Biological responses to pediatric stainless steel crowns

Author

Zafar, Sobia, Siddiqi, Allauddin

Published

2020

Journal Title

Journal of Oral Science

Version

Version of Record (VoR)

DOI

10.2334/josnusd.20-0083

Rights statement

Downloaded from

Griffith Research Online

J-STAGE Advance Publication: June 10, 2020
Journal of Oral Science

Review

Biological responses to pediatric stainless steel crowns

Sobia Zafar[1)] and Allauddin Siddiqi[2)]

[1)] Discipline Lead Paediatric Dentistry, School of Dentistry, The University of Queensland, Queensland, Australia
[2)] School of Dentistry and Oral Health, Griffith Health Centre, Gold Coast campus, Griffith University, Queensland, Australia

(Received February 29, 2020; Accepted April 11, 2020)

Abstract: A systematic review was conducted to identify the biological responses, allergic reaction, hypersensitivity, toxicity, and ion release profile associated with pediatric stainless steel crowns (SSCs) in the existing literature. A systematic search was undertaken according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines. The inclusion criteria consisted of patients younger than 20 years of age with SSC placement on primary or permanent teeth and *in vivo* and *in vitro* exposure to SSCs. Outcomes measures included adverse oral/mucosal effects; removal/failure/replacement of the SSC; type of allergic reaction; nickel (Ni) or other ion levels in bodily fluids, cellular, genotoxic, cytotoxic, mutagenic or carcinogenic effects related to the SSC. After an initial search of 764 studies in the database, 17 articles were included in the analysis. Evidence of allergic reactions to SSCs in children is limited and obtained from mostly low-quality research. Some studies showed that the amount of Ni detected was less than the amount ingested in the daily diet. In contrast, other studies reported a significantly higher release of Ni occurred into the saliva in acidic environments. There is some concern about the leaching of metal ions such as Ni from SSCs in children at high risk for caries. Further long-term studies are required to investigate this phenomenon.

Keywords; biological response, children, hypersensitivity, nickel release, stainless steel crown

Introduction

Dental caries is considered the most prevalent chronic disease in children [1]. Over time, various restorative materials have been introduced in pediatric dentistry in an attempt to maintain the primary teeth in the arch prior to the eruption of the permanent successors [2,3]. One of the most durable, retentive, and relatively inexpensive restorative materials available today is the stainless steel crown (SSCs). SSCs, also known as chrome steel crowns or preformed metal crowns, are metallic restorations that have shown good long-term retention and significant clinical success in the restoration of larger carious lesions on primary molars [2,4,5]. First introduced by the Rocky Mountain Company in 1947 and later popularized in 1950 by Engel and Humphrey, SSCs remain an integral part of pediatric dental care [6,7]. The average maximum number of SSCs placed in the mouths of pediatric patients at high risk for caries receiving treatment under general anesthesia is up to eight or more, as some clinicians tend to use them on anterior teeth as well. These restorations are expected to remain in the oral environment for extended periods of time, ideally coinciding with the time of primary tooth exfoliation; thus, on average, they are in place for a maximum of eight to nine years, depending on the age at which the child receives their crowns [8]. Studies have suggested that SSCs exhibit lower failure rates relative to other primary restoration types such as amalgam, glass ionomer, composite, and compomer restorations [4,9]. SSCs, therefore, are considered to be a reliable long-term primary tooth restoration modality.

Chemically, SSCs are manufactured from type 303 austenitic alloy with the chemical composition of iron (Fe: 69%), chromium (Cr: 18.4%), nickel (Ni: 9.1%), magnesium (Mg: 1.5%), silicon (Si: 1%), and other elements, including aluminum (Al: 0.6%) and molybdenum (Mo: 0.4%) [10]. Ni is a trace mineral or micronutrient that plays an important role in overall health in small doses, aiding in Fe absorption as well as glucose metabolism. However, at higher doses, Ni has been found to be harmful [11,12]. Ni has been reported as the most frequent cause of allergic contact dermatitis (ACD) worldwide; such was first recorded at the end of the 19th century among workers in the Ni plating industry and was recognized as an allergic response in 1925[13]. Allergy to Ni is found more frequently among women (10%-17%) than men (1%-3%) [14-17]. Ni hypersensitivity reactions are serious medical conditions that can be life-threatening and require the removal of the stimulus to prevent further sensitization [18]. A study by Elshahawy et al. documented fibroblast cell cytotoxicity induced by metal salt solutions representing ions found in stainless steel alloys [19]. Specifically, their study demonstrated that zinc (Zn), copper (Cu), and Ni salt solutions have high cytotoxic effects on fibroblast cell cultures in an *in vitro* experiment. Other studies have reported Ni carcinogenicity and mutagenicity [20,21]. Elsewhere, Feasby et al. reported an increased Ni-positive patch test result in children eight to 12 years of age treated with old-generation SSCs (72% Ni content) [22].

