Metal release from arch bars used in maxillofacial surgery

An in vitro study

Sissel Torgersen and Nils Roar Gjerdet
Department of Dental Materials and Department of Oral Surgery and Oral Medicine, School of Dentistry, University of Bergen, Bergen, Norway

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Surgical arch bars (splints) are used in maxillofacial surgery as an aid to intermaxillary fixation procedures. Two different types of stainless steel arch bars, a solid bar and a silver-brazed bar, were studied with regard to metal release in vitro. Arch bars were ligated to jaw models and immersed in 0.9% saline solution. The electrolyte was analyzed for Ni, Cr, Fe, Cu, Zn, and Cd by atomic absorption spectrophotometry on days 3, 10, and 28. The amounts of metal released from the brazed arch bar were 140–600 times higher than those released from the solid arch bar. Clinical implications are suggested. □ *Brazing; chromium, adverse effects; corrosion; nickel, adverse effects; stainless steel*

Sissel Torgersen, Department of Dental Materials, School of Dentistry, Årstadveien 17, N-5009 Bergen, Norway

Arch bars that are attached to the teeth with ligatures are widely used in oral and maxillofacial surgery. These devices are inserted as temporary appliances after jaw fractures or osteotomies to prevent jaw movements and to gain stability between bony fragments during healing. Surgical arch bars (splints) are usually made with hooks (lugs) to facilitate intermaxillary fixation (1). Some are made in one piece, whereas in others the hooks are brazed to the bar. According to the manufacturers, the bulk material of the most commonly used surgical arch bars is stainless steel. These arch bars are usually exposed to oral fluids for a period of about 4–6 weeks, extending up to 12 weeks before removal (2).

Stainless steel devices corrode in the presence of an electrolyte, resulting in metal release from the material (3). Nickel, chromium, and constituents of the brazing material are released in significant amounts from brazed orthodontic wires. Corrosion and metal release from stainless steel devices can be detected within hours after exposure to an immersion solution (4). Metal release from orthodontic stainless steel appliances have been studied, under various conditions (5–7). The extent of metal release from stainless steel devices varies with production variables during manufacturing and during the clinical handling of the devices before application in the mouth (7–9).

There are several reports on adverse reactions to stainless steel appliances (10–15). Nickel is the commonest source of metal hypersensitivity reactions in man (16–18). Chromium is also known as a sensitizer (19–21).

The aim of this in vitro investigation was to study the corrosion behavior of two different types of stainless steel arch bars used in maxillofacial surgery.

Materials and methods

Arch bars were ligated to acrylic jaw models and immersed in an electrolyte, and the release of metals to the electrolyte was measured with atomic absorption spectrophotometry. The two types of arch bars tested were 1) a stainless steel surgical arch bar with hooks, made in one piece (solid bar)

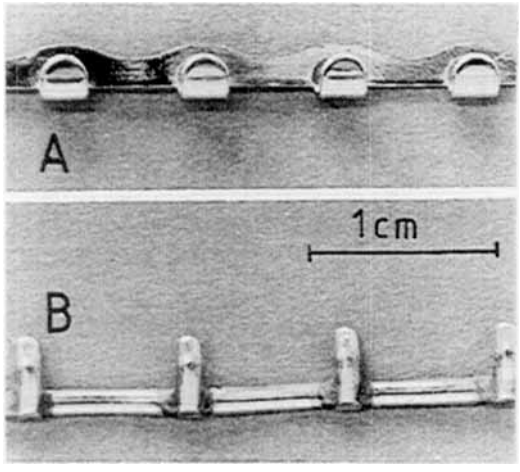

Fig. 1A. Solid arch bar (Erich type). 1B. Brazed arch bar (Dautrey type).

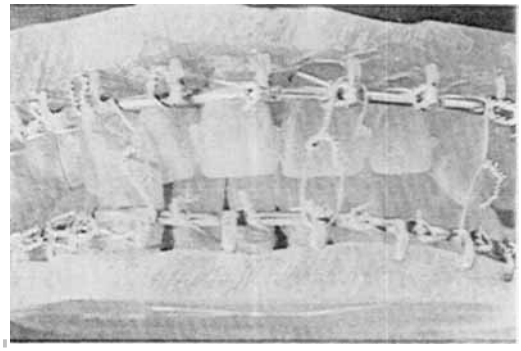

Fig. 2. Bars ligated to acrylic models

(Erich arch bar, Oswald Leibinger GmbH), and 2) a stainless steel product in which the hooks are brazed to the bar (brazed bar) (Dautrey arch bar, Oswald Leibinger GmbH) (Fig. 1). Both arch bars were received in precut lengths. The ligatures were made of stainless steel (Oswald Leibinger GmbH, Delco Wire Winding Co.) with a diameter of 0.4 mm, cut from the spool in lengths about 15 cm. Batch numbers and composition were not available from the manufacturers. Energy-dispersive X-ray microanalysis (Jeol JSM 6400 Scanning Microscope, Tracor Northern, Series II X-ray Analyzer, SQ Standardless Quantitative Analysis Program) was used for elemental examination of the arch bars and wires.

