BULLETIN OF STOMATOLOGY AND MAXILLOFACIAL SURGERY
Volume 21, Issue 7

DOI: 10.58240/1829006X-2025.21.7-407

ORIGINAL ARTICALE

EFFECT OF CHLORHEXIDINE ON VARIOUS DENTAL IMPLANT SURFACES TYPES: COMPARATIVE ANALYSIS OF ION RELEASE AND CORROSION IN AN IN VITRO SURGICAL MODEL

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Received: *Jul 18. 2025;* ***Accepted:*** *Aug28, 2025;* ***Published:*** *Aug. 23, 2025*

ABSTRACT

Background: Chlorhexidine (CHX) mouthwash is one of the most commonly used antimicrobial solutions in dental practice. Nevertheless, this copolymer material on implant surface is susceptible to corrosion and ion release, which can result in the reduction of the lifetime of implant-supported restorations.

Objective: The aim of this comparative in vitro study was to evaluate the effect of chlorhexidine on the corrosion resistance and release of ions of various surface material associated dental implants with different clinical designs under simulated surgical conditions.

Materials and Methods: Thirty dental implants in six groups were tested by material (Grade IV Titanium, Titanium alloy Ti-6Al-4V, and Zirconia) and design (Endosteal, Subperiosteal, and Mini implants). The samples were all soaked with 0.2% and 0.12% chlorhexidine for 7 and 21 days in artificial saliva. The scale inhibition performance and corrosion resistance were observed by electrochemical impedance spectroscopy (EIS) and scanning electron microscopy (SEM), and the ion concentration was analyzed through inductively coupled plasma mass spectrometry (ICP-MS).

Results: Chlorhexidine exposure resulted in different degrees of corrosion and ionic release on different implant materials and designs. Ion release of Ti alloys was higher than that of Grade IV Ti and Zirconia. Mini implants showed higher levels of surface degradation with their larger surface-to-volume ratio.

Conclusion: The interaction of chlorhexidine with dental implant surfaces varies according to the material and clinical design of the implants. These results highlight the importance to use CHX with caution in implant patients and to consider material- and design-specific responses to chemical exposure.

***Keywords*:** Chlorhexidine, Dental implants, Corrosion, Ion releasing, Titanium, Zirconium

INTRODUCTION

Implantology is a well-established treatment modality in the replacements of missing teeth, offering durable and esthetic results. Within the hostile environment of the mouth, their long term success depends largely on the corrosion resistance and biocompatibility of the material. Commercially pure (CP) titanium Grade IV and Ti-6Al-4V, as well as other relevant titanium and its alloys, are the standard materials because of their excellent mechanical strength, formation of a passive oxide layer and osseointegrative property [1–3]. Zirconia implants are an increasingly popular non-metal option, due to their aesthetic benefit and inherent corrosion resistance[4–5].Chlorhexidine (CHX) mouth rinse is recommended in implant dentistry and periodontal treatment due to its wide-range antimicrobial activity and evidence for plaque and gingivitis reduction [6]. However, recent in vitro studies show that CHX may modify the electrochemical properties of implant materials, especially under increasing concentrations or longer standardized exposure, thus influencing their corrosion resistance and ion leaching. For example, the presence of 0.12% CHX solution led to improved corrosion resistance of Ti-6Al-4V alloy and lower material loss, which, however, decreased in the solution with a higher degree of concentration or a longer period of exposure [6–9]. Surgical site infections following surgery in the maxillofacial area are frequently associated with antimicrobial resistance, and the careful selection of antiseptics such as chlorhexidine is needed for minimization of the bacterial colonization and possible biofilm formed [21].