The oral environment that SSCs are most often deployed usually exhibits a significant caries risk, higher salivary acidity, and greater plaque retention [23]. There have been several articles reporting hypersensitivity reactions from Ni that leached out from orthodontic appliances [24-27]. However, a lack of significant research considering biological and hypersensitivity responses to SSCs, despite the more strenuous environment they are placed under in the pediatric population, remains. Additionally, SSCs must withstand high occluding forces while being present in a patient's mouth for prolonged periods of time. For these reasons, further investigation into this area is necessary to improve the understanding of the characteristics of SSCs and, most importantly, assess their safe use in pediatric patients. The aim of this systematic review was, therefore, to analyze studies focused on biological kinetics, hypersensitivity responses, allergic/toxic reactions, and the release of ions (mainly Ni) associated with pediatric SSCs.

Materials and Methods

Data sources

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [28]. A comprehensive literature search was carried out using databases such as MEDLINE (via EBSCOhost), CINAHL (via EbscoHost), EMBASE (via ScienceDirect), and SCOPUS. The search was conducted using the keyword combinations: ("hall crown*" or "hall technique*" or "metal crown*" or "stainless steel crown*" or "nickel chrome crown*" or "chrome steel crown*" or "preformed crowns*" or "prefabricated crowns*") AND ("primary molar*" or "primary teeth" or "primary dentition*" OR "permanent molar*") AND (child* or pediatric* or paediatric or "in vitro*") without any language restriction. All published studies covering pediatric SSCs and allergy/hypersensitivity were identified. The initial screening process consisted of reviewing the titles and abstracts, while the reasons for exclusions were determined. Hand-searches using the aforementioned keywords were also performed, and the reference lists of selected studies were reviewed for any additional relevant studies. The listed databases were searched from the earliest available date to March 20,

Correspondence to Dr. Sobia Zafar, Discipline Lead Paediatric Dentistry, School of Dentistry, The University of Queensland, 288 Herston Road, Herston Qld 4006, Australia
E-mail: s.zafar@uq.edu.au

Color figures can be viewed in the online issue at J-STAGE.
doi.org/10.2334/josnusd.20-0083
DN/JST.JSTAGE/josnusd/20-0083

Table 1 The inclusion and exclusion criteria adopted in the literature search

Inclusion criteria	Exclusion criteria
P: Participants: any gender, up to 20 years old I: Interventions: SSC placement on primary or permanent teeth, *in vivo* and *in vitro* exposure to SSC C: Comparison: Ni/SSC/chromium allergy or biological or hypersensitivity reaction in relation to SSC; Ni release from SSC O: Outcomes: adverse oral/mucosal effects; removal/failure of SSC; type of allergic reaction; Ni or other ion levels in bodily fluids; any cellular, genotoxic, cytotoxic, mutagenic, or carcinogenic effects Publication year: no restrictions Language: no restrictions Study design: randomized and nonrandomized control trials, cohort studies, surveys, case reports, case-control studies, *in vivo* and *in vitro* studies	Reviews, letters to the editor, editorials Participants: adults (older than 20 years); patients with any systematic disease or who are taking medications that effect dermal/mucosal health Interventions: cast metal crowns, zirconia crowns, orthodontic appliances placed in the mouth with no comparison to SSCs, patients with oral piercings (or other Ni exposure) Outcome: known Ni allergy

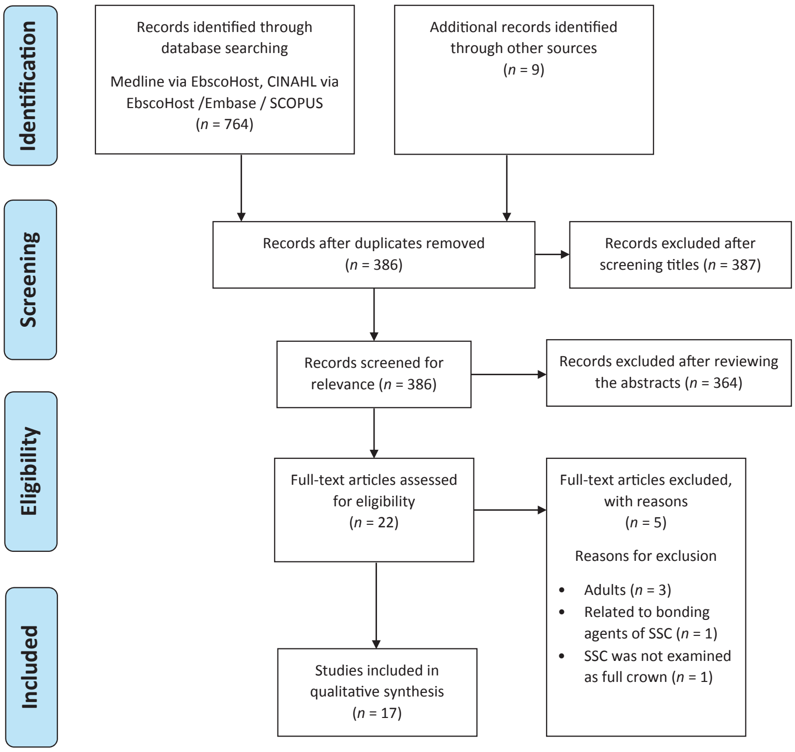

Fig. 1 PRISMA (preferred reporting items for systematic reviews and meta-analysis) flowchart of studies.

2019, without any language restrictions.