Pairs of acrylic jaw models simulating the upper and lower jaw were produced. Before use the models were cleaned in 37% HCl (Merck, Suprapur). The arch bars and ligatures were degreased in acetone before application to the jaw models. Specimens consisting of two similar arch bars either of the solid type or of the brazed type were ligated to an upper and a lower jaw model. Ligatures were twisted around teeth from the first molar on one side to the first molar on the other side in both jaws, using stainless steel pliers and a simulated clinical procedure. Additional ligatures establishing an intermaxillary fixation were placed in the premolar regions and in the midline (Fig. 2). Ten specimens with solid bars and six specimens with brazed bars were made. Two pairs of models without metallic devices were used as controls. The prepared specimens were placed in separate plastic beakers containing 150 ml saline solution (0.9% NaCl in deionized water, pH 5.6–6.0). To distinguish between corrosion products released from the arch bars and from ligatures, 24 twisted ligatures (Oswald Leibinger GmbH) immersed in 50 ml saline solution were included. The total length of ligatures corresponded to the amount used for ligation of a test specimen. The sealed beakers were subjected to continuous agitation at 100 rpm at 37°C. The immersion solutions were changed after 3 and 10 days. After 28 days the specimens were removed from the beakers and visually inspected.

The saline solutions were analyzed by electrothermal or flame atomic absorption spectrophotometry (Model 372 A.A. Spectrophotometer, Perkin Elmer Corp.). Flame atomization was used for concentrations above 5 μg/ml. Before analysis the solutions were acidified with 0.3–12 ml HCl 30% (Merck, Suprapur). The elements analyzed were Fe, Ni, Cr, Cu, Zn, and Cd. The amounts of metals (in micrograms) were calculated, and the results for each time interval accumulated. The results are presented as medians and quartiles. The Mann–Whitney procedure was used to test for statistical significance. P values < 0.01 were considered significant.

Table 1. Elements analyzed in the products investigated (weight %). Results are mean of two analyses

	Fe	Ni	Cr	Mo	Ag	Zn	Cu	Cd
Solid arch bar	65	8.5	18	0.1				
Brazed arch bar (bar and hook)	64	8.0	18	0.7				
Brazed arch bar (silver brazing material)					29	24	40	6.2
Ligature	63	10	16	2.3				

Results

Energy-dispersive X-ray microanalyses showed that the main elements of the bulk material of both arch bars were iron, chromium, and nickel. The brazing material consisted of silver, copper, and zinc. Cadmium was also found in the brazing material (Table 1).

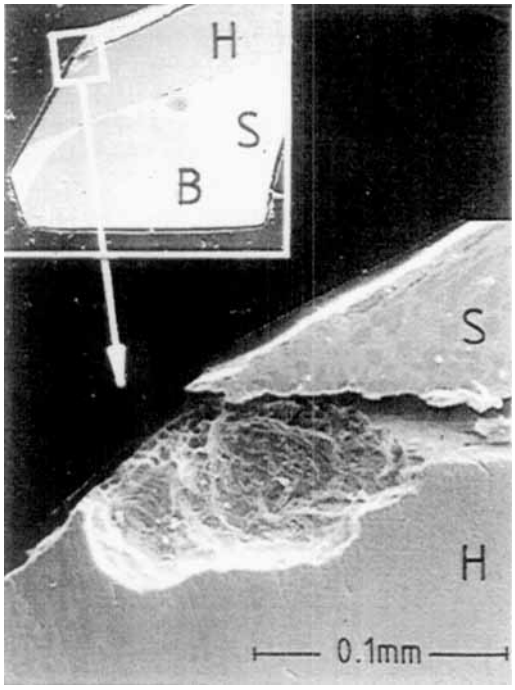

Fig. 3. Cross section of the brazed bar (insert). Magnification of the brazed junction between hook (H) and bar (B), showing corrosion defect. Silver brazing material (S). Scanning electron micrograph.

