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Research Article

Titanium allergy: diagnostic challenge in dental pre-implant surgery patch testing

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Abstract

Introduction: Titanium dental implants are the most common type of dental implants. Although titanium and its alloys are considered biocompatible, there are concerns about the induction of metal allergy with dental implants.

Aim: To evaluate the presence of titanium sensitization by patch testing in patients who intend to have titanium dental implants.

Materials and methods: A retrospective study was performed in which data on sensitization to titanium collected from the Allergy Office at the Faculty of Dentistry in Plovdiv from January 2022 to April 2024 were analyzed. We analyzed data from 95 patients who had patch testing done before their dental implant surgery.

Results: Thirty-eight (40.0%) patients exhibited positive patch test reactions to at least one metal. The most common allergen was nickel (32.6%). Titanium (IV) oxalate was the only one with a positive rate (7.4%) among titanium reagents. Almost one-half (42.9%) of the patients were monosensitized to titanium (IV) oxalate. No association between positive reaction to titanium (IV) oxalate and history of suspected metal allergy was identified (p=0.064).

Conclusions: The absence of positive reactions to other titanium reagents, as well as a correlation with a history of metal allergy and other allergies in patients who tested positive for titanium oxalate, makes determining the clinical relevance of the positive reactions difficult. Standardization in titanium allergy research is required to ensure the accuracy of the findings.

Keywords

dental implants, diagnostic difficulties, titanium sensitization

Introduction

Titanium dental implants are widely accepted as the gold standard for tooth replacement due to their superior mechanical properties, biocompatibility, and high corrosion resistance. As the most commonly used type of dental implant, titanium has been extensively studied for its biological performance and long-term success rate. According to the American Society for Testing and Materials (ASTM), titanium is available in two primary forms: commercially pure titanium (Grades 1-4), which varies in oxygen content and mechanical strength (with Grade 1 being the weakest), and titanium alloys, such as Ti-6Al-4V (ASTM Grade 5), which contains 6% aluminum (Al) and 4% vanadium (V) by weight. Additionally, a binary alloy consisting of approximately 85 mass% titanium (Ti) and 15 mass% zirconium (Zr) is used, though it is not yet standardized.[1] While titanium and its alloys exhibit high corrosion resistance and biocompatibility, increasing evidence suggests that titanium ions and particles released from dental implants may contribute to local and systemic immunological reactions.[2,3] Furthermore, trace amounts of other metals

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present as impurities in titanium implants—such as nickel, cobalt, chromium, and copper—are known contact sensitizers and may also trigger hypersensitivity reactions.[4] Consequently, the role of metal allergies in implant failure has been increasingly scrutinized.[5] Comino-Garayoa et al.[6] conducted a comprehensive review of 52 studies on hypersensitivity reactions related to titanium dental implants, analyzing mechanisms, clinical manifestations, diagnostic approaches, and management strategies. Although titanium allergies are uncommon, they can cause localized reactions such as erythema, edema, pruritus in peri-implant tissues, and proliferative hyperplasia. Systemic reactions, though uncommon, may present as dermatitis, urticaria, or other hypersensitivity responses distant from the implant site. Poli et al.[7] provided evidence suggesting that implant failure in some patients is associated with allergic reactions rather than mechanical or infectious causes. They reported a clinical case of an epulis-like lesion in the peri-implant mucosa, histologically confirmed as an allergic response to titanium. Since dental implant treatment is both time-consuming and expensive, many patients seek assurance that they will not experience implant intolerance. As a result, implantologists frequently refer patients for epicutaneous testing to metals before implant surgery. Individuals with multiple allergies, particularly those with a history of metal allergy, have a higher risk of developing allergic reactions to titanium implants.[8] Moreover, titanium, not in its metallic form but as titanium dioxide, is widely used in cosmetics, pharmaceuticals, and food products, raising concerns that prior exposure may contribute to titanium sensitization.[9] The risk of titanium sensitization should be evaluated preoperatively to prevent implant failure. If a positive reaction to titanium is detected, alternative implant materials are considered. Metal allergy is traditionally considered a type IV hypersensitivity reaction. Patch testing remains the gold standard method for assessing delayed-type (type IV) hypersensitivity reactions, including those potentially triggered by titanium compounds.[10] In the literature, various titanium salts have been used as testing agents. Titanium dioxide 10.0% is the most common patch test formulation; however, it has certain limitations, such as poor penetration through the epidermis and the inability of oxides, in general, to bind to proteins and function as haptens.[11]

Aim

The objective of this study was to evaluate the presence of titanium sensitization using patch testing in patients who intend to receive titanium dental implants.

