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Effect of Fluorides on the Corrosion Properties of Titanium Mini-Implants: A Systematic Review

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Abstract

Objective: This systematic review plans to evaluate the effects of fluoride ions on the corrosion properties of titanium mini-implants.

Background: Mini-implants are broadly used in orthodontics as an alternative to traditional intraoral anchorage. They comprise of Ti-6Al-4V with a passive oxide film of titanium dioxide for high corrosion resistance properties. To maintain oral hygiene orthodontic patients are often prescribed fluoride mouth rinses, toothpastes, etc, which might affect the corrosion resistance properties of mini-implants.

Materials and methods: A literature search by means of proper MeSH terms and PICO format was done using the following databases: Google Scholar, PubMed, and EBSCO HOST. The following studies will be included- Randomized Controlled Trials, Observational studies, In-vivo studies, In-vitro studies, Clinical studies, and Human studies on the corrosion of titanium mini-implants subjected to fluorides. Exclusion criteria included surveys and questionnaire-based studies, review letters, personal opinions, book chapters, and conference abstracts.

Results: A total of 134 articles were obtained, and 5 were selected for inclusion in the review. Results showed that fluoride ions significantly dropped the corrosion resistance properties of titanium.

Conclusion: The acidic environment due to low pH and increase in the fluoride ion concentration seems to directly affect the corrosion resistance properties of titanium mini-implants, and attention must be paid while prescribing fluoride agents when titanium mini-screws are used.

Keywords: Temporary anchorage devices, Miniscrew, Fluoride, Corrosion

INTRODUCTION:

During the course of the orthodontic treatment, the patient is unaware of the consequences of negligence in terms of oral hygiene maintenance which can lead to plaque retention around the orthodontic appliances, the micro-organisms from this plaque colonize on the teeth reducing the oral pH, and can lead to demineralization of the enamel subsequently leading to opaque, white, chalky spots known as white spot lesions. These white spot lesions are one of the major adverse effects of orthodontic treatment [1-4].

To reduce the incidence of these white spot lesions; orthodontic patients are often prescribed fluoridated mouthwashes and toothpaste, these F- ions form an association with H+ ions in an aqueous solution and form hydrofluoric acid (HF) [5-8].

Presently, with an expansion of the envelope of discrepancy, Temporary anchorage devices are the most commonly used alternative to traditional intraoral/extraoral anchorage in patients [9]. Most of the commercially available mini-implant systems are made of pure titanium (Ti) or titanium alloys Ti-6Al-4V. Ti and titanium alloys exhibit superior biocompatibility, low thermal conductibility, high strength, low modulus of elasticity (MoE), re-passivation, and enhanced mechanical properties such as high fatigue resistance, fracture toughness, and corrosion resistance [9,10].

The corrosion resistance of Ti & Ti alloys is due to the formation of titanium dioxide (TiO_2), because of the presence of this passivating surface layer, corrosion resistance of titanium is much higher than that of stainless steel alloys [11].

Titanium in the mini-implant has shown a high chemical reactivity to hydrofluoric acid that results in corrosion depending on the exposure time, pH of the environment, and HF content. These fluoride ions form complexes with other ions present within the saliva on the mini-implant alloy surface and can aggressively remove the passive oxide layer formed by TiO_2 film on the mini-implants, consequently leading to the weakening of the passive oxide layer, causing corrosion and failure of the implant.

Corrosion can take place from the gradual deterioration of a metal due to interaction with the surrounding environment. The most common types of corrosion found in metallic implants are galvanic, fretting, pitting corrosion, and environmental-induced cracking (EIC), these conditions can lead to premature deterioration, and loosening of the implant leading to its failure [12,13].

Corrosion resistance is critical in orthodontics since corrosion can lead to surface roughness and reduction in strength of appliances leading to their mechanical failure and also leaching of ions from the alloy causing allergic reactions in the adjacent mucosa and may lead to peri-implantitis[14].

There has been no clear, concise literature regarding the reactivity of fluoride agents with titanium mini-implants concerning corrosion.

Hence this systematic review aims to analyse the effects of different fluoride mouthwashes on titanium for the signs of corrosion.