Resources selection

Studies were imported into the EndNote software (Clarivate Analytics, Philadelphia, PA, USA), and duplicate articles were removed. Two assessors (S. Z. and A. S.) performed a first-level selection based on titles and abstracts by following the inclusion and exclusion criteria independently. Population, intervention, comparison, and outcome (PICO) inclusion criteria were adopted in this study (Table 1). Studies were excluded according to the exclusion criteria listed in Table 1.

Next, the full texts of all included or potentially relevant articles were imported into the EndNote. Then, a second-level selection among these articles was performed by the same two assessors independently by reading the full texts of the articles and following the same inclusion and exclusion criteria. Any discrepancies between the assessors were resolved by discussion.

Review

Inter-rater reliability agreement

Inter-rater reliability was calculated between the two independent assessors during the data extraction (identification, screening, eligibility, and inclusion) stage (%). Inter-rater reliability agreement for the three stages (selection, comparability, and outcome) was evaluated using Cohen's kappa in the Statistical Package for the Social Sciences version 24.0 software program (IBM Corp., Armonk, NY, USA).

Quality of included studies

The quality of included studies was determined using the mixed methods appraisal tool (MMAT) [29]. The MMAT is designed for application to systematic reviews that include qualitative, quantitative, and mixed methods studies. The quality of each study was assessed by responding to screening questions with either "yes," "no," or "can't tell." The calculation of an overall score is discouraged when using the MMAT, which provides a more detailed presentation of the ratings of each criterion to better inform on the quality of the assessed studies.

Results

Literature search

The search returned 764 papers, with nine additional papers included after hand-searching appropriate journal publication sites and reference lists, for a total of 773 articles. After titles and abstracts were screened, 386 papers were thought to be appropriate, and 387 papers were excluded. A further of 364 papers were excluded as they did not match the inclusion criteria. Following a review of 22 papers retrieved for full-text evaluation, an additional five studies failed to meet the inclusion criteria; therefore, 17 papers were finally included in the review. A PRISMA flowchart describing the number of studies included and excluded at the first and second levels, as well as the reasons for their exclusion at the second level of selection, is presented in Fig. 1.

Inter-rater reliability agreement

The inter-rater reliability agreement between the two assessors was 95.4% (768/773 studies), 96.7% (385/387 studies), 93.8% (19/21 studies), and 100% (17/17 studies) at the identification, screening, eligibility, and inclusion stages, respectively. Any discrepancies were resolved through

Table 2 Characteristics of the included human studies

Author	Design	Participants	Intervention			Key findings
			Clinical context	Time	Measure	
Basir et al. 2019 [46]	NRT	Children ($n = 30$)	SSC placement	After 2 months	● Atomic absorption in saliva ● Salivary pH	Salivary Ni and chromium concentrations increased after placement of SSC; similarly, salivary pH also increased. Ion levels were not correlated with pH except for Cr during follow-up. Ni increase (but not Cr) was correlated with pH increase.
Hernández-Martínez et al. 2018 [61]	NRT	Children ($n = 32$)	SSC placement	At baseline, after 1 week, and after 1 month	Metal levels in saliva	Statistically significant differences were found in Ni release after 1 week and after 1 month following crowns placement. There was a positive correlation between the number of crowns and Ni release. However, the levels of Fe, Cr, and Ni released were below toxic health levels.
Mohamed et al. 2013 [62]	NRT	Children ($n = 34$)	SSC placement ($n = 17$) Lingual arch space maintainer ($n = 17$)	At baseline and after 1, 3, and 6 months	Saliva atomic absorption	The amounts of salivary Ni and Cr released after lingual arch space maintainer placement were more than those after SSC placement. The maximum amounts of released Ni and Cr were much lower than the dietary intake and were not capable of causing any toxicity.
Kodaira et al. 2013 [50]	● NRT ● DS	Children ($n = 37$)	SSC placement	After 3 months	● Hair mineral analysis ● Questionnaire survey of life style habits	Analysis of hair samples showed a significant difference in the level of the trace element Cr between the crown and control groups, but no significant differences were noted in the Fe or Ni levels. Levels of the trace elements Ni, Cr, and Fe were within allowable ranges, indicating that these minerals were not likely to be harmful.
Morán-Martínez et al. 2013 [47]	NRT	Children ($n = 37$)	SSC placement	At 1, 15, and 45 days after crown placement	● Micronucleus assay ● Urinary excretion of Ni	Odontological exposure to metal crowns resulted in genotoxic damage at the cellular level of the oral mucosa and an increase in the urinary excretion of Ni within 45 days of exposure.
Yilmaz et al. 2012 [35]	DS	Child ($n = 1$)	SSC placement (for restoring the decayed first permanent molar in a 13-year-old Caucasian girl)	After 1 week	Skin allergy patch test	Delayed hypersensitivity reaction was triggered by the Ni in the SSC. The eruptions completely healed within one week after removal of the SSC and the tooth was restored with a bis-acryl crown and bridge. The patient was followed for six months thereafter with no further allergic reactions.
Barcroft et al. 1997 [36]	DS	Child ($n = 1$)	SSC ($n = 12$) placement (in a 2-year-old boy)	After 1 month	Skin allergy patch test	The SSCs were replaced with composite resin crowns, and the patient tolerated the replacement procedure well and did not report any problems at follow-up visits.
Feasby et al. 1988 [22]	NRT	Children ($n = 700$)	Ni-containing intra-oral devices including SSC ($n = 350$) No Ni-containing intra-oral devices ($n = 350$)	NA	Ni-sensitivity skin patch test	No significant correlation was found between children with and without Ni-containing intraoral devices. A statistically significant correlation was found with the positive patch test readings and the presence of Ni-chromium crowns (old formulation of 72% Ni). There was a significant correlation between the presence of the Ni-chromium crowns and a positive patch test.