No visible corrosion was observed with the solid arch bars at any time during the experiment. Scanning electron microscopy did not show corrosion defects. In the beakers containing the brazed arch bars, yellow sediments were noticed in the solution on day 3 of immersion. Gross deposits were seen after 10 and 28 days. All brazed arch bars showed accumulation of corrosion products adjacent to the junctions between the hooks and the bar, and the hooks separated easily from the bar after 28 days of immersion. Scanning electron microscopy showed major corrosion defects and deposits, particularly in the junctional areas (Fig. 3). No visible deposits were seen in the solutions with ligatures only.

The chemical analyses of the electrolyte after 3, 10, and 28 days showed that the main elements iron, nickel, and chromium were released from both the solid stainless steel arch bars and the brazed arch bars. Iron was the element of the bulk material found in highest concentrations in the solutions from both arch bars. For pairs of the brazed bars the amount of iron after 3 days was 275 μg (median), whereas the accumulated amount after 28 days was 2513 μg (Fig. 4). The corresponding values for nickel were 89 μg and 407 μg (Fig. 5), and for chromium 68 and 526 μg (Fig. 6). The accumulated amount of metal released from pairs of solid bars was 140–600 times lower depending on the element (Fig. 4–6). The differences between the bars were always statistically significant. After 28 days elements contained in the silver brazing material (Cu, Zn, Cd) of the brazed bars reached 42 to 1877 μg (median), depending on the element (Fig. 7). Accumu-

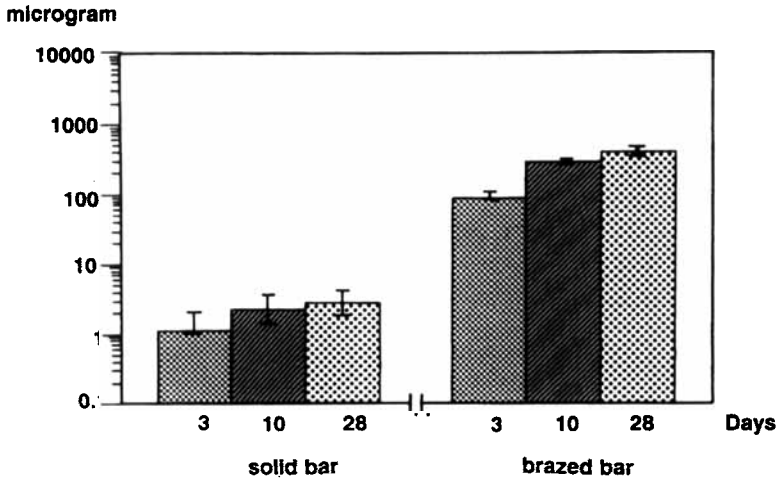

Fig. 4. Accumulated amount of iron released from solid and brazed surgical arch bars. Median values, with upper and lower quartiles imposed.

lated metal release from the ligatures was less than 0.5 μg for each of the elements Fe, Ni, and Cr. No metal release was detected in the solutions containing acrylic models only.

Discussion

The bulk material of both the solid (Erich type) and the brazed (Dautrey type) surgical arch bar is stainless steel. This study showed great differences between the two types of arch bars with regard to metal release under the same conditions. Stainless steel devices will release metal ions to an electrolyte when the passivating layer of chromium oxide covering the surface of the stainless steel is degraded (22). The use of 0.9% saline solution as immersion solution instead of saliva may alter the corrosion behavior of stainless steel devices. There is a constant controversy about the type of electrolyte to use for in vitro corrosion tests. For example, the presence of serum seems to increase pitting corrosion, whereas fretting corrosion is

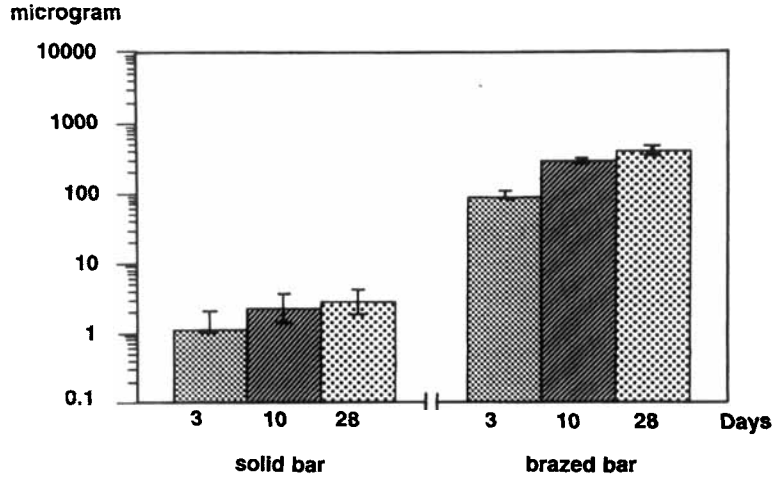

Fig. 5. Accumulated amount of nickel. See also legend to Fig. 4.