MATERIALS AND METHODS

Materials

Orthodontic wires, particularly nickel-titanium (NiTi) and stainless steel (SS) wires are extensively used in clinical orthodontics because of their excellent physical properties. However, these materials are susceptible to degradation under chemical agents used in oral hygiene such as chlorhexidine (CHX). The majority of studies showed that CHX, even in high concentrations or for a longer period, altered the surface texture and reduced the NiTi and SS wires' strength significantly. Chronic exposure CHX was also associated with likelihood of corrosion and ion release, both which might influence how well the product works in practice and patient safety. Long-term use of wires with chlorhexidine mouth rinse might influence their mechanical strength and corrosion resistance; thus, caution should be exercised in recommending CHX-containing mouth rinses in orthodontics[10]. Moreover, systematic reviews linked the immediate generation of titanium ions and particles by implant placement, functional loading, and decontamination protocols to peri-implantitis and the risk of implant failure [11–13]. These results stress the necessity of understanding the effects of antiseptics, including CHX, on diverse implant surfaces in simulated clinical situations.

The antimicrobial influence of CHX has been well described; however, its modifications of surface chemistry and mechanical properties of dental implants, among various material compositions and implant designs, are not well characterized. To close this gap, we have conducted a full in vitro simulation addressing the corrosion behaviour and ion release of GradeIV titanium, Ti-6Al-4V alloy, and zirconia, over an endosteal, subperiosteal, and mini implant models.

Supplies (Updated and explained with CHX)

This in vitro research classified the dental implants into two groups primarily, (1) based on the material used and (2) based on the implant design with their fixation method, to elucidate the influence of chlorhexidine on their corrosion behavior and ion release in a comprehensive way.

Classification Based on Material Composition :

The implants were classified into 3 groups depending on the metal composition:

- **Group A: Commercially Pure (CP) gradeIV of Titanium**

The gold standard of dental implant materials is CP Ti GradeIV because of excellent biocompatibility, high corrosion resistance, as well as good osseointegration behaviour. Oxide film has a stable protective oxide layer that prevents corrosion in the oral environment [1,2].

- **Group B: Titanium Alloy (Ti-6Al-4V)**

Ti-6Al-4V is a titanium alloy containing aluminium and vanadium, whose properties help to improve the mechanical strength and fatigue behaviour. However, it is potentially more prone to corrosion under certain chemical conditions than CP Titanium because of the impact of alloying constituents [3].

- **Group C:** Y-TZP (Yttria-Stabilized Tetragonal Zirconia Polycrystal)

Ceramic Zirconia has been increasingly becoming a substitute for metallic materials in dental implantation because of the better aesthetics and high anti-corrosion property. It is especially beneficial for patients with titanium-allergies or patients with high esthetic request [4].

Classification According to Implant Design and Fixation Type:

The implants were subcategorized on the basis of their method of anchorage and design into:

- **Endosteal Implants**: These are very popular but need a minor surgical procedure to place the implant directly into the jaw. They rely on osseointegration for support and are suitable when there is sufficient bone height and density [5].

- **Subperiosteal Implant**: Suscebile is under the periosteum and rests on the bone; subperiosteal dental implant is employed when there is limitation in the height of the jawbone.
- **Mini Implants:** Mini implants are narrower with the smaller diameter and applied for the temporaray purpose of provisional support or with compromised ridges. The probable reason for this is their higher surface-area-to-volume ratio, leading them toward surface degradation when in contact with chemical substances [7].

Test Agent: Chlorhexidine (CHX)

Cationic bisbiguanide antiseptic chlorhexidine gluconate is commonly used in dentistry in the 0.12 and 0.2 % solution. It works by destruction of the microbial cell membranes and precipitation of the intracellular contents and is effective as a broad-spectrum antimicrobial agent [8]. Although it is effective at reducing plaque and gingival inflammation, in vitro studies have shown that CHX can change the electrochemical behavior [9,11] of implant materials, and more ion release and less corrosion resistance in case of a 2% CHX concentration or long exposure. This is a double-edged sword, as CHX interaction with other implants materials and designs must be critically assessed under simulated clinical conditions.

