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Evaluation of the Efficiency of Surface-Treated Mini Screws in Space Closure Mechanics: A Three-Dimensional Perspective Study

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Abstract:
A total of 10 patients with excessively protruded upper anterior teeth were subjected to orthodontic treatment and subsequently divided into two equal groups: one group received sandblasted and acid-etched miniscrews, while the other group used titanium miniscrews. The miniscrews (MSs) with surface treatment and the smooth ones were placed between the maxillary second premolar and first molar at the mucogingival junction on both sides of each patient. A closed coil spring was extended from the head of the miniscrews to a hook secured onto the main arch wire between the maxillary lateral incisor and canine on both sides, applying a force of 250 g per side for the en-masse retraction of the upper anterior teeth. Cone Beam Computed Tomography (CBCT) scans were performed twice: prior to force application (CBCT 1) and six months later (CBCT 2). To assess the displacement of the mini-screws, the distances from the mini-screw head (HMS) and tail (TMS) to the coronal, sagittal, and axial planes were measured at both CBCT time points. ***Results:*** *There was a statistically significant difference in HMS displacement between titanium and Sand blasted and Acid etched groups in all three- dimensions (coronal, sagittal, axial). While no statically significant different was found in TMS displacement between titanium and Sand blasted and Acid etched groups in all three- dimensions (coronal, sagittal, axial).* ***Conclusions****: Miniscrews were displaced in the direction of orthodontic loading. The displacement was experienced in the movement of the head more than the tail of the miniscrews.*
Keywords*: Orthodontic miniscrew, Displacement, Sandblasted and Acid-Etched, Cone Beam Computed Tomography.*

1. INTRODUCTION

Orthodontic treatment is a transformative experience for many individuals, not just in terms of improving oral health, but also in enhancing appearance and boosting self-confidence. However, one ongoing challenge with traditional orthodontic care is the extended treatment timeline, which can be challenging for both patients and practitioners. Over the past few decades, anchorage support has relied on intraoral (teeth) and intramaxillary appliances. Nevertheless, these treatment methods may not be effective in providing sufficient anchorage control.[5]

The stability of mini-implants (MIs) is crucial for successful orthodontic treatment, particularly when they are placed in the inter-radicular areas between tooth roots and subjected to long-term loading. This stability is essential to prevent displacement, which could potentially affect vital structures such as nerves or neighboring roots, and may necessitate a mid-treatment adjustment in the positioning of the MIs.[7]

Miniscrews serve both light and continuous (orthodontic) force applications and heavy dynamic and rotational (orthopedic) force applications. As a result, it is crucial for them to maintain stability throughout the treatment process. Over the years, it has been demonstrated that a significant benefit of using miniscrews is their ability to minimize anchorage loss.[15]

While achieving primary stability is important during orthodontic loading, it alone is insufficient for maintaining clinical stability of the miniscrews. This is primarily due to the dynamic and rotational forces generated during treatment. Secondary stability comes from bone remodeling around the implant, which helps maintain the clinical stability of the screw over time. A key factor in this stability is called partial osseointegration, where direct structural and functional contact occurs between the bone and the implant surface. Treatments such as sandblasting or sandblasting followed by acid etching are common practices that remove contaminants and create a rougher surface. This texture promotes the attachment of osteoblasts to the implant surface, leading to better contact between bone and implant, and therefore greater clinical stability.[11]

Additionally, advancements in 3D reconstruction and visualization using CBCT imaging can provide orthodontists with comprehensive insights into the movement of mini-screws and teeth. By superimposing pretreatment and post-treatment CBCT data, orthodontists can accurately and reliably quantify the movement of mini-screws, providing a more precise understanding of treatment progress.[2,10]

From all the previously mentioned, the study of the Efficiency of Surface Treated Mini Screws in space closure mechanics was found to be a point of worthy investigation. Accordingly, this study was conducted to highlight this aim.

2. MATERIAL AND METHODS

Sample:

All patients in the sample were treated with miniscrews. ten patients were included in the study and divided into two groups; 5 assigned to each group, the titanium mini screw group and sandblasted and acid etched group.

The patient assigning was based on randomization to each group. They were randomly assigned to either group according to the order of referral with a randomization ratio of 1:1 by supervisor who did not know which course of treatment the following patient would receive.

These patients were selected from the outpatient clinic of the Orthodontics Department, Faculty of Dentistry, Minia University.

Ethical regulations:

- Ethical approval was obtained from the ethical committee at Faculty of Dentistry, Minia University.
- All patients signed an informed consent describing the research steps.
- All Cone Beam Computed Tomography (CBCT) scans were coded by numbers to mask patient names.

Inclusion criteria:

Patients that were included in the study should follow these criteria:

- Being in good physical health and free from systemic diseases.
- Fair intraoral conditions.
- Adult Patients from 20-35 years old.
- whose treatment plan included the use of orthodontic miniscrews bilaterally between the upper first permanent molar and the second premolar for enmasse retraction of the upper six anterior teeth with space closure requirements.

Exclusion criteria:

- The patients suffering from bone diseases like osteopetrosis or osteoporosis.
- cases where there was a high expectation of failure due to anatomical limitations such as pneumatization of the maxillary sinus.
- narrow Interradicular alveolar bone.

