

Release of nickel and chromium in common foods during cooking in 18/10 (grade 316) stainless steel pots

Fabrizio Guarneri¹, Chiara Costa², Serafinella P. Cannavò¹, Stefania Catania³, Giuseppe D. Bua³, Concettina Fenga² and Giacomo Dugo³

¹Department of Clinical and Experimental Medicine – Dermatology, University of Messina, 98125, Messina, Italy, ²Department of Clinical and Experimental Medicine – Occupational Medicine, University of Messina, 98125, Messina, Italy, and ³Department of Biomedical Sciences and Morphological and Functional Images, University of Messina, 98125, Messina, Italy

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Summary

Background. Literature data on the release of nickel and chromium from stainless steel cookware during food preparation are contrasting, have often been obtained with uncommon foods and/or procedures, and are thus not widely applicable.

Objectives. To assess the release of nickel and chromium from 18/10 (grade 316) stainless steel pots in cooking conditions that are common in an urban lifestyle.

Methods. Tomato sauce and lemon marmalade were cooked for 1 h, alone or with added EDTA, in used or unused stainless steel pots from different manufacturers. Additionally, aqueous solutions at pH 2.3, 7.7 and 9 were boiled for 1 h in the same pots. Metal release was assessed with inductively coupled plasma mass spectrometry.

Results. The release of nickel and chromium increased with cooking/boiling time, was higher with unused pots, at low pH or with EDTA, and was sometimes remarkably different between manufacturers. In all experiments, the amounts released were below known allergy-triggering thresholds.

Conclusions. Under common conditions, the use of 18/10 stainless steel pots is considered to be safe for the majority of nickel-allergic and/or chromium-allergic subjects. However, the total amount of nickel contained in foods and released from pots may exceed the individual threshold for triggering allergy, potentially causing problems for highly sensitive patients, or, conversely, contribute to induction of immunotolerance by oral low-dose exposure.

Key words: allergy; chromium; contact dermatitis; food safety; nickel; stainless steel.

Stainless steel is an iron–carbon alloy that may contain, in variable percentages, other elements such as Ni, Cr, Mo, As, Cd, Pb, Sn, Mn, Cu, Zn, Al, S, and Si. The presence of Cr in this alloy is fundamental, and a minimum percentage (~6.5%) ensures the formation of an oxide that covers

the entire surface and protects it from corrosion; increasing the Cr content beyond the threshold of 10.5% further increases resistance to corrosion. The addition of other metals (e.g. Ni and Mo) improves resistance to corrosion and confers additional properties to steel: in particular, the protective oxide ensures the build-up of a very thin, clear surface layer in contact with the oxygen contained in air and water. This layer depends on the chemical composition of stainless steel, the heat treatment used during production, and the type of oxidizing environment (1). Stainless steels are generally considered not to be dangerous to human health, and are used in applications where safety and hygiene are considered to be of the utmost importance, such as kitchenware.

Correspondence: Fabrizio Guarneri, Department of Clinical and Experimental Medicine – Dermatology, University of Messina, Via Consolare Valeria-Gazzi, 98125 Messina, Italy. Tel: +39 090 2212891; Fax: +39 090 2927691. E-mail: f.guarneri@tiscali.it

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The elicitation or exacerbation of allergic cutaneous reactions by ingestion of allergy-causing metals such as Ni is a well-known issue: more than 30 years ago, some authors (2) reported that Ni can cause exacerbation of hand eczema in sensitized patients. Also well known is the possibility of systemic contact dermatitis developing after the ingestion of haptens to which a patient is sensitized, such as Ni, Co, Cr, and Zn (3). This has become a 'hot topic', particularly in the last few years, after the definition of the 'systemic nickel allergy syndrome'.

Some studies (3–11) have focused on the evaluation of the release of Ni and Cr from stainless steel cookware during food preparation. Data from such studies often appear to be conflicting, and are sometimes not applicable to the general population on a worldwide scale, because of non-standard procedures or conditions that do not reflect common domestic use, for example new or almost new cookware, food or cooking procedures that are common only to specific geographical areas or socio-cultural contexts, excessively long cooking times, different chemical characteristics (particularly pH values) of foods, and cookware made of stainless steel grades that are infrequently used for food containers (4, 5). Nonetheless, some authors, and even some guidelines, advise Ni-allergic patients not only to reduce ingestion of Ni-containing foods, but also to avoid foods of any kind, acid ones in particular, cooked in stainless steel utensils (6).

In this study, we aimed to evaluate the release of Ni and Cr from 18/10 (grade 316) stainless steel cookware in conditions that can be considered to be representative for a large part of the world population. To this end, we chose foods that are widely consumed in many nations and cultures (lemon and tomato), and cooked them, according to times and procedures typical of an urban lifestyle, in commonly available stainless steel pots, new or already subject to domestic use for several years, produced by three manufacturers located in different countries. We also evaluated the release of metals in the above food preparations after the addition of a chelating agent (EDTA), as well as in boiling water at different pH levels (2.3, 7.7, and 9).

