Ion release from dental casting alloys as assessed by a continuous flow system: Nutritional and toxicological implications

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Abstract

Objectives. The aims of this study were to quantify the metallic ions released by various dental alloys subjected to a continuous flow of saliva and to estimate the nutritional and toxicological implications of such a release.

Methods. Four pieces of three nickel-based, one noble, one high-noble and two copper–aluminum alloys were cast and then immersed in a continuous flow of artificial saliva for 15 days. To simulate three meals a day, casts were subjected to thrice-daily episodes, lasting 30 min each and consisting of pH decreases and salinity increases. After 15 days, the metallic ions in the artificial saliva were analyzed. Data were expressed as averaged release rate: g/cm²/day of ion released for each alloy. The highest value of 95% CI of each ion was adapted to a hypothetical worst scenario of a subject with 100 cm² of exposed metal surface. The results were compared with the tolerable upper daily intake level of each ion.

Results. The copper–aluminum alloys released copper, aluminum, nickel, manganese and iron. The nickel-based alloys essentially released nickel and chromium, while the beryllium-containing alloy released beryllium and significantly more nickel. The noble and high-noble alloys were very resistant to corrosion. The amount of ions released remained far below the upper tolerable intake level, with the exception of nickel, released by beryllium-containing nickel-based alloy, whose levels approach 50% of this threshold.

Significance. The daily amount of ions released seems to be far below the tolerable upper intake levels for each ion.

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1. Introduction

There are currently hundreds of alloys available for prosthodontic restorations. The major factors affecting alloy selection are economics, physical properties, casting technique, corrosion and biocompatibility [1,2]. In recent years, there has been increasing concern about the adverse effects, both local and systemic, of prosthodontic alloys [3,4]. These adverse effects can be toxic or allergic and are linked to ion release in the organism, as well as to the kind of ions released [5–7]. However, as some elements are essential nutrients involved in biological functions, a minimum daily intake is needed. The tolerable upper intake level is the highest daily nutrient intake, from food plus other sources
of supply, which can be safely ingested by the vast majority
of individuals without posing any adverse health effects [8].
Given that prosthodontic restorations are a supply source for
metal ions, the amount of ion released must be below the
tolerable upper intake level.

Ion release from dental alloys has been evaluated mainly
by in vitro studies, in which the alloy is subjected to different
settings: oral bacteria [9], galvanism [10], electrolyte bath [11],
coral proteins [12], different pH levels [13] and brushing with
teeth paste [14]. In general, the most frequently used method
for monitoring the number of elements released from casting
dental alloys is a static system. However, to mimic the in vivo
setting of the oral cavity more closely, a continuous flow sys-
tem has been employed for studying the fluoride release of
glass-ionomer materials [15,16].

The aims of this study were: (1) to identify and quantify the
different ions released by various dental alloys subjected to a
continuous flow of saliva, thereby reproducing certain in vivo
conditions, such as the constant flow of saliva and the sudden
changes in pH and salinity that occur during meals and (2)
to compare the number of ions released over time with the
tolerable upper intake level of minerals.

2. Materials and methods

Five current prosthodontic alloys were chosen: three nickel-
based alloys, Will-Ceram Litecast® (Williams Dental, USA),
Litecast® (Williams Dental, USA) and Nibon® (Ventura,
Spain), one noble alloy, Cerapall® (Alidabdent, USA), were silicified as
positive controls due to their highly corrosive properties. Their
composition was verified by semi-quantitative analysis using
X-ray diffraction, which indicates the presence of elements in
a proportion greater than 1% (Table 1).