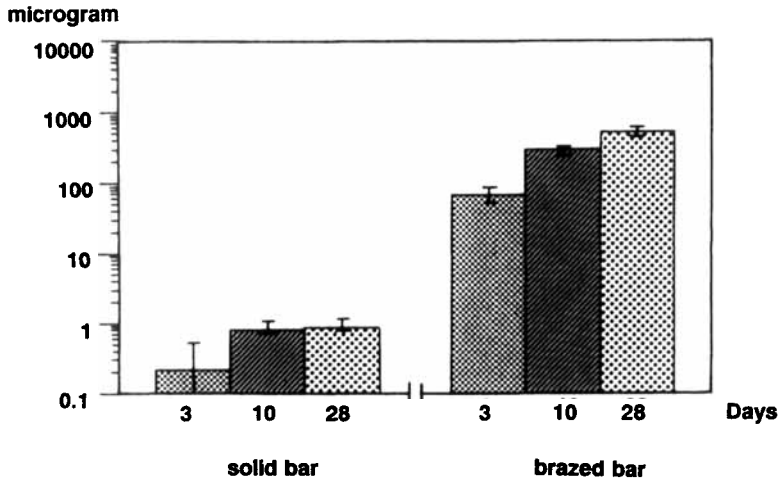

Fig. 6. Accumulated amount of chromium. See also legend to Fig. 4.

reduced (23–25). The saline solution was chosen because it is stable and easily reproduced and is extensively used in comparable studies.

Surface imperfections of wires may serve as sites for localized corrosion attack (9). It has been shown with coldworked stainless steel in saline solution that deformation caused an increasing area covered by pits and corrosion. The growth rate of the pits also accelerated even with minor deformation (8). Thus the corrosion observed in both types of arch bars may be influenced by effects of manipulation.

Heat treatment of stainless steel devices may also contribute to reduction in corrosion resistance. Exposure of stainless steel material to temperatures above 400°C has been shown to cause chromium depletion in the surface microstructure, thereby reducing the passivating potential of the material (7). The severe corrosion of the brazed bar may be a result of heat application during the manufacturing process.

Increased corrosion has been observed in brazed or welded stainless steel appliances (4, 26, 27). Galvanic cells created between the brazing material and the bulk material in the presence of an electrolyte (4, 28) may partly explain why the brazed arch bar showed markedly reduced corrosion resistance compared with the solid bar.

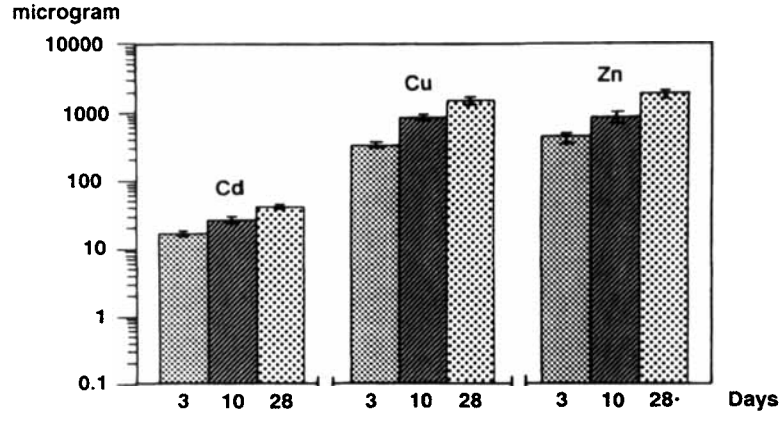

Fig. 7. Accumulated amounts of cadmium, copper, and zinc. See also legend to Fig. 4.

Both nickel and chromium are powerful haptens in hypersensitivity reactions (15, 20). Nickel allergy in the general population is reported to be 10–15% in females and about 2–8% in males (17, 29–31); one report (16) indicates a frequency of about 30%. Clinical signs of hypersensitivity reactions caused by nickel-containing devices will often appear within days after insertion of the stainless steel material (10–15, 21, 32, 33). The eliciting threshold for nickel contact dermatitis in sensitive subjects is assumed to be 0.6 μg/ml nickel (34). In our study the release of nickel from the solid arch bar was below this threshold value, whereas the amounts of nickel released from the brazed arch bar were above this value.