Materials and Methods

Chemical and standard solutions

Ultrapure water with resistivity of 10 M Ω cm, HNO₃ (65% vol/vol) and H₂O₂ (30% vol/vol) for trace metal analysis grade were purchased from J. T. Backer (Mallinckrodt Backer, Milan, Italy). Stock standard solutions at 1000 mg/l in HNO₃ (2% vol/vol) of Cr and Ni were purchased from Merck (Darmstadt, Germany). Also, a solution of Re at 1000 mg/l in HNO₃ (2% vol/vol) was

acquired from Fluka (Milan, Italy), and was used, as a preparation standard, to verify sample digestion and to correct volumetric changes. Stock standard solutions at 1000 mg/l in HNO₃ (2% vol/vol) of ⁴⁵Sc and ⁷²Ge were purchased from Fluka, and used as on-line internal standards (diluted with HNO₃ 2% vol/vol to 1 mg/l) to correct for instrumental drift and variations caused by the matrix. Appropriate amounts of each standard element were mixed to prepare a standard mixture, which was diluted with HNO₃ (5% vol/vol) at five concentration levels, and then used for the construction of calibration curves. The internal standard of Re was prepared by diluting a standard solution to 1 mg/l with HNO₃ (2% vol/vol). EDTA was purchased from Sigma Aldrich (Milan, Italy). All glassware was treated with HNO₃ (5% vol/vol) overnight to avoid contamination, and then rinsed with ultrapure water and dried.

Cookware

Three commercial grade 316 stainless steel pots (18/10 steel, i.e. steel containing 18% Cr and 10% Ni) produced by manufacturers from different countries, used in a domestic setting for 10–12 years, and three unused pots identical to the above ones were chosen for cooking procedures. The stainless steel grade was engraved on each pot. Between procedures, all pots were washed with tap water and a common dishware detergent, reproducing the home scenario.

Foods and cooking procedures

Experiments were performed with tomato sauce (TS) and lemon marmalade (LM), two foods that are regularly consumed by many populations worldwide. Additionally, these foods are acid, and low pH is associated, according to the literature, with increased release of metals from stainless steel (6–9): thus, our choice was aimed at evaluating the maximum release that may occur in everyday conditions. In the first case, 750 ml of commercial TS was mixed with 50 ml of water before cooking; in the other case, 500 g of lemon pulp was mixed with 300 g of sugar to prepare an LM. The two preparations (pH 4.5 and 2.6, respectively) were cooked in each of the pots used, with a lid, for 60 min, mixing with a spoon every 10 min. Five 5-ml aliquots were withdrawn at 0, 15, 30, 45 and 60 min. In another round of experiments, foods were prepared according to the same procedure, but with the addition of 0.2 mg of EDTA per gram of TS or LM. Finally, an acid (citric acid 0.1 M in water, pH 2.3), a saline (NaCl 0.06 M in water, pH 7.7) and a basic (NaOH 3 μ M in water, pH 9) solution (1 l each) were prepared and boiled in the

Table 1. Linearity, sensitivity and intra-day and inter-day precision of the inductively coupled plasma mass spectrometry method used

Element	R^2	LOD ($\mu\text{g/l}$)	LOQ ($\mu\text{g/l}$)	Intra-day precision (RSD%)	Inter-day precision (RSD%)
Ni	0.99999	0.009	0.032	3.2	2.6
Cr	0.99999	0.010	0.031	3.4	1.4

LOD, limit of detection; LOQ, limit of quantification; R^2 , determination coefficient; RSD, relative standard deviation.

pots for 60 min, and five aliquots were obtained at 15-min intervals. All samples collected were measured and stored in plastic vials for subsequent analysis.

Sample preparation

For sample digestion, approximately 0.5 g of TS and LM was first added with 8 ml of HNO_3 (65% vol/vol) and 2 ml of H_2O_2 (30% vol/vol) in acid-pretreated PTFE vessels; 1 ml of Re at a concentration of 1 mg/l was also placed inside the samples. Mineralization was carried out with a closed-vessel microwave digestion system (Ethos 1; Milestone, Bergamo, Italy) at 200°C with a power of 1000 W for 20 min. After being cooled to room temperature, the digested samples were quantitatively transferred into pre-cleaned volumetric flasks, diluted to 25 ml with deionized water, and stored at +4°C. The reference material was digested under the same conditions as the samples. All determinations were carried out in triplicate. The aqueous solutions with different pH levels were directly analysed after addition of 0.375 μl of HNO_3 (67–69% vol/vol) to a volume of 25 ml.