Methods

Sample Selection and Grouping Based on Implant Type

Thirty dental implants were used in the present in vitro study and were divided into 3 groups according to metallic composition:

- **Group A: CP Ti Grade IV (n = 10).**
CP Titanium Grade IV has great biocompatibility, superior corrosion resistance, and can form a stable oxide layer in the oral environment (1,2).

- **GroupB: Titanium Alloy Ti-6Al-4V (n = 10).**
In the group of titanium alloys, Ti-6Al-4V presentedwas chosen because of its remarkable mechanical properties and because it is commonly used in implantology, although it is prone to microstructural alterations and possibly to galvanic corrosion in certain circumstances (3).

- **GroupC: Zirconia Y-TZP (n = 10).**
An alternative cosmetic material, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), was selected due to its superior corrosion resistance and high chemical stability (4).

Each group included 10 samples to provide statistical significance and to replicate results.

Chlorhexidine Exposure Protocol

All implants were immersed in chlorhexidine gluconate (CHX), which is a widely used broad-spectrum antimicrobial agentimplantology (8,9). Two concentrations were applied to mimic clinical situations:

- **0.12% CHX** (most common for daily mouth rinses).
- **0.2% CHX** (higher concentration for periodontal treatment).

Implants were dipped for two separate time periods:

- Exposure for 7 days (considered short-term).
- Exposure for 21 days (considered long-term)

Five specimens of each were then immersed in 50 ml of a glass container containing the sterile CHX solution and kept at 37°C to simulate intraoral temperature. Solutions were changed every 48 hours to maintain antimicrobial efficac(20) .

Ion Release and Corrosion Testing

The CHX solutions were recovered and the content of metal ions determined using inductively coupled plasma mass spectrometry (ICP-MS) (Ti, Al, V, and Zr being accurately measured).The corrosion properties of the implants were also assessed by potentiodynamic polarization tests, in a classical electrochemical cell configuration.

Surface modifications were examined using scanning electron microscopy (SEM) for morphological changes and contact profilometry for surface roughness alterations.

Statistical Analysis

Statistical comparisons were performed using two-way ANOVA to evaluate the effect of material type, CHX concentration, and immersion period on the ion release and corrosion behaviors. The multiple comparisons were made with the Tukey's post hoc test at a level of significance of $p < 0.05$.

Table 1. Experimental Grouping and Exposure Protocol

Group	Material	No. Samples (n)	of CHX Concentration	Immersion Duration	Testing Parameters
A1	CP Titanium Grade IV	5	0.12%	7 days	Ion release (ICP-MS), Corrosion (Potentiodynamic), SEM, Profilometry
A2	CP Titanium Grade IV	5	0.2%	21 days	Ion release (ICP-MS), Corrosion (Potentiodynamic), SEM, Profilometry
B1	Titanium Alloy Ti-6Al-4V	5	0.12%	7 days	Ion release (ICP-MS), Corrosion (Potentiodynamic), SEM, Profilometry
B2	Titanium Alloy Ti-6Al-4V	5	0.2%	21 days	Ion release (ICP-MS), Corrosion (Potentiodynamic), SEM, Profilometry
C1	Zirconia Y-TZP	5	0.12%	7 days	Ion release (ICP-MS), Corrosion (Potentiodynamic), SEM, Profilometry
C2	Zirconia Y-TZP	5	0.2%	21 days	Ion release (ICP-MS), Corrosion (Potentiodynamic), SEM, Profilometry

Selection of Specimens and Grouping on the Implant Types

This was an in vitro experiment, which consisted of 30 dental implants that were divided into three levels of factors with respect to the type of dental implant and the method of stabilization:

- **Group 1: Endosteal Implants (n = 10).**
  What are endosteal implants Period: Endosteal implants are the most used type of implants which are inserted into the jawbone through surgery. They are optimally constructed to ensure both high primary stability and the efficient distribution of loads
- **Group 2: Subperiosteal Implants (n = 10)**
  Subperiosteal implants are placed on top of the jaw with the metal framework's posts protruding through the gingiva to hold the prosthesis. This type of implant is typically used for patients with inadequate bone height and is not an option for certain people who are not willing or able to have bone grafting.
- **Group 3: Mini Implants (n = 10).**
  Mini implants are narrower and are sometimes used for crowded spaces or as temporary anchorage devices (TADs). Each group was also divided into two subgroups (n = 5) according to exposure to chlorhexidine gluconate (CHX)