NRT, quantitative non-randomized trial; DS, quantitative descriptive study

discussion until a consensus was reached. Each domain had either a strong to almost perfect inter-agreement reliability between the independent reviewers, with kappa scores of 0.813 (selection), 0.796 (comparability), and 0.913 (outcome).

Quality of the included studies

A variety of study designs were observed among the included studies, including quantitative non-randomized trial ($n = 6$), quantitative descriptive study ($n = 2$), and experimental study ($n = 9$). All studies that included a quantitative design performed well in the MMAT assessment; however, those that included a quantitative descriptive study among their mixed methods were more variable, as they were case reports. The MMAT inter-rater reliability between the two raters was 99.98%. The studies with *in vitro* experimental designs could not be analyzed using the MMAT. The summary and characteristics of the final studies included can be found in Tables 2 and 3.

Discussion

Traditionally, the SSC has been the most commonly used restorative option for primary teeth due to its durability and longevity [2,30]. The optimal placement of SSCs on primary teeth requires a "snap-fit," with the margins of the crown coming into contact with the surrounding tissues, including the gingiva and the alveolar bone. There is limited research regarding the biocompatibility of SSCs in the oral environment as a reliable long-term restoration approach. The hostile oral environment can often induce electrochemical corrosion, and metals can be degraded under enzymatic, microbiological, thermal, and occlusal stresses [11,31]. Research into orthodontic appliances has demonstrated that a critical ion of interest is Ni, which has been shown to be released from these appliances under various stresses [32,33]. The literature search identified a previous systematic review by Syed et al.; however, the focus of their review was on allergic reactions to dental materials, while allergic reactions related to SSCs were only briefly discussed [34]. Hypersensitive reactions, allergic reactions, and potential adverse reactions related to SSCs in children have not been previously evaluated in any systematic research.

The present study revealed two case reports of Ni hypersensitivity reactions in children. In the first, a 13-year old patient presented with perioral skin eruptions following placement of the SSC. Ni hypersensitivity was diagnosed by a patch test, and the lesions resolved following the removal and replacement of the SSC with another material [35]. The second case reported the severe occurrence of ulcerative contact gingivitis in a two-year-old boy following placement of SSCs that resolved following crown removal and replacement with composite resin crowns [36]. Ni allergy can induce different clinical and morphological patterns, but more commonly, involves a localized cutaneous reaction at the site of contact with the metal known as ACD or, in a minority of patients, a systemic reaction referred to as Ni allergy syndrome (SNAS) [37]. ACD is characterized by itching, pompholyx, maculopapular exanthema, flexural eczema, urticarial, and vasculitis-like lesions [37]. SNAS is a condition characterized by contact dermatitis in association with systemic symptoms, including diarrhea, vomiting, fever, arthralgia, asthenia, headache, and malaise [38]. Intra-oral reactions to Ni include stomatitis, papula pert-oral rash, a loss of taste sensation or metallic taste, numbness, burning sensation, tongue soreness, angular cheilitis, severe gingivitis (in the absence of plaque), lichen planus, mucosal ulcers, toxicity on the cellular level, and the alteration of cell function [13,39,40]. Extraoral symptoms include edema of the eyelids, swollen and fissured lips, and chronic eczema of the cheeks and palms [13,39]. In high doses, Ni provokes an allergic response through a type IV delayed hypersensitivity immune reaction [11,41,42].

Evidence of the nature of allergic reactions to SSCs in children is limited. One study reported a significantly higher rate of release of Ni in the saliva with a decreased pH [43]. Saliva is rich in chloride ions, and the presence of sodium chloride may result in pitting/corrosion of stainless-steel surfaces if they are scratched or nicked [44]. Similar results have been released by other researchers [45,46]. Morán-Martínez et al. reported that a significant increase in Ni level was observable among urine samples collected over time [47]. Similarly, another study demonstrated the highest release (with