Sample analysis with inductively coupled plasma mass spectrometry (ICP-MS)

The determination of Cr and Ni in digested samples was carried out with an iCAP Q (Thermo Scientific, Waltham, MA, USA) inductively coupled plasma mass spectrometer equipped with an ASX520 autosampler (Cetac Technologies, Omaha, NE, USA). The ICP-MS operating conditions were as follows: radiofrequency power, 1550 W; plasma gas flow rate, 14 l/min; auxiliary gas flow rate, 0.89 l/min; carrier gas flow rate 0.91 l/min; He collision gas flow rate, 4.5 ml/min; spray chamber temperature, 2.70°C; sample depth, 4.27 mm; sample introduction flow rate 0.93 ml/min; nebulizer pump, 0.1 rps; and extract lens 1 voltage, 1.5 V. The instrument was operated in He KED mode to remove spectral interference for both the low-mass elements and the high-mass elements. The monitored isotopes were ^{52}Cr and ^{60}Ni . These isotopes were chosen to maximize sensitivity and to minimize interference caused by the matrix. As on-line internal standards, ^{45}Sc for ^{52}Cr and ^{72}Ge for ^{60}Ni were used. The integration times were 0.05 s/point for ^{52}Cr

and 0.01 s/point for ^{60}Ni , whereas the integration time for both internal standards was 0.01 s/point. To integrate the peaks, three points for each mass were taken and three replicate acquisitions were performed.

Method validation

The procedures for method validation were the same as reported by other authors (5). Table 1 summarizes the data on sensitivity, linearity, and the intra-day and inter-day precision of the method employed. The limit of detection (LOD) was defined by 15 successive blank measurements, performed with a 1% HNO_3 solution as blank. The value was extrapolated multiplying it by $3s/m$, where s is the standard deviation of the successive assays, and m is the slope of the calibration curve (12). The limit of quantification (LOQ) was calculated as $10s/m$. The experimentally determined LOD and LOQ values were 0.009 and 0.032 $\mu\text{g/l}$ for Ni, and 0.010 and 0.031 $\mu\text{g/l}$ for Cr.

The evaluation of linearity was based on injection of five standard solutions. Each solution was injected six times ($n = 6$). Excellent linearity was observed in each concentration range, with $R^2 \geq 0.99999$. The accuracy of the method was determined with the standard addition analysis. Three calibration concentrations (0.5, 5 and 50 ppb for both Ni and Cr) were added to 1% HNO_3 solution and analysed. The accuracy of the method was 86.70% for Ni and 94.5% for Cr. Intra-day and inter-day precision were obtained by analysing six replicates of the same standard mixture, on the same day and on different days, respectively. The data obtained were expressed as relative standard deviation percentage; they were 3.2% (Ni) and 3.4% (Cr) for intra-day precision, and 2.6% (Ni) and 1.4% (Cr) for inter-day precision. Recovery of Re as an internal standard confirmed good reliability of the extraction method ($99.3\% \pm 1.06\%$ and $99.8\% \pm 1.14\%$ for TS and LM, respectively).

Statistical analysis

PRISM 5 software (GraphPad Software, La Jolla, CA, USA) was used to analyse all test results. The results were calculated as the mean of three experiments, each performed in triplicate, and expressed as mean \pm standard deviation. Statistical analysis of food preparation data was

Table 2. Cr and Ni release (mg/l) from three used pots produced from different stainless steel brands (SS1, SS2, and SS3) into lemon marmalade (LM) and tomato sauce (TS), with and without EDTA added

Element	SS1		SS2		SS3	
	LM	LM + EDTA	LM	LM + EDTA	LM	LM + EDTA
Cr	0.033 ± 0.004	0.072 ± 0.005	0.074 ± 0.009	0.075 ± 0.009	0.030 ± 0.003	0.063 ± 0.004
Ni	0.038 ± 0.003	0.061 ± 0.005	0.077 ± 0.006	0.096 ± 0.003	0.034 ± 0.004	0.053 ± 0.006

Element	SS1		SS2		SS3	
	TS	TS + EDTA	TS	TS + EDTA	TS	TS + EDTA
Cr	0.039 ± 0.002	0.069 ± 0.001	0.098 ± 0.007	0.158 ± 0.003	0.028 ± 0.003	0.055 ± 0.005
Ni	0.066 ± 0.004	0.099 ± 0.006	0.144 ± 0.024	0.171 ± 0.008	0.098 ± 0.003	0.121 ± 0.005

Data represent mean ± standard deviation (n = 3) of the difference ($t_{60 \text{ min}} - t_{0 \text{ min}}$).

performed by means of one-way ANOVA followed by Dunnett *post hoc* tests. Experiments performed with aqueous solutions at pH 2.3, 7.7 and 9 were statistically analysed by the use of one way ANOVA with Newman–Keuls multiple comparison tests. Differences were considered to be statistically significant when the *p*-value was <0.05.