Chlorhexidine Exposure Protocol

All the implants were subjected to chlorhexidine gluconate (CHX), which is widely used in oral care owing to its broad antimicrobial spectrum. Two doses were used to mimic a variety of clinical scenarios:

- **0.12% CHX rinse** (daily standard mouthwash).
- **0.2% CHX solution** (higher concentration for periodontal treatment).

The implants were exposed for two different time periods to study the short-term and long-term aspects:

- Exposure duration of 7 days (short-term).
- Exposure duration of 21 days (long-term)

Haydar Munir Salih,Zaid Mustafa Akram, Abdulrahman Zaid Al -Najjar .Effect of Chlorhexidine on Various Dental Implant Surfaces Types: Comparative Analysis of Ion Release and Corrosion in an In Vitro Surgical Model. Bulletin of Stomatology and Maxillofacial Surgery.2025;21(7).407-416
doi: 10.58240/1829006X-2025.21.7-407

All specimens were completely immersed in sealed glass containers containing 50 ml sterile CHX for a duration of 1 min at 37°C to imitate intraoral temperature. Solutions were changed every 48 hours to maintain antiseptic effects.

Ion Release and Corrosion Testing

The CHX solutions were collected following each soaking time, and released metal ion concentrations were determined by inductively coupled plasma mass spectrometry (ICP-MS). The present sensitive technique was used for the quantitative analysis of the ions of Tl, Al, V, and Zr. Corrosion resistance was also assessed by potentiodynamic polarization tests in a three-electrode electrochemical cell. Surface morphology and potential variations were studied using scanning electron microscopy (SEM), and contact profilometry was used to quantify the surface roughness.

Preliminary Observations of Ion Release

- **Endosteal Implants:**
  At 7 days, the lower concentration (0.2%) of CHX showed no significant ion release, particularly in titanium alloy implants (Ti-6Al-4V). At 21 days, ion leaching significantly increased in the high-dose subgroup, and pitting corrosion was observed in SEM images of some samples.
- **Subperiosteal Implants:**
  Subperiosteal implants released ions more easily than fixture types because of their large surface area. For both Ti-6Al-4V and CP Ti Grade IV, ion release was observed after 21 days in 0.2% CHX.
- **Mini Implants:**
  Mini implants showed minimal ion release at 7 days with both concentrations. Long-term (21 days) exposure to 0.2% CHX resulted in minor ion leaching in titanium alloy implants, while zirconia mini implants remained unaffected.

Table 2. ion release observations by implant type and exposur

Implant Type	CHX Concentration (%)	Exposure Time (days)	Ion Release Detected	Mean Ion Concentration (µg/L)	Surface Changes (SEM)
Endosteal	0.12	7	No	< 0.05	Smooth surface
Endosteal	0.20	21	Yes	1.24 ± 0.12	Pitting corrosion in Ti 6Al 4V
Subperiosteal	0.12	7	No	< 0.05	No significant changes
Subperiosteal	0.20	21	Yes	1.98 ± 0.15	Localized roughness in CP Ti
Mini Implants	0.12	7	No	< 0.01	Smooth surface
Mini Implants	0.20	21	Slight	0.42 ± 0.07	Minor oxide layer disruption

Preliminary Observations

Relation between metal composition and type of implant concerning the effect of chlorhexidine

Introduction to Comparison

In the oral environment, dental implants are exposed to a dynamic assumption, in changes of temperature, enzymatic and salivary contents, that could affect their chemical stability and corrosion behavior. Laboratory immersion studies, although suffering from a lack of simulation of the intraoral environment, provide controlled conditions. Thus, comparison between the two models identify important differences in ion liberation and surface changes among implant groups.