Table 3 Characteristics of included *in vitro* studies

Author	Experimental design	Sample size	Time	Measure	Key findings
Amanna et al. 2019 [63]	Evaluation of ion release from SSCs in artificial saliva	SSCs ($n = 30$)	At 1, 7, 14, 21, and 28 days	Release of metal ions in artificial saliva using atomic absorption spectrometry	A measurable release of Ni and Cr was observed at each time point, with both reaching the maximum level at the end of 28 days; however both remained below the toxic level.
Basir et al. 2018 [64]	Evaluation of Ni release from SSCs with crown trimming	SSCs ($n = 18$)	At 1, 7, and 21 days	pH (3.5, 5.0, and 6.7) and oral temperature (27°C, 37°C, and 47°C)	The concentration of released Ni decreased with trimming of margins and increased when the temperature rose. Time and pH had no significant effect on Ni release.
Tiwari et al. 2016 [43]	Effect of pH on Ni ion release from SSCs	SSCs ($n = 45$)	At 15 days	Artificial saliva of pH (4.3, 5.5, and 6.3) using atomic absorption spectrometry	A significantly higher amount of Ni ions was released at a pH of 4.3, while the pH of artificial saliva was inversely related to Ni ion release.
Kulkarni et al. 2016 [45]	Biodegradation (leaching effect) of space maintainers and SSCs in the artificial saliva using atomic absorption spectrophotometer	SSCs ($n = 45$) and space maintainers ($n = 45$)	At 1,7 and 21 28 days	Atomic absorption spectrophotometer	A measurable release of Ni was observed and reached the maximum level at the end of seven days, which was statistically significant ($P < 0.05$)
Ramazani et al. 2014 [42]	Assessment of Ni release from SSCs	SSC ($n = 270$)	At 1, 7, 14, 21, and 28 days	Amount of Ni release in artificial saliva using an atomic absorption spectrophotometer	The amount of Ni released was below the toxic level and did not exceed the dietary intake.
Menek et al. 2012 [49]	Investigation of Ni ion release from SSCs in saliva	SSC ($n = 120$)	At 1, 3, 7, 14, 21, and 28 days	Ion release in saliva from SSCs by square wave voltammetry	Metal ions released in this experimental condition were well below the critical value needed to induce allergy and below the daily dietary intake level.
Keinan et al. 2010 [48]	Comparison of absorption of Ni, chromium, and iron by the root surface of primary molars covered with SSCs versus normal intact molars	SSCs ($n = 17$)	Present in the mouth for at least 24 months	Energy dispersive X-ray spectrometry chemical analysis	Significantly ($P < 0.001$) higher amounts of Ni, chromium, and iron (five- to sixfold) were found in the cementum of molars covered with SSCs as compared with in intact molars.
Bhaskar and Reddy, 2010 [11]	Biodegradation (leaching effect) of space maintainers made out of stainless steel band materials (Dantaurum, Unitek, SSC wire, solder and flux) in artificial saliva	SS band space maintainers ($n = 20$)	At 1, 7, 14, 21, and 28 days	Atomic absorption spectrophotometer	Results showed that there was measurable release of both Ni and Cr, reaching the maximum level at the end of seven days, which was statistically significant ($P < 0.05$). However, levels remained below the dietary average intake for all four bands used and were not capable of causing any toxicity.
Gagneja, 2007 [65]	Measure the Ni ion release from conventional SSCs and compare with the Ni ion release from the SSCs coated with a proprietary material	Specimens ($n = 18$), conventional SSCs ($n = 9$), and SSCs coated with proprietary layer ($n = 9$)	Immersion times of 1, 10, 100, and 1,000 hours	Optically missioned spectrometry	There was a measurable release of Ni elements in the nominal compositions of a SSC alloy and a coated SSC alloy. The use of stainless steel coated with a proprietary material for the fabrication of crowns may decrease the ion release and perhaps prevent various health hazards in children.

eight SSCs) of Ni *in vitro* [42]. In contrast with the above studies, however, some research contended that the amount of Ni detected in body fluids was less than the typical nutritional intake of Ni and is therefore below the level of a toxic dose for humans [11,42,48-50]. While the quantity of Ni ions required to produce sensitivity differs with the individual, even a low concentration of 40 µg of Ni per day can trigger a delayed hypersensitivity reaction [35,51]. Although this, indeed, is below the normal daily intake of 300 to 500 µg per day [Underwood E (1977) Trace elements in human and animal nutrition. 4th Ed, Elsevier Academic Press, 159-169], such a low concentration of Ni may induce a local hypersensitivity reaction in the oral environment in certain patients [51,52]. As a type IV hypersensitivity reaction, Ni allergy typically takes days to develop [53]. The sensitization phase, which is complex and not fully understood, commences after the patient exposes themselves to Ni, a hapten classified into the "transition metals" category [53,54]. When metal ions penetrate into the skin and bind to tissue proteins to become complete antigens, chemokines and proinflammatory cytokines, such as tumor necrosis factor-alpha and interleukin-1β, are released [53,55,56]. The antigens are then processed by dendritic cells, which then migrate to the lymph nodes to present the antigens to T-cells [53,55,56]. Subsequently, effector T-cells will migrate out of the draining lymph nodes, and, during the elicitation phase, the application of the same hapten will promote the production of cytokines and chemokines at the specific exposure site, creating inflammation on the skin [53].

Existing studies have assessed various biological samples to determine the level of Ni release in the body, including urine samples [47], hair samples [50], and saliva samples [11,43,45,46]. Keinan et al. reported that a significantly higher absorption of metal ions was released from SSCs by the root surface of primary molars when compared with normal intact molars [48]. Elsewhere, a review of SSCs concluded that it is difficult to evaluate the degree of Ni release into the oral cavity due to the corrosion inhibitor effect of salivary proteins [57]. However, Basir et al. found that the concentration of released Ni decreased with trimming of margins and with increased temperature, while time and pH experienced no significant effects [46]. Randall recommended smoothing and polishing the margins of the crown after cutting or crimping to decrease the likelihood of corrosion [57]. The literature includes few studies that have examined the effects of SSCs in children at the cellular and genetic levels. One study investigated genotoxic carcinogens and cell structural lesions caused by Ni released from SSCs and suggested that the ion release from these crowns caused genotoxic damage at the cellular level of the oral mucosa [47].