METHODOLOGY:

This systematic review protocol was registered at the International Prospective Register of Systematic Reviews (PROSPERO- CRD42022356752) and performed in accordance withthe Preferred Reporting Items for Systematic Reviews (PRISMA) checklist (Page MJ et al., 2020) [15].

SEARCH STRATEGY AND DATABASES:

An electronic search of PubMed (including MEDLINE), EBSCO Host database & Google Scholarsearch engine for articles published from 1st January 1990 to January 2023 was conducted.

PICO i.e., the Population Intervention Comparison Outcome format was used [16].

P: POPULATION -Mini implants that are subjected to fluoride and non-fluoride mouth rinses.

I: INTERVENTION-Mini implants that are subjected to fluoride mouth rinses.

C: COMPARISON-Mini implants that are subjected to non-fluoride solutions.

O: OUTCOME-Corrosion of Mini implants.

The following concept table was made on the basis of PICO criteria which includes the KEYWORDS using the PubMed database [Table 1].

PICO	POPULATION	INTERVENTION	COMPARISON	OUTCOME
Mesh terms	- Mini implants - Miniscrew - Temporary anchorage device - TAD - Titanium mini implants -Orthodontic implant	- Sodium Fluoride - Fluoride - Flouride mouth rinses - Fluoride mouthwash	-Amine Fluoride - Inorganic Fluoride -Organic Fluoride -Fluoride - Flouride mouth rinses - Fluoride mouthwash	- Corrosion - Corrosion resistance

Table 1- Keywords using pico format

SELECTION CRITERIA:

The selection was based on the following inclusion and exclusion criteria-

Inclusion criteria:

- Mini implants that are subjected to fluoride mouth rinses.
- Randomized Controlled Trials on mini-implants that are subjected to fluoride mouth rinses.
- Case-Control Studies on mini-implants that are subjected to fluoride mouth rinses.
- In-vivo Studies on mini-implants that are subjected to fluoride mouth rinses.
- In-vitro Studies on mini-implants that are subjected to fluoride mouth rinses.
- Clinical Studies on mini-implants that are subjected to fluoride mouth rinses.
- Human Studies.
- Articles published in the English language.

Exclusion criteria:

- Surveys and Questionnaire Based studies.
- Review letters, personal opinions, book chapters, and conference abstracts.
- Articles published in languages other than English.

STUDY SELECTION:

A total of 134 articles that were obtained through electronic searches were exported into the Mendeley Desktop software. There were 92 articles in Google Scholar search, 40 in PubMed, and 02 in Ebsco Host. The Mendeley Desktop software was used for the elimination of duplicate articles.