Materials and methods

Study design

This retrospective observational study analyzed titanium sensitization data collected from the clinical records of patients who visited the Allergy Office at the Faculty of Dental Medicine in Plovdiv between January 2022 and April 2024. A total of 95 patients who had patch testing for metal sensitization and were scheduled for dental implant surgery were assessed. Most patients were referred by dental clinics (n=91, 95.8%), while the remainder were self-referred (n=4, 4.2%).

Eligibility criteria

Inclusion criteria:

- No previous exposure to titanium dental implant or orthopedic surgeries involving titanium products.
- A documented history of suspected metal allergy or other suspected allergic conditions, including atopy, non-metal contact allergies, drug allergies, and food allergies.

Exclusion criteria:

Patients receiving immunosuppressive treatment at the time of testing.

Patch testing

Patch testing was carried out according to the International Contact Dermatitis Research Group guidelines (ICDRG). The test substances were supplied by Chemotechnique Diagnostics (Vellinge, Sweden). A total of 14 metal reagents were used, including titanium compounds: 10.0% titanium, 10.0% titanium dioxide, 5.0% titanium (III) nitride, 5.0% titanium (IV) oxalate hydrate, and other metal compounds: 0.5% potassium dichromate, 1.0% cobalt (II) chloride hexahydrate, 5.0% nickel sulfate hexahydrate, 2.0% copper sulfate, 5.0% molybdenum, 2.0% palladium (II) chloride, 0.1% zirconium dioxide, 1.0% zirconium (IV) chloride, 2.0% aluminum (III) chloride hexahydrate, and 2.5% zinc. To ensure standardized allergen application and minimize the risk of irritant reactions or false-positive responses, hypoallergenic patches with polyethylene chambers (IQ Ultra Chambers®, Chemotechnique Diagnostics, Vellinge, Sweden) were utilized.

Patch tests were removed 48 hours post-application. Skin reactions were assessed by visual inspection and palpation at removal on day 2 (D2), after 72/96 hours (D3/D4), and after 7 days (D7). All readings were conducted by the same investigator. The globally acknowledged reading criteria of the ICDRG are shown in **Table 1**.[12] All positive reactions were clustered as positive, despite the degree of intensity, weak (+), strong (++), or extreme (+++). Doubtful reactions (?+) and irritant reactions (IR) were also recorded and read as negative. The progression of patch test reactions was carefully monitored. Positive reactions fulfilled the criteria of at least one plus (+) reaction on D2 and/or D3/4. A reaction that was positive on day 2 but negative at the second reading was classified as an irritant reaction.

Table 1. Reading criteria of the ICDRG

Symbol	Morphology	Assessment
–	No reaction	Negative reaction
?+	Faint erythema only	Doubtful reaction
+	Erythema, infiltration, possibly papules,	Weak positive reaction
++	Erythema, infiltration, papules, vesicles	Strong positive reaction
+++	Intense erythema, infiltrate, coalescing vesicles	Extreme positive reaction
IR	Various morphologies, e.g. soap effect, bulla, necrosis	Irritant reaction

We also analyzed the evolution of positive reactions from D3/D4 to D7. 'Decrescendo' was defined as a decrease in their strength (+++, ++, +, ?+, or 0), 'plateau' as unaltered morphology (+++, +++, ++, ++, +, +), and 'crescendo' as an increase in the strength of reactions (0 or ?+, +, ++, +++).