It has been found that the Ni component of stainless steel orthodontic appliances may produce a burning sensation as the most frequent symptom, along with gingivitis, gingival hyperplasia, periodontitis, metallic taste, erythema, and angular cheilitis [24-27]. Furthermore, patients with conventional braces experience more changes in the periodontium relative to those receiving Ni-free braces and often experience gingival overgrowth even without plaque accumulation around the orthodontic appliances [58]. This overgrowth has been shown to be the result of the impact of Ni on gingival epithelial cells and, even at low concentrations, Ni promotes epithelial cell proliferation [41,59]. Similarly, the existence of titanium hypersensitivity in an oral environment has also been reported in the literature [60]. On the other hand, there is a lack of significant research done on SSC materials despite being placed under a strenuous environment. The oral environment that SSCs are most often deployed in usually boasts a significant caries risk, higher saliva acidity, and greater plaque content [23]. Additionally, SSCs must withstand high occluding forces while being present in a patient's mouth for prolonged periods of time.

The present systematic review revealed several adverse effects of the ionic composition of SSCs in children, ranging from induction of local inflammation/allergic reaction to the systematic distribution of the ions, and also touched upon cytotoxic or genotoxic effects. However, the scientific evidence concerning the use of SSCs in the pediatric population is not yet adequately established, as inadequate research prevents the conclusion of whether SSCs could potentially be responsible for any adverse cellular and allergic/hypertensive reactions in the pediatric population. Most evidence comes from *in vitro* and *in vivo* studies that typically investigated the short-term effects of SSCs. Further research investigating the long-term release of these ions in *in vitro* and *in vivo* settings is necessary for aiding the understanding of SSC and, most importantly, assessing their safe use in pediatric patients.

In conclusion, while SSCs are economical and durable, there remains some concern about the leaching of metal ions such as Ni in the hostile oral environment, which may cause serious consequences in pediatric patients. Given the popularity of SSCs and the lack of any long-term reports about their biological, cellular, and molecular effects on the oral mucosa, further research aiming to elucidate such effects is required. Despite the popularity of SSCs among pediatric dentists, there have been no previous reviews published investigating the adverse effects of these crowns. Considering the possible cumulative effect of the ionic concentration of SSCs in the oral environment over a period of time, it is advisable that pediatric dentists should inform parents about such potential adverse effects when restoring multiple decayed teeth in young children.

Acknowledgments

We would like to acknowledge the assistance of Ms Jackie Devenish (Liaison Librarian, Herston Health Sciences Library, The University of Queensland) and Mr. Christopher Sexton (Associate Lecturer, School of Dentistry, The University of Queensland) in preparation of this manuscript.

Confilict of interest

None.