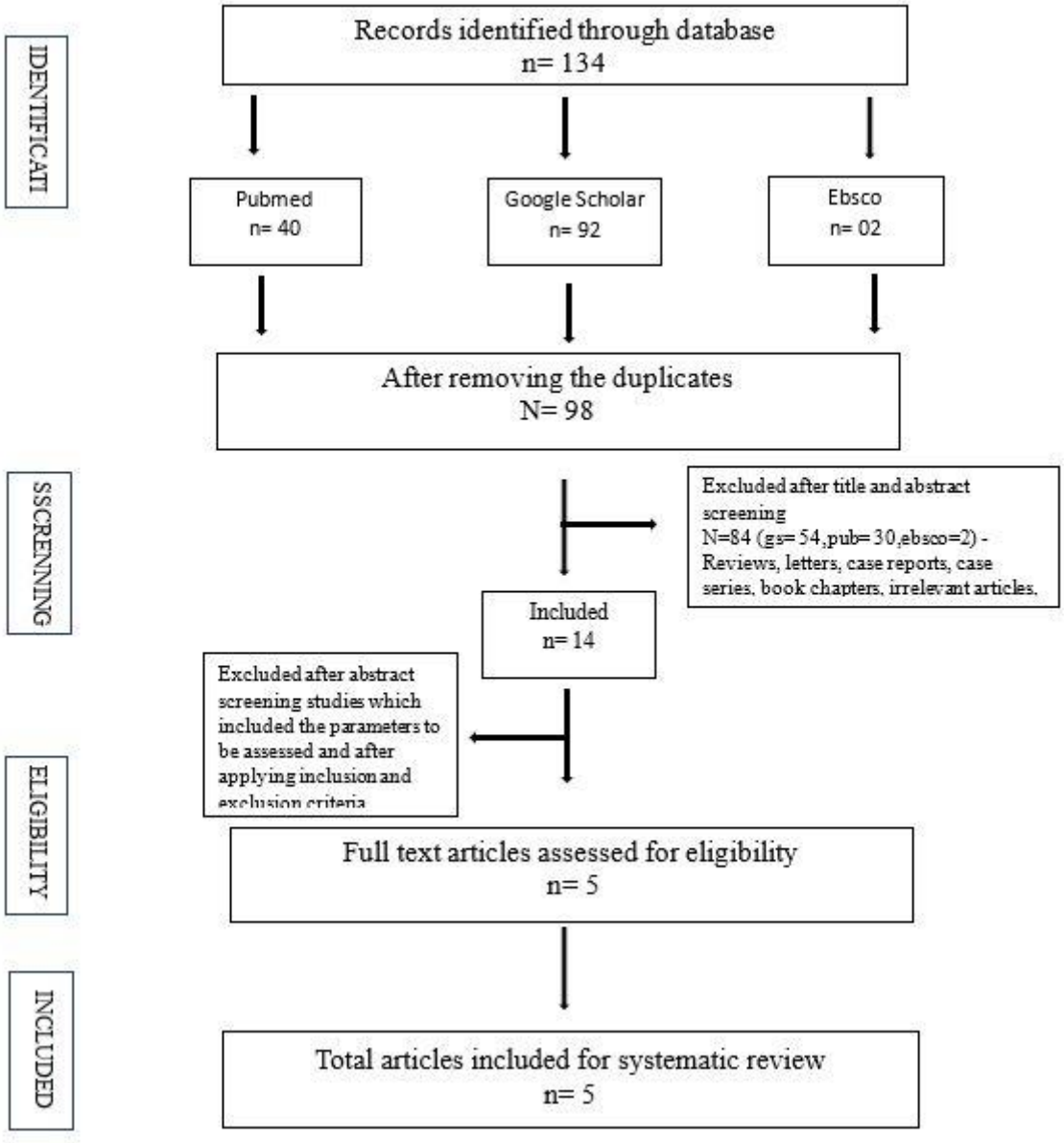
98 articles were left after the elimination of duplicates and were subsequently taken into further consideration for the data selection process.

Two calibrated reviewers independently screened the relevant titles of the studies found through the electronic search. In case of any doubt, the study was included for further screening in the next stage. Out of 98 articles, 14 articles were included after reading the title and abstract. Two calibrated reviewers now independently reviewed the full texts of the studies found relevant after the title and abstract screening. Only 5 articles met the inclusion and exclusion criteria and were thus included in this systematic review. The articles thus eliminated were either literature reviews, pilot studies, case reports, case series scoping

reviews, narrative reviews, or irrelevant articles. Discussion among reviewers was done if there were any disagreements. A third reviewer was called in for a final decision if any disagreement over article selection persisted between the two calibrated reviewers.

A descriptive summary of data selection has been put forth in the PRISMA Flowchart i.e. PRISMA Flow Diagram [Figure 1] [17].

Figure 1: Flow Diagram of literature search and selection criteria adapted from PRISMA (.Liberati A, Altman G, Tetzlaff J, Mulrow C, Gøtzsche C, Ioannidis P, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. Jour Clin Epidem. 2009 Oct 1;62(10):1-34.



RESULTS:

DATA EXTRACTION AND ANALYSIS:

- A customized data form was prepared which included the Author's Name/Year of publication, Study design/Methodology, samples and groups tested, the fluoride agent used, the methodology used to test corrosion resistance, and their inferences [Table 2]. To eliminate subjective bias, two independent observers were employed to study the articles and fill out the forms. The final form was based on consensus opinion.
- To assess the methodological quality and applicability of the included studies, the quality assessment tool for diagnostic accuracy studies (QUIN) was applied [Table 3].