Results

The amounts of Ni and Cr released into TS and LM from stainless steel pots were found to increase with cooking time, as expected; with the aim of considering the worst possible scenario for patients, we evaluated results at 60 min. Table 2 shows the amounts of Cr and Ni released after 60 min of cooking from used pots from different manufacturers (labelled as SS1, SS2, and SS3) into LM and TS, with or without the addition of EDTA. When foods were cooked alone, the maximum quantities found (including basal levels contained in food and amounts released from pots) in TS were 0.148 mg/l Ni and 0.102 mg/l Cr, and values were similar for LM (0.080 mg/l Ni, and 0.077 mg/l Cr). It is noteworthy that remarkable differences (up to a factor of three) were observed between brand SS2 and the other brands (Fig. 1a–d).

With the addition of EDTA, the amount of Cr in LM almost doubled for brands SS1 and SS3 ($p < 0.001$), but remained stable for SS2; the maximum value was 0.078 mg/l, which was essentially identical to that obtained without EDTA (Fig. 1c). However, a remarkable increase in Ni release into LM was observed for all brands ($p < 0.01$), and the overall maximum level was, in this case, 0.100 mg/l (Fig. 1d). Addition of EDTA also enhanced the release of metals into TS: the increase, observed for all steel brands, was significant for Cr (Fig. 1a), but smaller and not significant for Ni (Fig. 1b).

The maximum values recorded in experiments with TS + EDTA were 0.162 and 0.175 mg/l for Cr and Ni, respectively.

Table 3 and Fig. 2a–f show the amounts of Cr and Ni released into three aqueous solutions with different pH levels from the three stainless steel pots used for at least 10 years or from new (unused) pots. With all brands, metal release was higher from unused than from used cookware. At lower pH, the maximum amounts of Cr released from unused pots were ~45% higher than from used pots, with some differences being seen between brands. In the case of Ni, the average increase for new pots was ~22% higher, without particular variations between brands. It is noteworthy that the absolute amounts of metals released were remarkably higher for pots of the SS2 brand than for the other two brands. Overall, the maximum levels recorded were 0.245 mg/l for Cr and 0.428 mg/l for Ni (for new pots). At higher pH levels, new pots still released higher amounts than used ones, but the absolute levels were much lower (maximum 0.067 mg/l for Cr and 0.028 mg/l for Ni, both at pH 7.7), and the average differences after 60 min between used and new pots were approximately 32% at pH 7.7 and 37% at pH 9 for Cr, and 18% at pH 7.7 and 22% at pH 9 for Ni. These data show a more aggressive effect of acidic solutions on stainless steel. At pH 7.7, the behaviour of the three brands was particularly variable. The results obtained from statistical comparison of old and new 18/10 (grade 316) stainless steel pots at three different pH levels showed the following: for the SS1 brand, $p < 0.05$ only for Cr at pH 2.3; for the SS2 brand, a significant difference for both metals at all pH levels (at pH 2.3, $p < 0.01$ for Cr and $p < 0.001$ for Ni; at pH 7.7, $p < 0.001$ for Cr and $p < 0.05$ for Ni; at pH 9, $p < 0.001$ for both Cr and Ni); for the SS3 brand, $p < 0.05$ only for Cr at pH 2.3, $p < 0.001$ and $p < 0.01$ for Cr and Ni, respectively, at pH 7.7, and $p < 0.05$ only for Ni at pH 9 (Fig. 3).