Data collection and statistical analysis

Data were collected from electronic medical records, including demographic information (age, sex), medical history, and patch test results. Descriptive statistics were used for data analysis. Categorical variables were presented as frequencies and percentages, while continuous variables were summarized as means ± standard deviations (SD). To compare the frequency of positive patch test reactions between patients with and without metal allergy (MA), we performed the chi-square (χ^2) test. Additionally, the chi-square test was used to evaluate the association between positive reactions to titanium, sensitization to other metals, and patients' allergy history. A p-value <0.05 was considered statistically significant. All statistical analyses were conducted using SPSS, version 25.0.

Results

A total of 95 patients underwent patch testing, including 71 (74.7%) women and 24 (25.3%) men, with a mean (±SD) age of 48.1±13.8 years. Of these, 24 patients (25.3%) reported a history of suspected metal allergy, with women reporting this condition more often than men (31.0% vs. 8.3%, p=0.031). The remaining 71 patients reported no symptoms of metal allergy, though 23 of these patients (32.4%) had other allergic conditions, which were also more common in women than men (40.8% vs. 13.6%, p=0.029). Among them, 16 reported atopic disease, 5 had drug allergies, and 2 had food allergies.

Patch test reactions

Half of the tested allergens demonstrated positive patch test reactions. Overall, 38 patients (40.0%) exhibited positive reactions to at least one metal. Frequencies of positive reactions are given in **Table 2**. The most common allergen was nickel (32.6%), followed by palladium (17.9%), cobalt (11.6%), copper (8.4%), chromium (7.4%), and titanium (7.4%). The history of suspected metal allergy was significantly associated with positive patch test reactions to nickel, palladium, cobalt, and copper **(Table 3)**. The history of other allergies was not significantly associated with positive patch test reactions to any of the tested preparations (p>0.05). A significant association between female sex and a positive reaction to nickel was observed (39.4% vs. 12.5%, p=0.022), while no such correlation was found for other test preparations.

Titanium sensitization

Among the seven patients (7.4%) with positive reactions to titanium compounds, all reacted to titanium (IV) oxalate, while no reactions were observed to other titanium reagents. The mean age of titanium (IV) oxalate positive patients was 43.3±15.2 years, and 57.1% were female. Reactions to titanium (IV) oxalate in our study were + and ++ positive in 57.1% and 42.9% of tested patients, respectively **(Table 2)**. In three patients, positive reactions to this allergen followed a decrescendo pattern, with two of them showing a complete decline to negative by the late reading. Three out of the 7 patients (42.9%) were monosensitized to titanium (IV) oxalate, while in the remaining patients, nickel and chromium were the most frequent co-reactants (42.9% and 28.6%, respectively). No significant association was found between titanium (IV) oxalate sensitization and reactivity to other metals (p=0.417) **(Table 4)**. Patients without a history of metal allergy had a threefold higher incidence of positive reactions to titanium (IV) oxalate than those with suspected metal allergy; however, this association was not statistically significant (p=0.064) **(Table 4)**. Positive patch test reactions to titanium (IV) oxalate were not observed in patients with allergic conditions unrelated to metal hypersensitivity. No clinical relevance of any of the positive reactions to titanium oxalate was identified.

Titanium (IV) oxalate demonstrated the highest rate of irritant reactions (21.1%, n=20), mainly observed at the first (D2) and/or the second reading (D3/D4). Among other titanium reagents, one irritant reaction to titanium (III) nitride was read (1.1%) **(Table 2)**.

Despite a positive reaction to titanium (IV) oxalate, one patient (patient 6, M, 52, in **Table 5**) proceeded with titanium dental implant surgery, as he had never experienced clinical allergic reactions. He was asked to inform us about the treatment outcome. A single titanium implant was

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Table 2. Results of patch testing with metal reagents