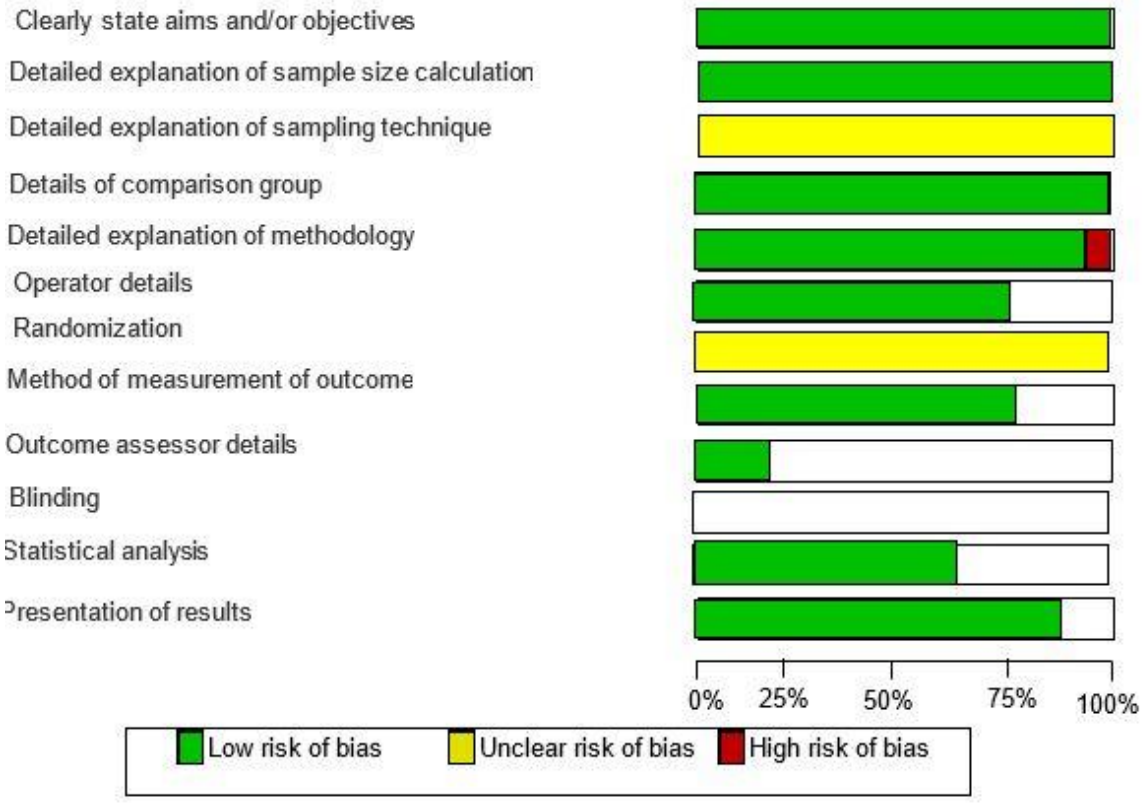
Table 2: Characteristics of the studies included in the qualitative analysis

Sr. No.	Author (Year)	Sample Size and Groups	Fluoride agent used	Corrosion test	Results and Conclusion
1.	Gui-Yue Huang.,2017	-25 titanium alloy (Ti-6Al-4V) circular plates were used. -n=5 plates each group	A - Listerine Natural Green Tea, pH 4.46/260 ppm fluoride B - Listerine Teeth &Gum Defence pH 4.41/178 ppm fluoride C-Garglin Regular Solution, pH 6.30/117 ppm fluoride D-Listerine Tartar Control, pH 4.17/3.92 ppm fluoride E- Saline as Control	-Corrosion test-Open-circuit potential (OCP) and potentiodynamic polarization test were done. -Surface analysis by field-emission scanning electron microscope (FE-SEM)	-Solution A showed maximum corrosion due to highest amount of fluorides and solution D, the least of all. -FE-SEM showed defects, crevices and pitting after exposure to the fluoridated mouthwashes. -They concluded that a low pH and high fluoride concentration may reduce the corrosion resistance of titanium miniscrews.