The prevalence of chromium hypersensitivity in the general population is about 1–8% (17, 18, 31), and there are clinical reports on chromium hypersensitivity (35–37). Fifty micrograms of potassium dichromate may provoke an adverse reaction (18). From the results of our study the amount of chromium released from the brazed bar after 28 days is 10 times this value. However, the effect of the duration of antigen exposure remains unclarified. On the other hand, some experimental data (38, 39) suggest the possibility of inducing immunologic tolerance to nickel and chromium by oral exposure of the metals in non-sensitized individuals.

Daily intake of nickel is estimated to be <350 μg/person/day (40, 41). Depending on the diet it may reach 900 μg/person/day (42). Chromium exposure is in the range of 150–300 μg/person/day through dietary intake (41). Toxicologically, the amounts of nickel and chromium released from the two arch bars are within the range of normal dietary exposure. The accumulated amounts of Cu and Zn released from the brazing material during the experimental period is within the daily normal dietary intake for both elements (41). On the other hand, clinical reactions based on the local and systemic toxicity potential of copper are described (43, 44). Cadmium release from some dental silver brazing alloys is well known (4, 27). Our study also confirms that cadmium is easily leached out of the brazed joints. Owing to toxicologically unwanted reactions (45) this element should be avoided in clinical appliances.

This study showed a great difference in corrosion resistance and metal release between two different types of surgical arch bars. Metal release from intraoral fixation devices may elicit adverse reactions in sensitive subjects. Our results suggest that even devices for temporary use should be evaluated for possible biologic effects before clinical application.

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References

1. Brindley HP. Maxillofacial fracture fixation prostheses, methods, and devices. In: Alling CC III, Osbon DB, editors. Maxillofacial trauma. Philadelphia: Lea & Febiger, 1988:174–80.
2. Petersen JK. Sammenbinding af kaeberne. Tandlaegebl 1984;88:91–6.
3. Hoar TP, Mears DC. Corrosion resistant alloys in chloride solutions: materials for surgical implants. Proc R Soc Lond 1966;294:486–510.
4. Berge M, Gjerdet NR, Erichsen ES. Corrosion of silver soldered orthodontic wires. Acta Odontol Scand 1982;40:75–9.
5. Park HY, Shearer TR. In vitro release of nickel and chromium from simulated orthodontic appliances. Am J Orthod 1983;84:156–9.
6. Gjerdet NR, Erichsen ES, Remlo HE, Evjen G. Nickel and iron in saliva of patients with fixed orthodontic appliances. Acta Odontol Scand 1991;49:73–8.
7. Gjerdet NR, Herø H. Metal release from heat-treated orthodontic archwires. Acta Odontol Scand 1987;45:409–14.
8. Stefec R, Franz F. A study of the pitting corrosion of coldworked stainless steel. Corrosion Sci 1978; 18:161–8.
9. Rentler RM, Greene ND. Corrosion of surface defects in fine wires. J Biomed Mater Res 1975;9: 597–610.
10. Roed-Petersen B, RoedPetersen J, Dreyer Jørgensen K. Nickel allergy and osteomyelitis in a patient with metal osteosynthesis of a jaw fracture. Contact Dermatitis 1979;5:108–12.
11. Schriver WR, Shereff RH, Domnitz JM, Swintak EF, Civjan S. Allergic response to stainless steel wire. Oral Surg 1976;42:578–81.
12. Cramers M, Lucht U. Metal sensitivity in patients treated for tibial fractures with plates of stainless steel. Acta Orthop Scand 1977;48:245–9.