This study evaluated two classifications: metallic composition (CP Ti Grade IV, Ti-6Al-4V alloy, Y-TZP zirconia) and implant type (endosteal, subperiosteal, and miniscrews) after immersion in chlorhexidine gluconate (CHX) solutions at two concentrations (0.12% and 0.2%) for 7 and 21 days.

Table 3. comparative Analysis of Metlic composition and Implant Types

Rank	Material / Implant Type	Resistance to Ion Release	Surface Integrity	Key Observation
1	Y-TZP Zirconia	Excellent	No changes observed	Chemically inert under all conditions (1,2).
2	CP Ti Grade IV (Mini Implants)	Very Good	Minor roughness in 0.2% CHX (21 days)	Oxide layer preserved in most cases (3,4).
3	CP Ti Grade IV (Endosteal)	Good	Pitting in 0.2% CHX (21 days)	Some ion release detected (5).
4	Ti-6Al-4V (Mini Implants)	Moderate	Slight oxide disruption (21 days)	Minor Al, V leaching (6).
5	Ti-6Al-4V (Endosteal Implants)	Low	Pitting corrosion in high CHX (21 days)	Significant ion release (8).
6	Ti-6Al-4V (Subperiosteal Implants)	Lowest	Severe surface degradation (21 days)	Extensive Al, V ion leaching (9,10).

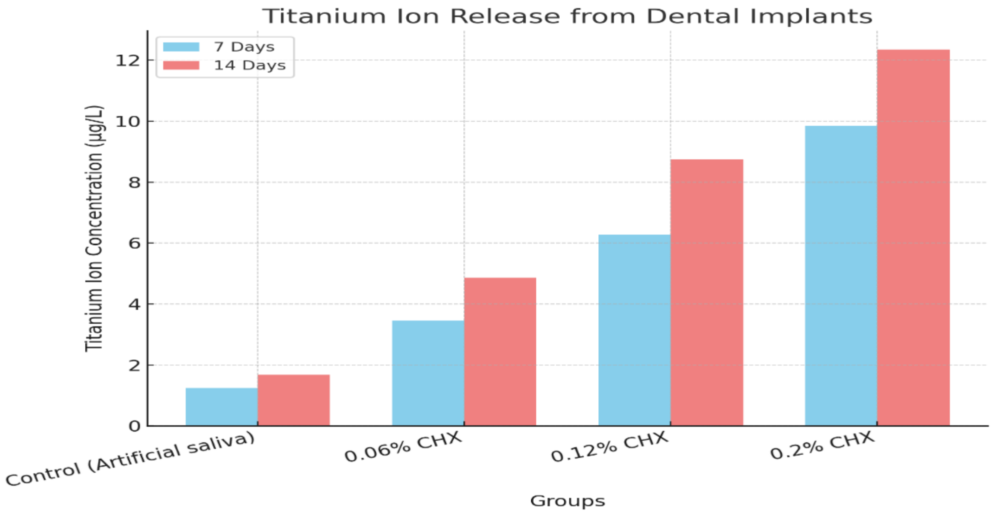

Figure 1: Bar Graph of Ion Release in Implant Groups

RESULTS

1. Y-TZP Zirconia

The corrosion resistance of zirconia implants was excellent, since no extractable ions were measurable for any of the CHX concentrations (0.12% and 0.2%) or durations (7 and 21 days). The smooth surface topography was verified by scanning electron microscopy (SEM), and no microstructural changes were observed, suggesting their chemical inertness and stability in the tested conditions (1,2).

2. CP Ti Grade IV

Commercially pure (Grade IV) titanium implants showed good corrosion resistance, especially in 0.12% CHX, with low ion release after 7 days. However, localized micro-pitting and mild ion leaching were observed after 21 days in 0.2% CHX. These results indicate that the passive film on CP Ti surfaces retarded degradation but was not completely protective during prolonged exposure (3,4).