2.	Kevin Knutson,2012	Three miniscrew products A-(VectorTAS; Ormco) B-Unitek TAD; 3M C-Through-Hole Screw; American Orthodontics - Sample Size: 30 (n=10/miniscrew/solution)	A-Fusayama-Meyer artificial saliva with NaF (1500 ppm F) B-Fusayama-Meyer artificial saliva without fluoride	- (OCP), polarization resistance (Rp), and corrosion current (Icorr).	-OCP, polarization resistance was significantly decreased and increase in the corrosion current of the miniscrews was seen due to exposure to fluoride ions affecting the integrity of the surface passive layer.
3.	Carllin Kuriakose,2021	Three miniscrew products A- (Absoanchor) B- (SK Ti implant) C- (JSV Miniscrews) - Sample Size:90 (n=30/miniscrew/solution)	A-Artificial saliva with NaF (1500 ppm F) B-Artificial saliva without fluoride	- Three cell electrochemical testing unit for corrosion was done. - Surface analysis by (SEM)	- Higher corrosion resistance was seen by the Absoanchor group than SK Ti implant and JSV miniscrews. - Artificial saliva solution containing fluoride ions showed significant drop in corrosion resistance properties in all the three groups.
4.	Manish Goutam,2022	Samples size – 40 A- Pure titanium B- Ti–6Al–4V	A-Artificial saliva with NaF (0.25%) B-Artificial saliva without fluoride	- Electrochemical cell used - Ecorr/V and J corr/V calculated.	-($P < 0.05$) signification for both the groups was seen. -Fluoride ions significantly affected the titanium implants in terms of corrosion.

5.	Nakagawa Masaharu,2001	Four Groups of Titanium A- CP Ti B -Ti-6Al-4V C -Ti-6Al-7Nb D -Ti-0.2Pd	A- 0.05 NaF B- 2.0% NaF	- Anodic polarization test. -Corrosion potential measurements. - Dissolved Ti analysis was done by inductively coupled plasma mass spectroscopy. - Surface analysis by XPS.	-In their study the corrosion resistance of Ti 0.2Pd alloy was greater than those of pure Ti, Ti-6Al-4V and Ti-6Al-7Nb alloys in the wide range of fluoride concentration and pH. According to their study the Ti-0.2Pd alloy maybe expected to be useful as a new Ti alloy with high corrosion resistance with fluoride mouthrinses.

Risk of bias assessment graph.



Risk of bias assessment summary.

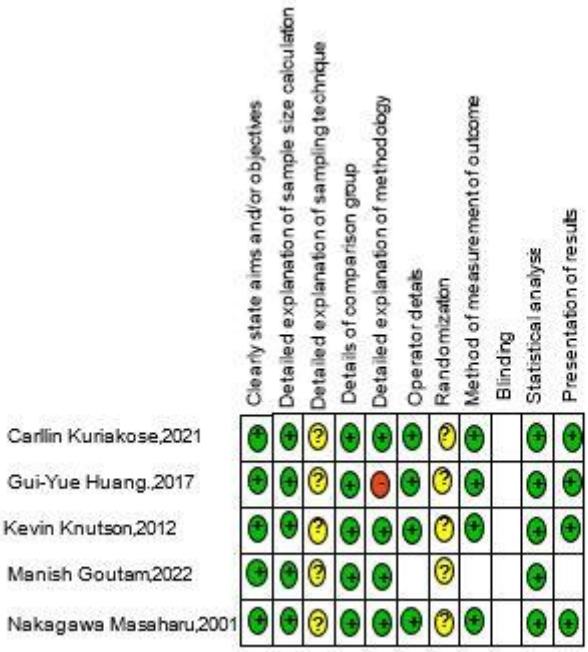


Table 3: Assessment of risk of bias of observational studies

AUTHOR	DOMAIN- REFERENCE STANDARD										
	state aims/ objectives Clearly	Detailed explanation of sample size calculation	Detailed explanation of sampling technique	Details of comparison group	Detailed methodology	Operator details	Randomization	Measurement of outcome	Blinding	Statistical analysis	Results
Carllin Kuriakose	Low risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk	Low risk	Unclear risk	Low risk	Low risk
Gui-Yue Huang	Low risk	Low risk	Unclear risk	Low risk	High risk	Low risk	Unclear risk	Low risk	Unclear risk	Low risk	Low risk
Kevin Knutson	Low risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk	Low risk	Unclear risk	Low risk	Low risk
Manish Goutam	Low risk	Low risk	Unclear risk	Low risk	Low risk		Unclear risk		Unclear risk	Low risk	

Nakagawa Masaharu	Low risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk	Low risk	Unclear risk	Low risk	Low risk

DISCUSSION:

Stable anchorage is an important factor in the success of orthodontic treatment. Temporary anchorage devices (TADs) are widely used as an alternative to traditional intraoral anchorage to facilitate various types of orthodontic tooth movement.