References

1. Benjamin R (2010) Oral health: the silent epidemic. Public Health Rep 125, 158-159.
2. Hickel R, Kaaden C, Paschos E, Buerkle V, Garcia-Godoy F, Manhart J (2005) Longevity of occlusally-stressed restorations in posterior primary teeth. Am J Dent 18, 198-211.
3. Afshar H, Sabeti A, Shahrabi M (2015) Comparisons of primary molar crown dimensions with SSCs in a sample of Iranian children. J Dent Res Dent Clin Dent Prospects 9, 86-91.
4. Einwag J, Dünninger P (1996) Stainless steel crown versus multisurface amalgam restorations: an 8-year longitudinal clinical study. Quintessence Int 27, 321-323.
5. Innes N, Ricketts D, Evans D (2007) Preformed metal crowns for decayed primary molar teeth. Cochrane Database Syst Rev CD005512.
6. Humphery W (1950) Uses of chrome steel in children's dentistry. Dent Surv 26, 945-949.
7. Sajjanshetty S, Patil P, Hugar D, Rajkumar K (2013). Pediatric preforemd metal crowns-an update. J Dent Allied Sci 2, 29-32.
8. Papathanasiou AG, Curzon ME, Fairpo CG (1994) The influence of restorative material on the survival rate of restorations in primary molars. Pediatr Dent 16, 282-288.
9. Roberts J, Sherriff M (1990) The fate and survival of amalgam and preformed crown molar restorations placed in a specialist paediatric dental practice. Br Dent J 169, 237-244.
10. Zinelis S, Lambrinaki T, Kavvadia K, Papagiannoulis L (2008) Morphological and compositional alterations of in vivo aged prefabricated pediatric metal crowns (PMCs). Dent Mater 24, 216-220.
11. Bhaskar V, Subba Reddy VV (2010) Biodegradation of Ni and chromium from space maintainers: an in vitro study. J Indian Soc Pedod Prev Dent 28, 6.
12. Dwivedi A, Tikku T, Khanna R, Maurya RP, Verma G, Murthy RC (2015) Release of Ni and chromium ions in the saliva of patients with fixed orthodontic appliance: an in-vivo study. Natl J Maxillofac Surg 6, 62-66.
13. Burrows D (1986) Hypersensitivity to mercury, Ni and chromium in relation to dental materials. Int Dent J 36, 30-34.
14. Jones IK, Hansen CA, Singer ML, Kessler HP (1986) Dental implications of Ni sensitivity. J Prosthet Dent 56, 507-509.
15. Al-Waheidi EMH (1995) Allergic reaction to Ni orthodontic wires: a case report. Quintessence Int 26, 385-387.
16. Wiltshire A, Ferreira M, Ligthelm J (1996) Allergy to dental materials. Quintessence Int 27, 513-520.
17. Thyssen JP, Menné T (2009) Metal Allergy: a review on exposures, penetration, genetics, prevalence, and clinical implications. Chem Res Toxicol 23, 309-318.
18. Bass JK, Fine H, Cisneros GJ (1993) Ni hypersensitivity in the orthodontic patient. Am J Orthod Dentofacial Orthop 103, 280-285.
19. Elshahawy WM, Watanabe I, Kramer P (2009) In vitro cytotoxicity evaluation of elemental ions released from different prosthodontic materials. Dent Mater 25, 1551-1555.
20. Kasprzak KS, Sunderman FW Jr, Salnikow K (2003) Ni carcinogenesis. Mutat Res 533, 67-97.
21. Suárez C, Vilar T, Gil J, Sevilla P (2010) In vitro evaluation of surface topographic changes and Ni release of lingual orthodontic archwires. J Mater Sci Mater Med 21, 675-683.
22. Feasby W, Ecclestone E, Grainger R (1988) Ni sensitivity in pediatric dental patients. Pediatr Dent 10, 127-129.
23. Varughese RE, Andrews P, Sigal MJ, Azarpazhooh A (2016) An assessment of direct restorative material use in posterior teeth by American and Canadian pediatric dentists: I. material choice. Pediatr Dent 38, 489-496.
24. Lamster I, Kalfus D, Steigerwald P, Chasens A (1987) Rapid loss of alveolar bone association with nonprecious alloy crowns in two patients with Ni hypersensitivity. J Periodontol 58, 486-492.
25. Starkjaer l, Menné T (1990) Ni allergy and orthodontic treatment. Eur J Orthod 12, 284-289.
26. Bishara S, Barrett R, Selim M (1993) Biodegradation of orthodontic appliances. Part II. changes in the blood level of Ni. Am J Orthod Dentofacial Orthop 103, 115-119.
27. Janson G, Dainesi E, Consolaro A, Woodside D, Freitas M (1998) Ni hypersensitivity reaction before, during, and after orthodontic therapy. Am J Orthod Dentofacial Orthop 113, 655-660.
28. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the prisma statement. Ann Intern Med 151, 264-269.
29. Hong QN, Gonzalez-Reyes A, Pluye P (2018) Improving the usefulness of a tool for appraising the quality of qualitative, quantitative and mixed methods studies, the Mixed Methods Appraisal Tool (MMAT). J Eval Clin Pract 24, 459-467.
30. Drummond BK, Davidson LE, Williams SM, Moffat SM, Ayers KM (2004) Outcomes two, three and four years after comprehensive care under general anaesthesia. N Z Dent J 100, 32-37.
31. Danaei SM, Safavi A, Roeinpeikar SM, Oshagh M, Iranpour S, Omidkhoda M (2011) Ion release from orthodontic brackets in 3 mouthwashes: an in-vitro study. Am J Orthod Dentofacial Orthop 139, 730-734.
32. Kerosuo H, Moe G, Kleven E (1995) In vitro release of Ni and chromium from different types of simulated orthodontic appliances. Angle Orthod 65, 111-116.
33. House K, Sernetz F, Dymock D, Sandy J, Ireland A (2008) Corrosion of orthodontic appliances - should we care? Am J Orthod Dentofacial Orthop 133, 584-592.
34. Syed M, Chopra R, Sachdev V (2015) Allergic reactions to dental materials—A systematic review. J Clin Diagn Res 9, ZE04-ZE09.