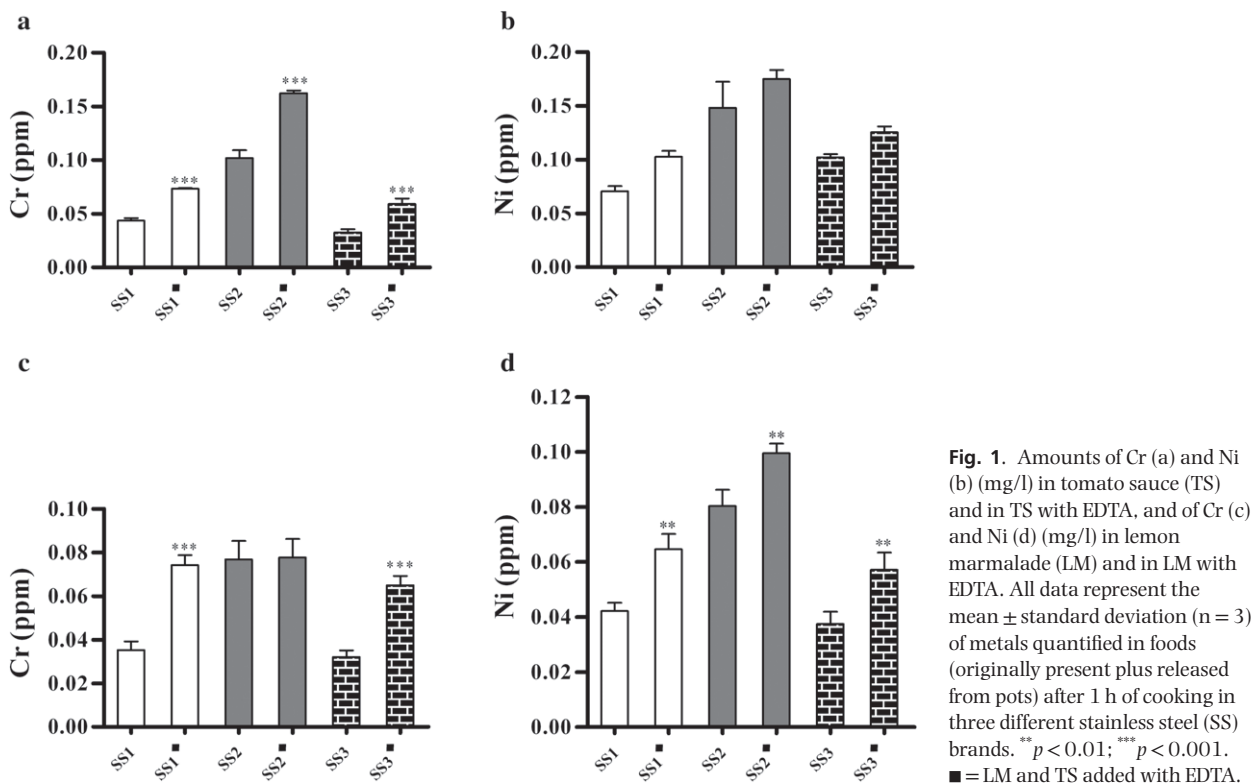


Fig. 1. Amounts of Cr (a) and Ni (b) (mg/l) in tomato sauce (TS) and in TS with EDTA, and of Cr (c) and Ni (d) (mg/l) in lemon marmalade (LM) and in LM with EDTA. All data represent the mean ± standard deviation (n = 3) of metals quantified in foods (originally present plus released from pots) after 1 h of cooking in three different stainless steel (SS) brands. **p < 0.01; ***p < 0.001. ■ = LM and TS added with EDTA.

Table 3. Cr and Ni release (mg/l) into aqueous solution at three different pH levels, with used and unused pots of three different stainless steel (SS) brands

pH	Element	Used pots			Unused pots		
		SS1	SS2	SS3	SS1	SS2	SS3
2.3	Cr	0.0360 ± 0.0032	0.1977 ± 0.0254	0.0560 ± 0.0047	0.0595 ± 0.0033	0.2453 ± 0.0063	0.0939 ± 0.0318
	Ni	0.0198 ± 0.0032	0.3557 ± 0.0033	0.0207 ± 0.0025	0.0261 ± 0.0018	0.4279 ± 0.0066	0.0261 ± 0.0013
7.7	Cr	0.0054 ± 0.0004	0.0152 ± 0.0008	0.0494 ± 0.0023	0.0071 ± 0.0006	0.0206 ± 0.0005	0.0666 ± 0.0024
	Ni	0.0013 ± 0.0002	0.0071 ± 0.0003	0.0250 ± 0.0018	0.0015 ± 0.0001	0.0089 ± 0.0005	0.0276 ± 0.0006
9	Cr	0.0016 ± 0.0001	0.0142 ± 0.0021	0.0033 ± 0.0003	0.0024 ± 0.0001	0.0200 ± 0.0008	0.0048 ± 0.0001
	Ni	0.0030 ± 0.0004	0.0130 ± 0.0010	0.0042 ± 0.0005	0.0036 ± 0.0001	0.0163 ± 0.0006	0.0052 ± 0.0001

Data represent mean ± standard deviation (n = 3) of the difference (t_{60 min} - t_{0 min}).

Discussion

The possibility of cutaneous and extracutaneous reactions resulting from deliberate or accidental systemic intake of Ni and/or Cr was reported and defined several years ago, but has recently become a ‘hot topic’ in dermatology and allergology (3). Mainly because of the mass media, systemic allergic reactions to metals have become also a matter of increasing concern among patients. Although the number of articles appearing in newspapers, on the radio and on television cannot be easily and precisely defined, a search in Google (<https://www.google.com>) with the terms ‘food’ and ‘systemic nickel allergy syndrome’ yielded, as of 6 June 2016, more than

800 documents, many of which are not published on websites of medical organizations or scientific journals. In particular, much attention is devoted to the possible release of metals from stainless steel pots into foods during cooking. Literature data are conflicting, because of variable characteristics of foods and stainless steel pots used in different countries (3–11). With reference to this topic, our study aimed to reproduce the worst possible scenario for Ni-allergic and/or Cr-allergic patients in an everyday domestic setting that can be considered to be common for many people, even in different nations. As there is general agreement in the literature that acid pH increases metal release from stainless steel (4, 6–11, 13), tomato and lemon were chosen because they are