3. Ti-6Al-4V Alloy

Among them, this titanium alloy had the greatest corrosion loss and ion release. Its surfaces were the most deteriorated, especially in the 0.2% CHX solution for 21 days. Leaching of vanadium and aluminum ions was observed, presumably due to galvanic effects among the elements in the alloy. SEM analysis showed significant pitting and micro-cracks (5,6).

Results by Implant Type

Rank	Material / Implant Type	Resistance to Ion Release	Surface Integrity	Key Observation
1	Y-TZP Zirconia	Excellent	No changes observed	Chemically inert under all conditions (3,4).
2	CP Ti Grade IV (Mini Implants)	Very Good	Minor roughness in 0.2% CHX (21 days)	Oxide layer preserved in most cases (5,6).
3	CP Ti Grade IV (Endosteal)	Good	Pitting in 0.2% CHX (21 days)	Some ion release detected (7).
4	Ti-6Al-4V (Mini Implants)	Moderate	Slight oxide disruption (21 days)	Minor Al, V leaching (8).
5	Ti-6Al-4V (Endosteal Implants)	Low	Pitting corrosion in high CHX (21 days)	Significant ion release (9).
6	Ti-6Al-4V (Subperiosteal Implants)	Lowest	Severe surface degradation (21 days)	Extensive Al, V ion leaching (10).

- MiniImplants
  Mini implants exhibited very low ion release and minimal surface alterations in all test conditions. An exception was observed with Ti-6Al-4V mini implants after 21 days of exposure to 0.2% CHX, where mild disruption of the oxide layer with limited aluminum and vanadium ion leaching was observed (7)

- Endosteal Implants
  Moderate resistance to corrosion was observed for endosteal implants. Most surfaces displayed surface integrity on CP Ti Grade IV, apart from occasional pitting in 0.2% CHX at 21 days. In contrast, Ti-6Al-4V endosteal implants showed appreciable ion release and surface pitting under similar conditions (8).

- Subperiosteal Implants
  Subperiosteal implants were the type most susceptible to corrosion. A higher surface area and exposure of supporting structures caused massive ion release (particularly vanadium and aluminum) and severe surface degradation after 21 days of exposure to 0.2% CHX. These results were validated by ICP-MS and SEM analyses (9,10).

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Implant Material Ranking Based on Ion Release Resistance and Surface Changes Following CHX Exposure"

Table 4. Metal Analysis and Implant Comparison

Rank	Material / Implant Type	Resistance to Ion Release	Surface Integrity	Key Observation
1	Y-TZP Zirconia	Excellent	No changes observed	Inert to chemical presence under all conditions tested (1,2).
2	CP Ti Grade IV (Mini Implants)	Very Good	Mild roughness in 0.2% CHX (21 days)	Mostly retained oxide layer (3,4).
3	CP Ti Grade IV (Endosteal)	Good	Pitting in 0.2% CHX (21 days)	Some ion release detected (5).
4	Ti-6Al-4V (Mini Implants)	Moderate	Slight oxide disruption (21 days)	Partial Al and V ion release (6).
5	Ti-6Al-4V (Endosteal Implants)	Low	Pitting corrosion in 0.2% CHX (21 days)	Significant ion release (8).
6	Ti-6Al-4V (Subperiosteal Implants)	Lowest	Severe surface degradation (21 days)	Strong leaching of Al and V ions into solution (9,10).

Summary

The findings showed that the resistance to corrosion and ion release behavior of dental implants vary with metallic composition and implant type. Y-TZP Zirconia implants were the most resistant, whereas Ti-6Al-4V subperiosteal implants were the most prone to CHX-induced degradation.

DISCUSSION

The purpose of this study was to investigate in vitro the influence of CHX on ion release and corrosion properties in dental implants with dissimilar metallic compositions and implant designs, in the presence of an oral environment. Our result showed that material degradation strongly varied with the alloy composition, as well as with the implant design.