№	Patch test preparation	Conc. in pet. (%)	Positive reactions n (% of tested; 95% CI)	Reading criteria of the ICDRG†					Only late (D7) positive reactions‡ n (% of pos.)	Evolution of positive reactions§		
				Doubtful (? +) n (% of tested)	Weak positive (+) n (% of pos.)	Strong positive (++) n (% of pos.)	Extreme positive (+++) n (% of pos.)	Irritant (IR) n (% of tested)		Decrescendo n (% of pos.)	Plateau n (% of pos.)	Crescendo n (% of pos.)
1	Nickel sulfate hexahydrate	5.0	31 (32.6; 23.4–43.0)	0	5 (16.1)	11 (35.5)	15 (48.4)	1 (1.1)	1 (1.1)	1 (3.2)	17 (54.8)	13 (41.9)
2	Palladium (II) chloride	2.0	17 (17.9; 10.8–27.1)	1 (1.1)	4 (23.5)	9 (52.9)	4 (23.5)	0	0	2 (11.8)	10 (58.8)	5 (29.4)
3	Cobalt (II) chloride hexahydrate	1.0	11 (11.6; 5.9–19.8)	2 (2.1)	2 (18.1)	8 (72.7)	1 (9.1)	2 (2.1)	0	3 (27.2)	2 (18.2)	6 (54.5)
4	Copper (II) sulfate pentahydrate	2.0	8 (8.4; 3.7–15.9)	0	4 (50.0)	3 (37.5)	1 (12.5)	0	0	2 (25.0)	4 (50.0)	2 (25.0)
5	Potassium dichromate	0.5	7 (7.4; 3.0–14.6)	2 (2.1)	3 (42.9)	4 (57.1)	0	0	1 (1.1)	1 (14.3)	2 (28.6)	4 (57.1)
6	Titanium (IV) oxalate hydrate	5.0	7 (7.4; 3.0–14.6)	0	4 (57.1)	3 (42.9)	0	20 (21.1)	0	3 (42.9)	4 (57.1)	0
7	Zinc	2.5	4 (4.3; 1.2–10.5)	0	1 (25.0)	3 (75.0)	0	0	0	1 (25.0)	2 (50.0)	1 (25.0)
8	Titanium	10.0	0									
9	Titanium dioxide	10.0	0									
10	Titanium (III) nitride	5.0	0					1 (1.1)				
11	Molybdenum	5.0	0									
12	Aluminum (III) chloride hexahydrate	2.0	0									
13	Zirconium dioxide	0.1	0									
14	Zirconium (IV) chloride	1.0	0									

† The strongest reactions observed across the three readings; ‡ Negative or doubtful on D2 and D3/D4, but positive on D7; § Evolution of positive reactions from D3/4 to D7 was classified as: 'decrescendo' (decrease in ICDRG criteria: +++, ++, +, ?+, or 0), 'plateau' (unaltered: +++, +++, ++, ++, +, +) or 'crescendo' (increase in ICDRG criteria: 0 or ?+, +, ++, +++).

Table 3. Prevalence of positive reactions for metal reagents according to the history of suspected metal allergy (MA)

N	HAPTEN	%	Vehicle	Positive reactions of all patients (%)	Positive reactions of patients with MA (%)	Positive reactions of patients without MA (%)	*p*-value
1	Nickel sulfate hexahydrate	5.0	pet	32.6	83.3	15.5	<0.001
2	Palladium (II) chloride	2.0	pet	17.9	45.8	8.5	<0.001
3	Cobalt (II) chloride hexahydrate	1.0	pet	11.6	29.2	5.6	0.005
4	Copper (II) sulfate pentahydrate	2	pet	8.4	29.2	1.4	<0.001
5	Potassium dichromate	0.5	pet	7.4	4.2	8.5	0.675
6	Titanium (IV) oxalate hydrate	5.0	pet	7.4	4.2	8.5	0.675
7	Zinc	2.5	pet	4.2	8.3	2.8	0.264
8	Titanium	10.0	pet	0.0	0.0	0.0	-
9	Titanium dioxide	10.0	pet	0.0	0.0	0.0	-
10	Titanium (III) nitride	5.0	pet	0.0	0.0	0.0	-
11	Molybdenum	5.0	pet	0.0	0.0	0.0	-
12	Aluminum (III) chloride hexahydrate	2.0	pet	0.0	0.0	0.0	-
13	Zirconium dioxide	0.1	pet	0.0	0.0	0.0	-
14	Zirconium (IV) chloride	1.0	pet	0.0	0.0	0.0	-