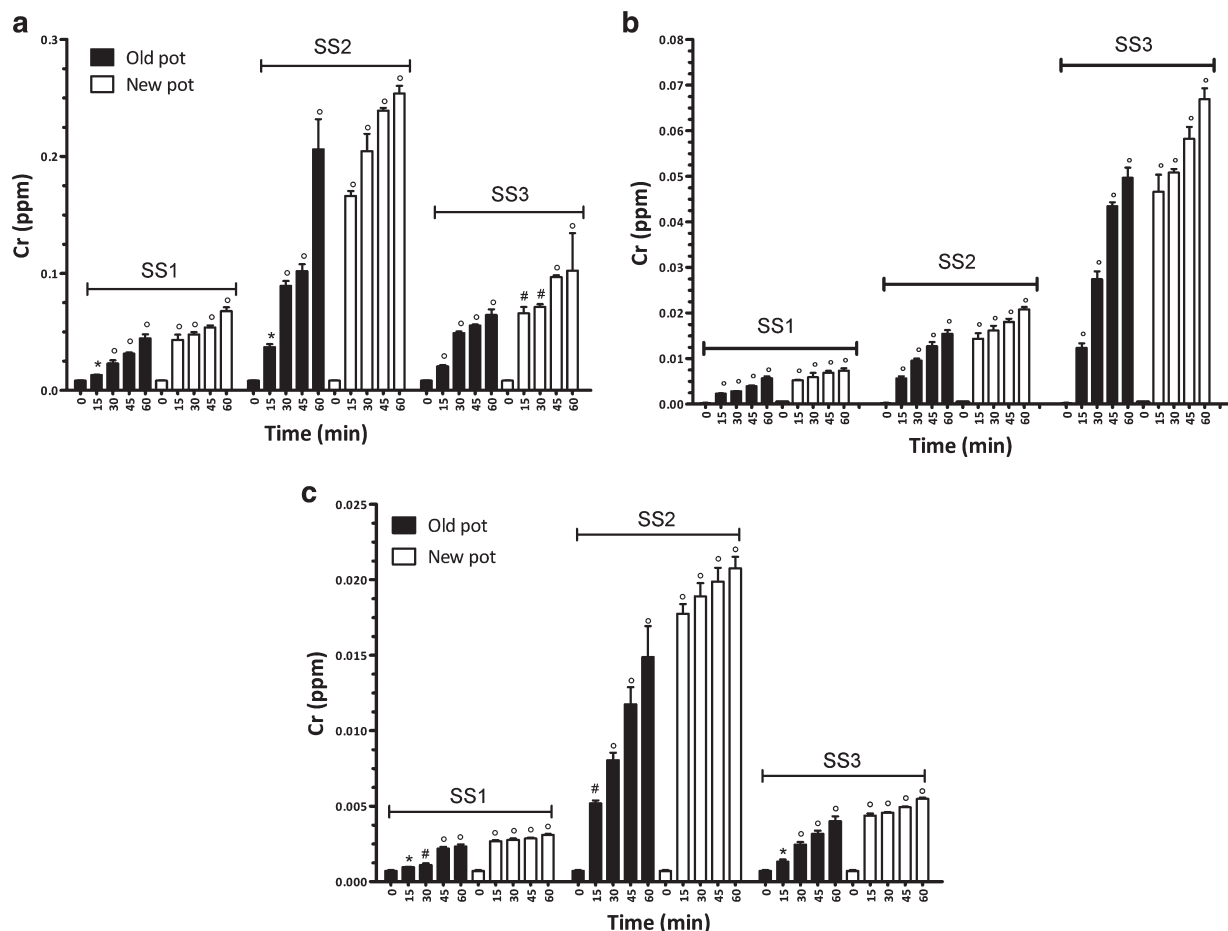


Fig. 2. Average ($n = 3$) amounts (mg/l) of Cr in aqueous solution [(a) at pH 2.3, (b) at pH 7.7, and (c) at pH 9], obtained with both used and unused pots. Five aliquots were taken at 0, 15, 30, 45 and 60 min for each solution. Statistical significance versus 0 min: * $p < 0.05$; # $p < 0.01$; ° $p < 0.001$.

two of the most acidic foods that are commonly used in many cultures and in large areas of the world. Cooking procedures were also defined by keeping in mind that the amount of time dedicated to food preparation is nowadays relatively limited, particularly in urban contexts, and is significantly reduced in comparison with past decades (14, 15). Finally, in a typical domestic environment, a pot remains in use for several years, to cook different types of foods, and undergoes many cleaning cycles with a mixture of more and less aggressive procedures. These conditions are very difficult to reproduce in a laboratory setting, with a necessarily limited number of cooking and cleaning cycles: for such reasons, pots that had been subjected to domestic use for years were used in addition to new ones.