For each alloy, 20 rectangular pieces of 1.3 cm × 2.6 cm × 0.04 cm wax (Technowax®, Protechno, Vilamalla, Spain) were
placed in 4 cylinders and then cast with a Diecast® induction
casting machine (Ogin Dentaire, Grenoble, France), following
the manufacturer’s instructions. All casts were subjected to a
standardized polishing procedure to obtain a glossy surface
with similar average roughness values, which ranged from
0.2 to 0.4 μm analyzed by Profilometry (Perthometer M4P®,
Perthen, Germany). The casts were subsequently put into
individual plastic corrosion recipients of 8.8 cm × 3 cm × 1.5 cm,
each containing five pieces of the same cast. Thus, each recip-
ient presented a metal surface of 33.8 cm². Casts were then
immersed in a constant flow of artificial saliva (named base
saliva) for 15 days by means of a peristaltic bomb (Watson Mar-
low 302S, 55 rpm). This permitted the artificial saliva to run
through the recipients (Fig. 1), regulating a flow of 2.7 mL/h,
which corresponds to 10% of real base saliva secretion. More-
over, the casts were subjected to thrice-daily episodes of pH
decrease and salinity increase to mimic the changes that
occur during meals. This was achieved by means of an elec-
trical valve (Acso Angar®) connected to a time programmer
that cut off the base saliva flow every 7 h and gave way to
modified saliva, with the addition of sodium chloride and
acetic acid (termed meal saliva) for 30 min. “Base saliva”
was a solution of Fusayama Meyer artificial saliva [17], con-
taining 0.4 g/L NaCl, 0.4 g/L KCl, 0.69 g/L NaH₂PO₄·H₂O, 0.79 g/L
CaCl₂·2H₂O and 1 g/L urea. “Meal saliva” consisted of modi-
ﬁed Fusayama Meyer artificial saliva, supplemented by 9 g/L
of sodium chloride and 0.1N acetic acid to attain pH 4. These
changes were made because most foods are eaten with NaCl
supplement and dental plaque pH decreases to approximately
5.5 for 30 min after each meal [18]. Acidity can also be reached
through acidic drink or regurgitation [19]. The metal pieces
were arranged vertically in corrosion recipients, alternating
right and left, so that the saliva flow was forced to zigzag
between them, thereby bathing the entire metal surface. Saliva
exiting the corrosion recipients was collected in 250 cm³ pre-
cipitate glasses covered with parafin to avoid contamination.

The entire circuit was prepared to prevent the saliva com-
ing into contact with metals other than the experimental
alloys. Artificial saliva solutions were, therefore, kept in plas-
tic bottles, the electrical valve was made entirely of Teflon,
and the tubes through which the saliva passed were made of
silicon, and were connected to the electrical valve by plastic
brackets. All connections between the silicon tubes, as well
as those between the silicon tubes and the plastic recipients,
were made watertight by means of silicone rubber glue (Rho-
dias CA5®, Rhine Poulenc). The metal pieces were stuck to
the floor, the lateral wall and the lid of the plastic recipient
were stuck with silicon, and the lid of the plastic recipient
was stuck to the recipient with an adhesive of rigid plastics

![Fig. 1 – Overall view of the peristaltic bomb, the corrosion recipients and the collection containers.](image-url)
This would represent an exposed metal surface of approximately 100 cm². The results of multiplying the maximum 95% CI value for the average release rate of each ion by 100 were compared with the tolerable upper daily intake level of each ion.

3. Results

Table 1 – Semi-quantitative analysis of the composition (wt%) of each alloy

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>Si</th>
<th>Be</th>
<th>Pd</th>
<th>Au</th>
<th>Ag</th>
<th>In</th>
<th>Ga</th>
<th>Zn</th>
<th>Cu</th>
<th>Mn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC-Litecast</td>
<td>70.6</td>
<td>15.2</td>
<td>13.0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Litecast® B</td>
<td>78.9</td>
<td>12.0</td>
<td>3.5</td>
<td>4.3</td>
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<td></td>
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<tr>
<td>Nibon®</td>
<td>63.2</td>
<td>18.2</td>
<td>7.1</td>
<td>5.5</td>
<td>3.6</td>
<td></td>
<td></td>
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<tr>
<td>Cerapall 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75.0</td>
<td>6.1</td>
<td>6.4</td>
<td>5.9</td>
<td>6.0</td>
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<td>Pontor® 4CF</td>
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<td></td>
<td></td>
<td>8.7</td>
<td>64.3</td>
<td>20.3</td>
<td>3.7</td>
<td>1.0</td>
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<tr>
<td>Orcast®</td>
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<td></td>
<td></td>
<td>3.6</td>
<td>3.6</td>
<td>83.0</td>
<td>1.5</td>
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<td>NPG®</td>
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<td></td>
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<td></td>
<td></td>
<td>80.9</td>
<td>1.5</td>
<td>2.1</td>
<td></td>
</tr>
</tbody>
</table>

Bold-face elements show the main component of each alloy.