Table 4. Association between positive reactions to titanium (IV) oxalate, other metal sensitization and history of allergy

Positive reactions to Ti (IV) oxalate	Positive reactions to other metals			History of allergy			
	Yes n (%)	No n (%)	*p*-value	Metal allergy n (%)	Other allergies n (%)	No allergy n (%)	*p*-value
	4 (11.4)	3 (5.0)	0.417	1 (4.2)	0 (0.0)	6 (12.5)	0.064

Table 5. Evolution of positive patch test reactions to titanium oxalate over three time points

No.	Sex	Age	D2 first reading	D3/D4 second reading	D7 late reading
1	M	38	++	++	++
2	F	51	++	++	+
3	F	39	++	++	-
4	F	30	+	+	-
5	M	24	?+	+	+
6	M	52	+	+	+
7	F	69	+	+	+

inserted in the left maxillary first molar region. The 2-year follow-up revealed successful osseointegration and no signs of hypersensitivity, as reported by the implantologist.

Discussion

Titanium is widely used as a material for dental implants due to its high corrosion resistance resulting from the oxide layer that protects the implant from the surrounding tissues. For this reason, it is accepted as an inert and completely biocompatible material.[13] However, metal particles have been detected in the tissues surrounding titanium dental implants, both in the presence and absence of periimplantitis.[14-16] These particles can be deposited into tissue at any stage of dental implant treatment—from insertion to maintenance—with rough implant surfaces releasing more particles than smoother ones.[17,18] The tribocorrosion process facilitates the release of titanium ions into the surrounding tissues, where they can form complexes with native proteins and potentially act as allergens, leading to hypersensitivity reactions.[19] Patients with a history of metal allergy are reasonably referred for patch testing, as multisensitization to metals is common, and traces of the most common metal sensitizers may be present in dental implants.[4] Despite the lack of legislative recommendations for routine allergy testing prior to dental implant surgery, some patients scheduled for dental implant surgery, even without any allergies, insist on doing the test as a guarantee against an intolerant reaction.

Our retrospective study evaluated patients scheduled for dental implant surgery who were tested for titanium contact hypersensitivity in the Allergy office of the Faculty of Dental Medicine. The overall prevalence of titanium sensitization was 7.4%, with positive reactions observed only to titanium (IV) oxalate. This rate was significantly higher

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than the 0.6% titanium sensitization prevalence reported by Sicilia et al.[20] However, their study did not include testing of titanium (IV) oxalate, which might account for the difference in sensitization rate from that in our study. In contrast, Niels et al. found that titanium oxalate had the highest reactivity among tested titanium compounds, with 17 patients (7.9%) exhibiting positive reactions[21], a prevalence similar to ours.

While patients with a history of metal allergy are typically referred for patch testing before implantation[5,6], our study found no significant association between a history of metal allergy or other allergies and titanium sensitization. Unexpectedly, patients without a history of allergies were more likely to exhibit positive reactions to titanium (IV) oxalate, although this trend did not reach statistical significance. Titanium sensitivity in patients suspected of metal allergy was estimated to be 4.2%, which is lower than the prevalence of 6.3% reported by Hosoki et al.[22] in the study conducted among patients suspected of dental metal allergy. While Hosoki et al. hypothesized that the prevalence of titanium sensitization in the general population would be significantly lower, our study found three times higher prevalence of titanium sensitization in individuals without a history of allergy. This might be attributed to the difference of tested titanium agents, as titanium chloride was used in their study, and all the titanium-positive patients also exhibited a positive reaction to other types of metal allergens. In contrast to their study, a positive test to titanium (IV) oxalate was identified as monosensitization in 42.7% of the positive patients in the current study.