In our experiments, the maximum amounts of Ni and Cr released by 18/10 (grade 316) stainless steel during

food preparation were 0.144 and 0.098 mg/l, respectively, in TS, and 0.077 and 0.074 mg/l, respectively, in LM. In other words, the amounts of Ni and Cr in a standard portion of 126 g of TS – as defined by Kamerud et al. (4) – would increase by up to 18.1 and 12.3 μg , respectively, as a result of 1 h of cooking in stainless steel pots under ordinary domestic conditions; in a portion of LM (~35 g), the additional amounts of metals following cooking would be approximately up to 2.7 μg of Ni and 2.6 μg of Cr. These values are below the limits reported in the literature as the lowest critical thresholds for elicitation of allergic reactions, which are 67 and 2500 μg for Ni and Cr, respectively (4). They also differ remarkably from those reported in some of the previous studies. Early articles, dating back to the end of the 1970s, reported significant increases in the amounts of Ni and Cr in acidic foods cooked in stainless steel utensils (8, 10); later, in 1992, Kuligowski and Halperin not only confirmed such

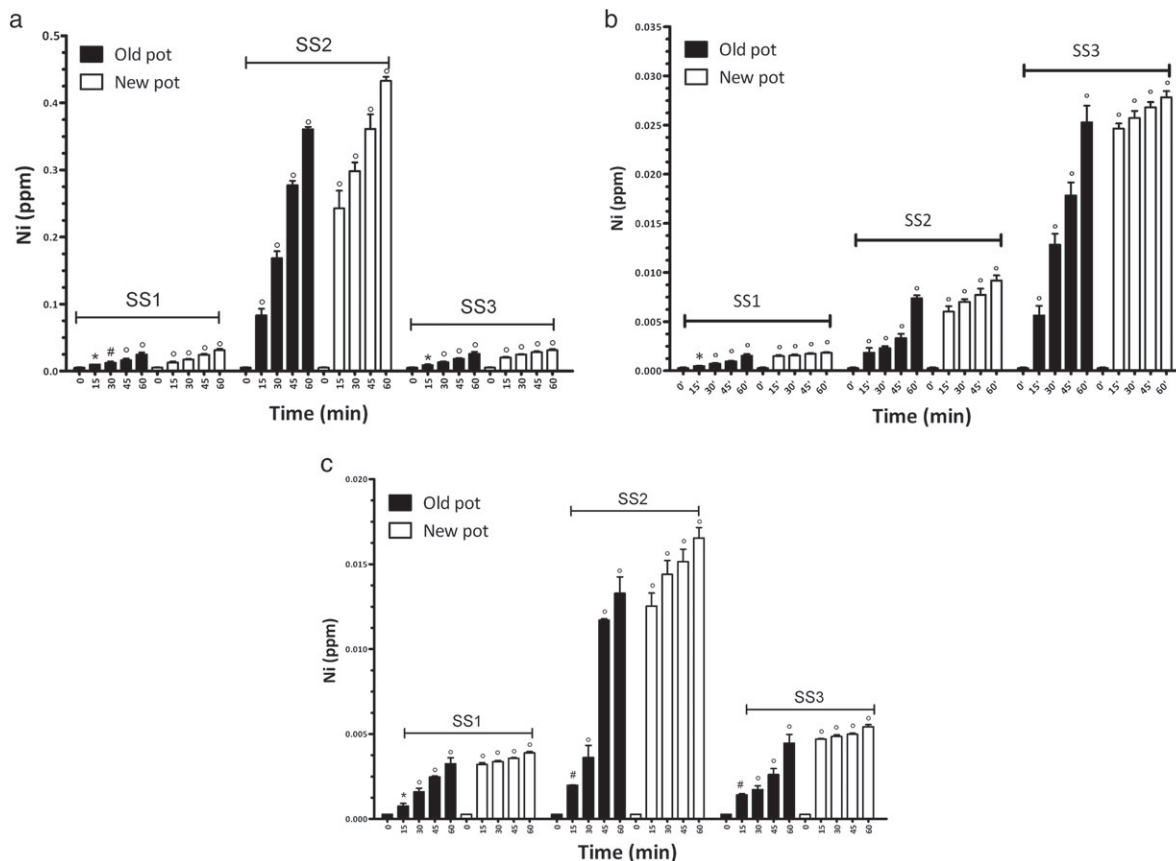


Fig. 3. Average ($n = 3$) amounts (mg/l) of Ni in aqueous solution [(a) at pH 2.3, (b) at pH 7.7, and (c) at pH 9], obtained with both used and unused pots. Five aliquots were taken at 0, 15, 30, 45 and 60 min for each solution. Statistical significance versus 0 min: * $p < 0.05$; # $p < 0.01$; O $p < 0.001$.