All of the studies that were analyzed showed that fluoride did cause corrosion of titanium and Ti–6Al–4V alloys.

According to Gui-Yue Huang's study, solutions A and B which had higher concentrations of fluorides of 260 ppm and 178 ppm showed a decrease in the OCP values of the titanium alloy, especially in solution A as compared to solutions C and D which had low concentration of fluorides 117 ppm and 3.92 ppm. A decrease in the OCP values of the titanium revealed an increase in its chemical reactivity, which might lead to corrosion. Also, after a stable passive current plateau occurred, E_{corr}, R_{corr} and the current density values in solutions A, B, and C decreased in sequential order, as the fluoride concentration increased. Greater dissolution of metallic ions occurred as the current density, $E_{corr,}$ and R_{corr} values increased.

The study found that a decrease in the corrosion resistance of titanium or titanium alloys was more significant in a solution containing a greater concentration of fluoride at the same pH, more dissolution of metal ions was seen with a greater concentration of fluorides.

Knutson et al in their study observed that there was no significant difference seen apart from OCP values as the composition of the mini-screws (Ti-6Al-4V) was the same for all the manufacturing companies. However, a more stable passive layer was seen in the Ormco and American Orthodontics miniscrew groups as compared to Unitek miniscrew group. A greater corrosion rate is generally seen as the stability of the passive layer decreases. An increase in the corrosion current was seen, when the mini-screws were placed in fluoride-containing solutions, suggesting a significant release of ions.

Carllin Kuriakose et al evaluated (OCP) values in artificial saliva medium which suggested that Absoanchor miniscrew showed higher OCP values than S K implant and JSV miniscrews. Their study also concluded that a significant drop in corrosion resistance properties in all three groups of mini-screws was seen when immersed in an artificial saliva solution containing fluorides.

They also said that the composition of mini-screws, type of implant used, fluoride concentration in mouth rinses, paste, gels, etc., manufacturing defects of implants, and oral environmental conditions all these factors should be taken into consideration which can affect the corrosion properties of the mini-screws.

Manish Goutam et al studied that, the E_{corr}/V and J_{corr}/V values were significantly high for pure titanium and titanium alloys Ti–6Al–4V when immersed in artificial saliva containing 0.25%fluoride solutions suggesting that fluoride ions have a significant effect on the titanium implants with respect to corrosion.

Nakagawa Masaharu et al said that, when the fluoride concentrations are higher and the environment is acidic in nature, corrosion could easily occur. However, the study said that the corrosion resistance of the Ti-0.2Pd alloy was significantly greater than those of pure Ti, Ti-6Al-4V, and Ti-6Al-7Nb alloys and this new alloy may be used as an alternative when fluoride mouth rinses are prescribed.

Currently, there are no clinical studies or randomized controlled trials regarding the corrosion of mini-implants due to fluoride agents, and thorough investigation should be done before concluding as the characteristics of the oral environment are complex and difficult to replicate in any artificial saliva.

CONCLUSION:

The results of this systematic review showed that attention must be given while prescribing fluoride agents for orthodontic patients when mini-implants made up of titanium and its alloys are used. The acidic environment due to low pH and increased fluoride ion concentration is directly related to the corrosion of titanium mini-implants.

Higher concentrations of fluorides and low pH significantly reduce the corrosion resistance properties of titanium mini-implants and can lead to leaching out of metal ions from the corrosive products into the oral cavity and subsequently its mechanical failure.

ABBREVIATIONS:

TAD: Temporary Anchorage Device
Ti: Titanium
TiO_2: Titanium Dioxide
HF: Hydrofluoric Acid
OCP: Open-circuit potential
Icorr: Corrosion Current
FE-SEM: Field-emission scanning electron microscope
XPS: X-ray Photoelectron Spectroscopy
PICO: Population, Intervention, Comparison, Outcome
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PROTOCOL AND REGISTRATION:

PROSPERO database registration number- CRD42022356752

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DECLARATIONS:

- **Trial registration-** Not applicable
- Ethics approval and consent to participate – Not applicable
- Consent for publication- Not applicable
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