13. Grimalt F, Romaguera C. Acute nickel dermatitis from a metal implant. Contact Dermatitis 1980;6:441.
14. Hensten-Pettersen A, Gjerdet NR, Kvam E, Lyberg T. Nikkelallergi og kjeveortopedisk behandling. Nor Tannlegeforen Tid 1984;94:567–72.
15. Hensten-Pettersen A. Nickel allergy and dental treatment procedures. In: Maibach HI, Menné T, editors. Nickel and the skin: immunology and toxicology. Boca Raton, Florida: CRC Press, Inc., 1989:195–206.
16. Blanco-Dalmau L, Carrasquillo-Alberty H, Silva-Parra J. A study of nickel allergy. J Prosthet Dent 1984;52:116–9.
17. Rudner EJ, Clendenning WE, Epstein E, et al. Epidemiology of contact dermatitis in North America: 1972. Arch Dermatol 1973;108:537–40.
18. Menné T, Burrows D. Contact sensitizations to nickel, chromate and cobalt. Epidemiology—effect of local and systemic exposure. Chicago: Workshop on biocompatibility of metals in dentistry, 11–13 July 1984:79–92,327–31.
19. Burrows D. Chromium and the skin. Br J Dermatol 1978;99:587–95.
20. Polak L, Turk JL, Frey JR. Studies on contact hypersensitivity to chromium compounds. Progr Allergy 1973;17:145–226.
21. Tilsley AD, Rotstein H. Sensitivity caused by internal exposure to nickel, chrome and cobalt. Contact Dermatitis 1980;6:175–8.
22. Hoar TP. The production and breakdown of the passivity of metals. Corrosion Sci 1967;7:341–55.
23. Brown SA, Merritt K. Electrochemical corrosion in saline and serum. J Biomed Mater Res 1980;14: 173–5.
24. Brown SA, Merritt K. Fretting corrosion in saline and serum. J Biomed Mater Res 1981;15:479–88.
25. Brown SA, Merritt K. In vivo and in vitro considerations of corrosion testing. Biomat Med Devices Artif Organs 1981;9:57–63.
26. Rogers OW. A study in the control of crevice corrosion of silver soldered stainless steel joints. Br Dent J 1977;143:397–403.
27. Mueller HJ. Some considerations regarding the degenerational interactions between mouth rinses and silver-soldered joints. Am J Orthod 1982;81: 140–6.
28. Joffe BM. Galvanic current generated by an orthodontic appliance. J Dent Assoc South Africa 1962;17:78–9.
29. Schubert H, Berova N, Czernielewski A, et al. Epidemiology of nickel allergy. Contact Dermatitis 1987;16:122–8.
30. Nethercott JR, Holness DL. Cutaneous nickel sensitivity in Toronto, Canada. J Am Acad Dermatol 1990;22:756–61.
31. Moffa JP, Ellison JE, Hamilton JC. Incidence of nickel sensitivity in dental patients [abstract 271]. J Dent Res 1983.
32. Merritt K, Brown SA. Metal sensitivity reactions to orthopedic implants. Int J Dermatol 1981;20:89–94.
33. Barranco VP, Soloman H. Eczematous dermatitis from nickel [letter]. JAMA 1972;220:1244.
34. Malten KE, Spruit D. The relative importance of various environmental exposures to nickel in causing contact hypersensitivity. Acta Derm Venerol 1969;49:14–9.
35. Goitre M, Bedello PG, Cane D. Chromium dermatitis and oral administration of the metal. Contact Dermatitis 1982;8:208–9.
36. Castelain M, Castelain PY, Ricciardi R. Contact dermatitis to acupuncture needles. Contact Dermatitis 1987;16:44.
37. Hubler WR Jr, Hubler WR Sr. Dermatitis from a chromium dental plate. Contact Dermatitis 1983; 9:377–83.
38. Vreeburg KJJ, de Groot K, von Blomberg M, Scheper RJ. Induction of immunological tolerance by oral administration of nickel and chromium. J Dent Res 1984;63:124–8.
39. Vreeburg KJJ, van Hoogstraten IMW, von Blomberg BME, de Groot K, Scheper RJ. Oral induction of immunological tolerance to chromium in the guinea pig. J Dent Res 1990;69:1634–9.
40. Grandjean P. Human exposure to nickel. WHO, Geneva: International Agency for Research of Cancer; Lyon: IARC Scientific Publications 1984;53: 469–85.
41. Hamilton EI, Minski MJ. Abundance of the chemical elements in man's diet and possible relations with environmental factors. Sci Total Environ 1973;1:375–94.
42. Flyvholm MA, Dalsgaard Nielsen G, Andersen A. Nickel content of food and estimation of dietary intake. Z Lebensm Unters Forsch 1984;179:427–31.
43. Sheppard BL. Endometrial morphological changes in IUD users: a review. Contraception 1987;36: 1–10.
44. Moberg LE. Korrosionsprodukter från dentala legeringer och effekten av kvicksilver och koppar på ett neuroeffektorsystem. Tandlakartidningen 1987;79:97–100.
45. Shukla GS, Singhal RL. The present status of biological effects of toxic metals in the environment: lead, cadmium and manganese. Can J Physiol Pharmacol 1984;62:1015–31.

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