolerated, even by nickel-sensitive individuals,[7-9,26] and oral administration of nickel has been reported to induce immunological tolerance to nickel in guinea pigs,[27] which gives new aspects for the studies on biological effects of nickel-containing alloys.

## Conclusions

Clearly detectable releases of nickel, and, to a minor extent, chromium, seem to occur with different stainless steel orthodontic appliances in vitro. The amount of nickel released increases during functional stress. The quantities released may be negligible from a toxicological standpoint, but might conceivably be of importance in individuals with a high degree of hypersensitivity to nickel. Caution should be exercised when applying the results to the in vivo situation.

The results indicate that dynamic conditions will alter the corrosion behavior of orthodontic alloys. In vivo studies should be performed to assess the importance of dynamic stress, saliva, and other factors on the corrosion process.

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