A high incidence of positive reactions to titanium oxalate (86%) was identified by Wang et al., and they were attributed to irritant reactions, as no hypersensitivity skin reaction was detected to other titanium salt formulations.[23] In accordance with their study, we also identified a high rate of irritant reactions (21.1%), and those that were registered as positive met the criteria for a positive result in at least two readings. In our study, titanium (IV) oxalate did not induce any crescendo-pattern positive reactions. Most reactions were weak (57.1%), and a decrescendo pattern was observed in 42.9% of cases. Among these, two out of three decrescendo reactions fully declined by the late reading, suggesting not only an allergic response but also resolution following the removal of an irritant.[24] We speculate that the positive reactions developed over time, possibly influenced by early-stage irritation. Ultimately, differentiating between a true allergic reaction and an irritant reaction remains particularly challenging, making the assessment of reactions to the current titanium (IV) oxalate preparation notably difficult, especially given the lack of established clinical relevance for the positive test results. In contrast, the other four positive reactions exhibited a plateau time course, which is a more reliable indicator of true contact hypersensitivity compared to the decrescendo pattern.[25] Determining the clinical relevance of these positive reactions to titanium oxalate in pretreatment testing remains challenging, as patients often lack a relevant medical history or clinical symptoms, making diagnostic interpretation difficult. The 2-year follow-up of the titanium oxalate-positive patient who proceeded with titanium dental implant surgery revealed no signs of hypersensitivity or implant failure, questioning the predictive value of positive reactions to titanium (IV) oxalate in assessing implant intolerance. While the observation of this clinical case was not the aim of the study, it highlights the potential for successful titanium implant integration despite positive patch test results. Nevertheless, this observation is limited by the single clinical case and the relatively short follow-up period. However, it raises additional questions regarding the risk of implant failure. The oral mucosa exhibits a weaker immune response compared to the skin, likely due to a lower density of Langerhans cells[26], and bone demonstrates a low reactivity potential.[27] Whether these factors may contribute to a tolerant response to a single dental implant or indicate the need to reevaluate the diagnostic value of titanium (IV) oxalate preparation remains unclear. Currently, no standardized protocol exists for evaluating patients scheduled for dental implant surgery. Our patch test results indicate that positive reactions to titanium were registered in patients without a history of allergy, a group generally considered low risk and not routinely referred for allergy testing. On the other hand, there is a need for reliable results from the patch test, as the false positive reactions might lead to inappropriate recommendations of alternative materials such as zirconium implants that are much more expensive.

Conclusion

The frequency of Ti sensitivity in our patch test group was 7.4% recorded only to titanium (IV) oxalate. The lack of both positive reactions to other titanium reagents and a correlation with a history of metal allergy and other allergies in these patients makes it difficult to determine the clinical relevance of the positive reactions and raises the question of whether the recommendation for alternative materials for dental implants is justified in the cases of pre-implant surgery epicutaneous testing. Standardization in research into titanium allergy is needed to ensure the reliability of results.

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Competing Interests

The authors have declared that no competing interests exist.