Table 2 – Mean (95% CI) of averaged release rate of metallic elements in µg/cm²/day

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>Si</th>
<th>Be</th>
<th>Pd</th>
<th>Au</th>
<th>Ag</th>
<th>In</th>
<th>Ga</th>
<th>Zn</th>
<th>Cu</th>
<th>Mn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC-Litecast</td>
<td>0.668 [0.530:0.79]</td>
<td>4.693 [4.17:5.22]</td>
<td>0.042 [0.030:0.05]</td>
<td>0.090 [0.070:0.11]</td>
<td>0.150 [0.090:0.19]</td>
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<tr>
<td>Litcast® B</td>
<td>0.024 [0.020:0.025]</td>
<td>0.018 [0.04:0.04]</td>
<td>0.048 [0.014:0.05]</td>
<td>0.042 [0.012:0.01]</td>
<td>0.141 [0.05:0.23]</td>
<td>0.181 [0.14:0.18]</td>
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<tr>
<td>Nibon®</td>
<td>0.303 [0.31:0.41]</td>
<td>0.020 [0.06:0.06]</td>
<td>0.006 [0.02:0.02]</td>
<td>0.007 [0.02:0.02]</td>
<td>0.027 [0.02:0.08]</td>
<td>0.029 [0.02:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td>0.053 [0.05:0.08]</td>
<td></td>
</tr>
</tbody>
</table>
The continuous flow system allows one to mimic the characteristics of the oral cavity, with its constant secretion of saliva and periodic changes in salinity and acidity coinciding with meals. In general, an advantage of using a continuous flow system is that the saturation limit is unlikely to occur. In the case of ions released from dental alloys, although there is no risk of reaching the saturation limit due to their very low release levels, the concentration profile could vary because the dissolved material is removed continuously from the metal surface by the flow of saliva. In fact, the results of the present study were similar to those of other authors who used static systems [14,21,22]. Ion composition and pH of the corrosive solution are of great significance, especially for nickel-based alloys [13,19,54]. Nevertheless, noble alloys and especially high-noble alloys are not significantly affected by low pH [13] or by different electrolytes [11]. The release of ions into cell culture medium from some high-noble, noble and base-metal casting alloys was investigated over a period of 10 months [20]. Although higher initial rates were suspected, they were not verified and metal ions were constantly released during this entire period. In appraisal of the safety of the ion release compared with the tolerable upper daily intake level, it is desirable to measure ion release in those situations where the number of elements released are significantly affected by the alloy type [20] as well as by the composition and the pH of the corrosion liquid [13,19]. In the present study, the amount of nickel released from beryllium-containing nickel-based alloy was very similar (4 μg/cm²/day approximately) to the amount found in other studies in which a beryllium-containing nickel-based alloy was immersed either in saline [13] or phosphate-buffered saline [14], but 30 times less than when this kind of alloy was immersed at pH 2.3 and saline [21]. The amount of nickel released from WC-Litecast, a non-beryllium-containing nickel-based alloy, was practically identical (0.6 μg/cm²/day) to that observed by Denizoglu et al. [22], who used Meyer saliva at pH 4. Noble and high-noble alloys are in general much more resistant to corrosion and release a very low amount of zinc [14,23] as in the present study.