data, but even suggested that Ni-sensitive patients should avoid the use of stainless steel containers for food preparation, and that the cookware industry should consider switching to a non-Ni formulation (9). More recently, in 1997, Agarwal et al. (11) presented similar results, but their conclusions cannot be applied to the general population, because their experiments were performed on typical Indian drinks, which are unusual in other parts of the world. In 2013, Kamerud et al. (4) reported significant release of metals from stainless steel pots, even if used for several cooking cycles. In particular, the authors suggested that the amount of Ni released into an ordinary serving of TS can be up to 88 μg , which is more than four times higher than in our study, and exceeds the minimum level required to elicit allergic cutaneous reactions, even without considering the Ni content of the food itself. Concerning Cr, the amount released into the same serving of sauce would be 86 μg , which is largely insufficient to cause allergic reactions, but is still over six times more than in our experiments. The contrast

with our data is particularly evident and surprising in the case of this latter study; the different experimental setting might be a possible explanation. In the majority of their tests, Kamerud et al. (4) cooked TS in polyethylene tubes, adding stainless steel chips, and this obviously does not reproduce what commonly happens during food preparation. Moreover, the types of steel used for such procedures are different from those of our pots, and this could influence metal release in specific conditions. Last but not least, the minimum cooking time was 2 h, a time that often does not correspond to real-life conditions. Only one experiment was performed by Kamerud et al. with a commercial saucepan, made of grade 316 steel, but the cooking time was 20 h, which is definitely too long to be considered ordinary.

Conversely, our data agree with those reported by Kumar et al. in 1994 (7), Flint and Packirisamy in 1997 (6), and Accominotti et al. in 1998 (5), which suggest limited release of metals during cooking procedures. In addition to foods, Kumar et al. used aqueous solutions

with different pH levels as food simulants, and showed that, even at low pH, the amounts of metals released during cooking were within safety limits (7). Although the reliability of such a method as a simulation of real-life conditions is questionable (6), for the sake of completeness, we also performed similar experiments, which showed release of metal higher than that with foods, but still within safety limits.

There is general agreement in the literature on higher metal release from stainless steel pots at first use, with significant reductions being seen after a few cooking cycles, but the amounts reported by various authors are different (4, 6). Our results confirm the above trend, but suggest that the release at first use is below critical limits. The data presented here also suggest that EDTA, a chelating agent used as a preservative in certain foods, increases the release of metals from stainless steel during cooking: although this increase is relatively small and not equal for all foods, it may represent a fact to be kept into account when calculating the total daily amounts of Ni and Cr ingested. EDTA enhances the effect of organic acids on metal leaching (10, 16).

Finally, the highest amounts of leached Cr and Ni in our study were observed in experiments with acidic aqueous solutions (Table 3): for each brand, minimum and maximum amounts were higher than those obtained with foods or foods plus EDTA, independently from the condition of the pots (used or unused). However, this fact has limited clinical implications: Flint and Packirisamy already suggested, in a previous study (6), that an acidic aqueous solution can only approximately simulate the behaviour of real foods. Other literature data on this topic are contrasting: Tupholme et al. (17) reported Ni release below the lower LOD in experiments performed with oxalic acid at pH 4, whereas Koerner and Haberle obtained Ni concentrations exceeding 3 mg/l at pH 2 (13). Concerning the possible mechanism(s), Agarwal et al. (11) suggest that leaching of metals from stainless steel can involve either a chemical process or electrochemical and galvanic corrosion. In the first case, the release of

metals in the presence of organic acids would be attributable to the action of the corresponding anions of these acids, instead of the H⁺ ion, whereas, in the second case, it would depend on different oxidation potentials of metals, which can couple with each other and form many microcells, resulting in the dissolution of the higher oxidation potential metal species through electrolysis.

Conclusions

Regarding procedures, foods and conditions that can be regarded as ordinary for a large part of the population, the amounts of Ni and Cr released from 18/10 (grade 316) stainless steel during cooking are insufficient to induce reactions in allergic subjects. For both metals, the daily intake mainly depends on the amounts naturally contained in foods, and recommendations for patients should be more focused on a correct dietary regimen. However, it is noteworthy that the relative importance of the amounts released from stainless steel may be different for the two metals. In the case of Cr, such importance is definitely negligible, because the threshold for eliciting allergic reactions is higher by a couple of orders of magnitude. Leached Ni can, however, be relevant for highly sensitive patients, who can react even to a dose of only 67 µg. In that case, the amount of 14–17 µg per 100 g of food detected in some of our experiments could, even in the context of a low-Ni diet, exceed the individual critical level. Additionally, literature suggests that immunological tolerance to nickel can be induced by oral low dose exposure (18, 19). In such a context, the relatively small quantity of Ni leached from stainless steel pots might have significant importance, and should be kept into account when daily Ni intake is calculated. Although it appears exaggerated to suggest avoidance of 18/10 stainless steel cookware to all patients who are allergic to Ni, it is certainly advisable to perform careful testing and establish close collaboration between physicians and patients, to define proper personalized prevention measures.

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