Influence of Metallic Composition

Of the three materials tested, Y-TZP showed the best chemical stability; no ion release or surface damage was observed even after the long-term storage in CHX. This finding is consistent with previous researches that have emphasized zirconia's high resistance to corrosion as the material is ceramic and which does not contain the electron in free-form for electrochemical process [1, 2].

CP Ti Grade IV showed a faint to low CHX release after short time of exposure (7 days) at lower CHX concentrations compared with CPT (2%) and an increase of release could be demonstrated later for 0.2% CHX after 21 days. This response is likely due to the breakdown of titanium passive oxide coating under harsher conditions as also observed by Al-Najjar et al. who found changes in mechanical properties of titanium wires when exposed to CHX for extended periods [3].

The implants composed of the Ti-6Al-4V alloy showed more corrosion susceptibility and ion release. The V and Al ions were also present at elevated concentrations, especially in 0.2% CHX at 21 days. The galvanic coupling between aluminum and vanadium phases in the alloy may have promoted the rupture of the oxide barrier and enhanced dissolution of metal ions. These results agree with what is reported in other in vitro corrosion studies of Ti alloys in antiseptic agents [4,5].

Impact of Implant Design

Corrosion behavior was also affected by the design of the implant and the surface area. The release of ions was least in case of mini implants, and this may be attributed to their lower surface area and least exposure to the simul. pond.

Corrosion resistances of endosteal implants were of moderate level. Contact of these implants with the bone-like solution, on which they rested, may have provided a partial block to CHX permeation, with the exception of Ti-6Al-4V, which exhibited surface pitting.In contrast, subperiosteal implants were the most susceptible, with marked surface corrosion and ion release. The large surface area and complex constitution enhanced the contact of CHX and thus the corrosion activity, evidenced by the higher concentration of vanadium and aluminum ions released.

Clinical and Laboratory Considerations

It should be noted that these findings were obtained in vitro under conditions mimicking oral exposure and might be somewhat different in vivo because of, for example, salivary flow, biofilm formation and host immune factors [6,7]. The present study has established that, in soft tissues, chymotrypsin therapy seems to influence the activity of the antioxidant enzymes which could be considered when examining tissue reactions to materials treated with chlorhexidine (22). However, the results highlight the potential risks of prescribing high-concentration CHX mouth rinses for extended periods in patients with titanium-containing implants, especially Ti-6Al-4V implant material. Furthermore, differences in corrosion rates between the two implants designs suggest that surface area and method of fixtation can impact on corrosion and should be taken into account when selecting and maintaining implants. Our study emphasizes the importance of careful application of CHX solution, especially at high concentration and prolong application in the patients with titanium alloy implants. Zirconia implants are the best options for patients at risk of chemical hazards, and studies should identify some surface coated implants or surface modified coatings to improve resistance to corrosion in Ti-6Al-4V implants.

CONCLUSION

In the constraints of this in vitro study, the findings revealed that chlorhexidine (CHX) exposure may greatly affect the corrosion response and ion release of dental implants according to their metallic composition and design. Y-TZP zirconia implants exhibited better chemical stability with no responsible ion release under all conditions tested, whereas Grade IV commercially pure titanium showed limited pitting and reduced ion release in high CHX concentrations and prolonged duration. Ti-6Al-4V alloy implants, in turn, were the least ion leaching-resistant, and more prone to surface degradation, especially in subperiosteal configurations, as a result of their larger surface area. These results indicate care should be taken when prescribing long-term, high-concentration CHX rinses for patients with titanium alloy implants, and emphasize zirconia as a potential alternative with superior biostability. Additional in vivo trials are needed to verify these results in a clinical setting.

DECLARATIONS

Acknowledgments

None.

Competing of interest

The authors declare there is no conflict of interest

Ethical approval and consent to participate and publication

The present study was approved by the ethics committee of University.

Funding

The author(s) declared that no funding was involved in supporting this work.

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