The physical properties and the biocompatibility of alloys depend on their composition and microstructure. In general, multiphase alloys are more prone to corrosion than monophase alloys, due to a galvanic effect between areas of different composition inside the alloy [23]. In fact, the same alloy can show different susceptibility to corrosion in different structural conditions created by heat treatment [25]. There are many factors that may change the final properties of the alloys, such as heating and cooling processes during casting, impurities [36] and the porcelain-fused-to-metal firing procedures. These may alter the surface oxides and corrosion properties of nickel-chromium alloys depending on their chemical composition [27].
In the present study, a beryllium-containing nickel-based alloy released the highest amount of nickel. The corrosion resistance of nickel–chromium alloys depends on the formation of a thin layer of oxides on the metal surface, resulting from an initial corrosion, thereafter acting as a protective layer. This phenomenon, known as passivation, generates a characteristic curve of ion release, with a high initial release, which drops after a time [21]. Nevertheless, this passivation layer can be disrupted under various conditions, including bruxism [28]. Even in very low proportions, beryllium is known to form a eutectic phase Ni-Cr-Be, which is susceptible to undergo a preferential corrosion, thereby releasing nickel and beryllium [21,29,30]. Nibon alloy had 15 times less corrosion than Will-Ceram Litecast. This is probably because Nibon contains 18 wt% chromium, which remains within the recommended range (16–27%) for reducing corrosive effects [31,32].

Will-Ceram Litecast and Litecast B contain 15.2 and 12 wt% chromium, respectively. In living systems some metals have biological functions. While iron is essential in relatively high concentrations, other elements, such as zinc, copper, nickel, cobalt, molybdenum and perhaps chromium are only essential in trace amounts, since at higher concentrations they are very toxic. Some metals, such as mercury, lead, cadmium and uranium, have no clear biological function and are toxic even at very low levels [33]. Even in the worst scenario, with all 32 teeth covered by full metal crowns, the results remain far below the upper tolerable intake level for each ion, with the exception of nickel released by nickel-based alloy containing beryllium litecast B®, which gives levels near to 50% of this threshold. Some studies have suggested that non-sensitized persons can develop a tolerance to nickel through continual exposure to it at a mucosal surface, such as the situation with dental braces [34]. A double-blind, placebo-controlled clinical study demonstrated that oral nickel exposure elicits cutaneous nickel-allergic reactions in nickel-sensitive individuals in a dose-dependent manner [35]. It is not known whether a constant release in the oral cavity of minute amounts of nickel is harmful or beneficial to the patient. At the population level, oral intake of small amounts of nickel may help reduce overall sensitivity to nickel prevalence in humans. At the individual level, however, once allergic contact dermatitis has been diagnosed, a reduced oral intake of nickel would be advisable in certain cases [36].

In the worst-case scenario, 41 µg of beryllium a day would be released from Litecast B. The primary route of human exposure to beryllium is inhalation of vapors or particles, an exposure associated with increased incidence of lung cancer and a number of other diseases, from, contact dermatitis to chronic granulomatous lung disease. Beryllium may also be ingested in drinking water or contaminated foodstuffs but at very low levels. Ingested beryllium enters the bloodstream, this is not thought to be a particularly dangerous mode of exposure. Beryllium can also be inhaled and ingested from cigarette smoke or can enter the body through cuts in the skin [37,38]. Therefore, the ADA Council recommends that practitioners do not use alloys containing beryllium in the fabrication of dental prostheses, a precaution to protect not the patient, but the dental technician. In the same hypothetical worst case, the maximum daily release of aluminum would be about 23 µg, in this case by Oncrat®. Aluminum is ingested in amounts of 4–6 mg every day in food and beverages. In certain circumstances, such as the use of aluminum-containing antacids, some people may ingest a thousand-fold greater amount than the average daily consumption. Normally, however, the digestive tract is an effective barrier against gastro-intestinal aluminum absorption, with most of what is ingested excreted wholly unabsobered in the feces [39]. It is nevertheless difficult to predict the clinical behavior of an alloy from in vitro studies, since such factors as changes in the quantity and quality of saliva, diet, oral hygiene, polishing of the alloy [40], the amount and distribution of occlusal forces [28], or brushing with toothpaste can all influence corrosion to varying degrees [14].

5. Conclusions

Under the conditions of the present study, the average daily release of ions from the alloys tested fell far below the tolerable upper intake level recommended for each ion.

Acknowledgement

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References