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References

1. Pettersson M, Romanos G. Metallic nanoparticles as a risk factor for peri-implant diseases. In: Romanos G, editor. Saving Dental Implants. John Wiley & Sons, Inc.; 2024. Available from: https://doi.org/10.1002/9781119807049.ch5
2. Suárez-López Del Amo F, Garaicoa-Pazmiño C, Fretwurst T, et al. Dental implants-associated release of titanium particles: A systematic review. Clin Oral Implants Res 2018; 29(11):1085–100.
3. Wilson TG. Bone loss around implants - is it metallosis? J Periodontol 2021; 92(2):181–5.
4. Stricker A, Bergfeldt T, Fretwurst T, et al. Impurities in commercial titanium dental implants - A mass and optical emission spectrometry elemental analysis. Dent Mater 2022; 38(8):1395–403.
5. Watanabe M, Liu L, Ichikawa T. Are allergy-induced implant failures actually hypersensitivity reactions to titanium? A literature review. Dent J 2023; 11(11):263.
6. Comino-Garayoa R, Cortés-Bretón Brinkmann J, Peláez J, et al. Allergies to titanium dental implants: what do we really know about them? A scoping review. Biology 2020; 18(9):404.
7. Poli PP, De Miranda FV, Polo TOB, et al. Titanium allergy caused by dental implants: a systematic literature review and case report. Materials 2021; 14(18):5239.
8. Hosoki M, Nishigawa K, Miyamoto Y, et al. Allergic contact dermatitis caused by titanium screws and dental implants. J Prosthodont Res 2016; 60:213–9.
9. Fage SW, Muris J, Jakobsen SS, et al. Titanium: a review on exposure, release, penetration, allergy, epidemiology, and clinical reactivity. Contact Dermatitis 2016; 74(6):323–45.
10. De Graaf NPJ, Feilzer AJ, Kleverlaan CJ, et al. A retrospective study on titanium sensitivity: Patch test materials and manifestations. Contact Dermatitis 2018; 79(2):85–90.
11. Hanawa T. A comprehensive review of techniques for biofunctionalization of titanium. J Periodontal Implant Sci 2011; 41(6):263–72.
12. Johansen JD, Aalto-Korte K, Agner T, et al. European Society of Contact Dermatitis guideline for diagnostic patch testing - recommendations on best practice. Contact Dermatitis 2015; 73(4):195–221.
13. Xu J, Aoki H, Kasugai S, et al. Enhancement of mineralization on porous titanium surface by filling with nano-hydroxyapatite particles fabricated with a vacuum spray method. Mater Sci Eng C Mater Biol Appl 2020; 111:110772.
14. Fretwurst T, Buzanich G, Nahles S, et al. Metal elements in tissue with dental peri-implantitis: a pilot study. Clin Oral Implants Res 2016; 27:1178–86.
15. Olmedo DG, Nalli G, Verdu S, et al. Exfoliative cytology and titanium dental implants: a pilot study. J Periodontol 2013; 84:78–83.
16. Berryman Z, Bridger L, Hussaini HM, et al. Titanium particles: An emerging risk factor for peri-implant bone loss. Saudi Dent J 2020; 32:283–92.
17. Mints D, Elias C, Funkenbusch P, et al. Integrity of implant surface modifications after insertion. Int J Oral Maxillofac Implants 2014; 29:97–104.
18. Wennerberg A, Ide-Ektessabi A, Hatkamata S, et al. Titanium release from implants prepared with different surface roughness. Clin Oral Implants Res 2004; 15:505–12.
19. Chaturvedi T. Allergy related to dental implant and its clinical significance. Clin Cosmet Investig Dent 2013; 5:57–61.
20. Sicilia A, Cuesta S, Coma G, et al. Titanium allergy in dental implant patients: a clinical study on 1500 consecutive patients. Clin Oral Implants Res 2008; 19:823–35.
21. De Graaf NPJ, Feilzer AJ, Kleverlaan CJ, et al. A retrospective study on titanium sensitivity: Patch test materials and manifestations. Contact Dermatitis 2018; 79:85–90.
22. Hosoki M, Nishigawa K, Tajima T, et al. Cross-sectional observational study exploring clinical risk of titanium allergy caused by dental implants. J Prosthodont Res 2018; 62:426–31.
23. Wang B, Kumar S. Irritant reaction to titanium oxalate on preoperative patch testing before NUSS procedure. J Allergy Clin Immunol 2023; 51(2):AB151.
24. Bizjak M, Adamič K, Bajrovič N, et al. Patch testing with the European baseline series and 10 added allergens: Single-centre study of 748 patients. Contact Dermatitis 2022; 87(5):439–46.
25. Brasch J, Geier J, Gefeller O. Dynamic patterns of allergic patch test reactions to 10 European standard allergens. An analysis of data recorded by the Information Network of Departments of Dermatology (IVDK). Contact Dermatitis 1996; 35(1):17–22.
26. Bass JK, Fine H, Cisneros GJ. Nickel hypersensitivity in the orthodontic patient. Am J Orthod Dentofacial Orthop 1993; 103:280–5.
27. Goutam M, Giriyapura C, Mishra SK, et al. Titanium allergy: a literature review. Indian J Dermatol 2014; 59(6):630.