35. Yilmaz A, Ozdemir CE, Yilmaz Y (2012) A delayed hypersensitivity reaction to a stainless steel crown: a case report. J Clin Pediatr Dent 36, 235-238.
36. Barcroft BD, Shen TJ, Lew DB (1997) Ulcerative contact gingivitis due to the Ni component of SSCs. Pediatr Asthma Allergy Immunol 11, 221-226.
37. Calogiuri GF BD, Foti C, Al-Sowaidi S (2016) Ni hypersensitivity: a general review on clinical aspects and potential co-morbidities. J Allergy Ther 7, 243-248.
38. Darlenski R, Kazandjieva J, Pramatarov K (2012) The many faces of Ni allergy. Int J Dermatol 51, 523-530.
39. Fernandez JP, Veron C, Hildebrand HF, Martin P (1986) Ni allergy to dental prostheses. Contact Dermatitis 14, 312.
40. Raap U, Stiesch M, Reh H, Kapp A, Werfel T (2009) Investigation of contact allergy to dental metals in 206 patients. Contact Dermatitis 60, 339-343.
41. Chakravarthi S, Padmanabhan S, Chitharanjan AB (2012) Allergy and orthodontics. J Orthod Sci 1, 83-87.
42. Ramazani N, Ahmadi R, Darijani M (2014) Assessment of Ni release from SSCs. J Dent (Tehran) 11, 328.
43. Tiwari S, Bhayya D, Gupta S, Saxena S, Kathal S, Roy S (2016) Effect of pH on Ni ion release from SSCs: an in vitro study. Int Educ Res J 2, 47-48.
44. Elshahawy W, Watanabe I (2014) Biocompatibility of dental alloys used in dental fixed prosthodontics. Tanta Dent J 11, 150-159.
45. Kulkarni P, Agrawal S, Bansal A, Jain A, Tiwari U, Anand A (2016) Assessment of Ni release from various dental appliances used routinely in pediatric dentistry. Indian J Dent 7, 81-85.
46. Basir L, Meshki R, Behbudi A, Rakhshan V (2019) Effects of restoring the primary dentition with stainless-steel crowns on children's salivary nickel and chromium levels, and the associations with saliva pH: a preliminary before-after clinical trial. Biol Trace Elem Res 187, 65-73.
47. Morán-Martínez J, Monreal-de Luna KD, Betancourt-Martínez ND, Carranza-Rosales P, Contreras-Martínez JG, López-Meza MC et al. (2013) Genotoxicity in oral epithelial cells in children caused by Ni in metal crowns. Genet Mol Res 12, 3178-3185.
48. Keinan D, Mass E, Zilberman U (2010) Absorption of nickel, chromium, and iron by the root surface of primary molars covered with SSCs. Int J Dent 326124, 1-4.
49. Menek N, Basaran S, Karaman Y, Ceylan G, Tunç ES (2012) Investigation of Ni ion release from SSCs by square wave voltammetry. Int J Electrochem Sci 7, 6465-6471.
50. Kodaira H, Ohno K, Fukase N, Kuroda M, Adachi S, Kikuchi M et al. (2013) Release and systemic accumulation of heavy metals from preformed crowns used in restoration of primary teeth. J Oral Sci 55, 161-165.
51. Park HY, Shearer TR (1983) In vitro release of Ni and chromium from simulated orthodontic appliances. Am J Orthod 84, 156-159.
52. Pazzini CA, Junior GO, Marques lS, Pereira CV, Pereira IJ (2009) Prevalence of Ni allergy and longitudinal evaluation of periodontal abnormalities in orthodontic allergic patients. Angle Orthod 79, 922-927.
53. Saito M, Arakaki R, Yamada A, Tsunematsu T, Kudo Y, Ishimaru N (2016) Molecular mechanisms of Ni allergy. Int J Mol 17, 202.
54. Martins I, Silva dos Reis V (2011) Immunopathology of allergic contact dermatitis. An Bras Dermatol 86, 419-433.
55. Campos R, Szczepanik M, Itakura A et al. (2003) Cutaneous immunization rapidly activate liver invariant Valpha14 NKT cells stimulating B-1 B cells to initiate T cell recruitment for elicitation of contact sensitivity. J Exp Med 198, 1785-1796.
56. Gober M, Gaspari A (2008) Allergic contact dermatitis. Curr Dir Autoimmun 10, 1-26.
57. Randall RC (2002) Preformed metal crowns for primary and permanent molar teeth: review of the literature. Pediatr Dent 24, 489-500.
58. Pazzini C, Pereira l, Carlos R, de Melo G, Zampini M et al. (2011) Periodontal status and blood parameters in allergic orthodontic patients. Am J Orthod Dentofacial Orthop 139, 55-59.
59. Gursoy U, Sokucu O, Uitto VJ, Aydin A, Demirer S, Toker H et al. (2007) The role of Ni accumulation and epithelial cell proliferation in orthodontic treatment-induced gingival overgrowth. Eur J Orthod 529, 555-558.
60. Siddiqi A, Payne AGT, De Silva R, Duncan WJ (2011) Titanium allergy: could it affect dental implant integration? Clin Oral Implants Res 22, 673-680.
61. Hernández-Martínez CT, Morales-Luckie RA, Robles-Berme NL, Jiménez-Gayosso SI, Ramírez-Cardona M, García-Hernández V et al. (2018) Detection of Ni, Fe, and Cr released in saliva after prefabricated metal crown placement in children. Preprints 2018, doi: 10.20944/preprints201804.0236.v1.
62. Mohamed AA, Amel Mahmoud Ahmed AM, Mahmoud TT (2013) Comparison between Ni and chromium levels in saliva of children having space maintainers versus SSCs (Comparative Study). Int J Sci Res 5, 663-666.
63. Amanna EN, Bhat SS, Hegde SK (2019) An in vitro evaluation of nickel and chromium release from different commercially available stainless steel crowns. J Indian Soc Pedod Prev Dent 37, 31-38.
64. Basir L, Shamsaei M, Ziaei SA (2018) Evaluation of nickel releasing from stainless steel crowns regarding to "trimming": an in vitro study. J Indian Soc Pedod Prev Dent 36, 58-64.
65. Gagneja M (2007) In vitro analysis of Ni ion release from stainless steel for preformed crowns. Scholar Archive 846, http://digitalcommons.ohsu.edu/etd/846.