Establishing Anchorage:

Two miniscrews were symmetrically positioned on each side to serve the same purpose. These miniscrews acted as skeletal anchorage for en-masse retraction mechanics, facilitating the distal movement of anterior teeth.

Force application:

The upper six anterior teeth were securely ligated to a 19 × 25 stainless steel wire using a soft stainless steel ligature wire (0.010 inches). Six weeks after placement, a continuous traction force of approximately 250 g was applied with a nickel-titanium (Ni-Ti) closed coil spring. The Ni-Ti closed coil spring was connected from the head of the miniscrew to a hook that was secured to the main arch wire between the maxillary lateral incisor and canine on both sides (Figure 1). A continuous retraction force of 250 g was applied on each side, as measured by the force gauge (Figure 2).

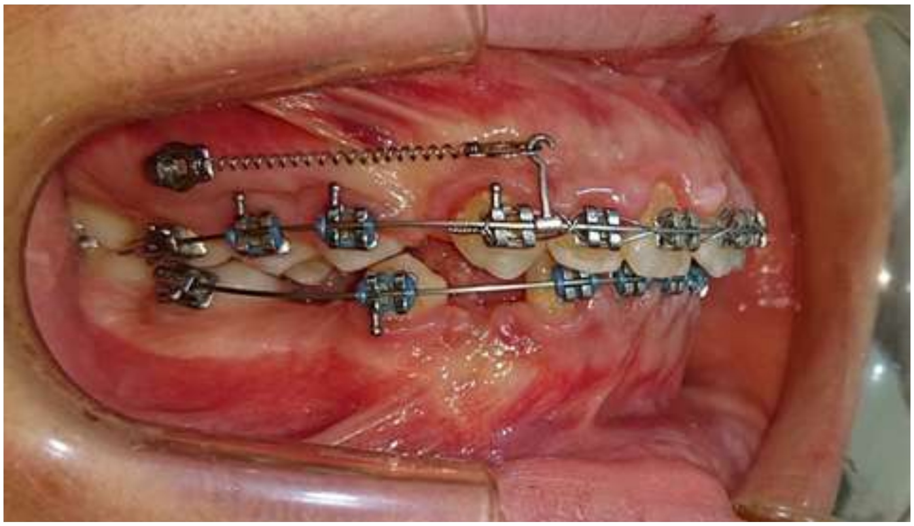

Fig 1. Ni-Ti Closed coil extended from the mini screw head to along hock secured onto the main arch wire between the maxillary lateral incisor and canine.

Fig 2. A constant 250g retraction force per side measured by force gauge.

The direction of the force loaded onto each pair of miniscrews within each patient was the same and was perpendicular to the screw.

Superimposition of CBCT scans:

For standardization of the measurements and visual assessment of the treatment outcomes, voxel-based superimposition of pre-treatment (T0) and post-treatment (T1) CBCT scans of each patient was performed; firstly, the two DICOM data of the patient's sans were imported to the "fusion" module of Ondemand 3D software (Ondemand 3D; Cybermed Co., Seoul, Korea).

the "Manual Registration" tool was used to approximate the two volumes to each other, the "VOI overlay" tool was used to set the anterior cranial base as the volume of interest during registration, then the "Automatic

Registration" tool was used to allow the software to finalize the superimposition of the two datasets by calculating the best agreement within the VOI area.

The MPR (multiplanar reformatted) images of the fused CBCT volumes allowed visual detection of the post-treatment dental and soft tissue profile changes. All of the study cases showed retroclination of the anterior teeth, decrease in the extraction space, and adjusted lip profile.

CBCT image adjustments before linear measurements:

⇨ **Visual display**

The viewing tools of the software were used to adjust the images according to the observer preference. However, to guarantee the standardization of the viewing conditions in both pre- and post-treatment images, the "Match WWL" tool was used to automatically match the secondary volume window width and level (WWL) to the primary volume WWL.

In order to examine axial, sagittal, coronal, and 3D images of both the primary and secondary CBCT volumes simultaneously, the layout was set to "MPR 4x2". It worth mentioning that the fusion module of the software allowed synchronization between both volumes so that any changes made to one of them would be duplicated on the other one. The slice thickness of all images was 0.025 mm.

⇨ **Head orientation:**

The adjustments were applied to the primary (pre-treatment) CBCT volume which were replicated automatically by the software to the secondary(post-treatment) CBCT volume.

The anatomical landmarks used during the head orientation were:[2]

- **Orbitale point (Or);** the most inferior point of the lower contour of the orbit.
- **Porion point (Po);** the most superior point of the external auditory meatus.
- **Nasion point (N);** the intersection of the frontal-nasal and internasal suture.

The axial plane was adjusted to pass through the two (right & left) orbitale points and the right porion point. While the coronal plane was adjusted to pass through the left and right porion and perpendicular to the axial plane. Finally, the sagittal plane was adjusted to pass through the nasion point and perpendicular to axial and coronal planes.

⇨ **Landmarks identification:**

Scrolling the coronal view to localize the screw was performed, then the head and tail of the mini screw (HMS and TMS respectively) were demarcated on both CBCT volumes according to the following criteria;

- **HMS:** the most superior and lateral point of the screw at the coronal plane, the middle point at the sagittal plane, and the most lateral point at the axial plane Figure (3).
- **TMS:** the most superior and medial point of the screw at the coronal plane, the middle point at the sagittal plane, and the most medial point at the axial plane (Figure4).

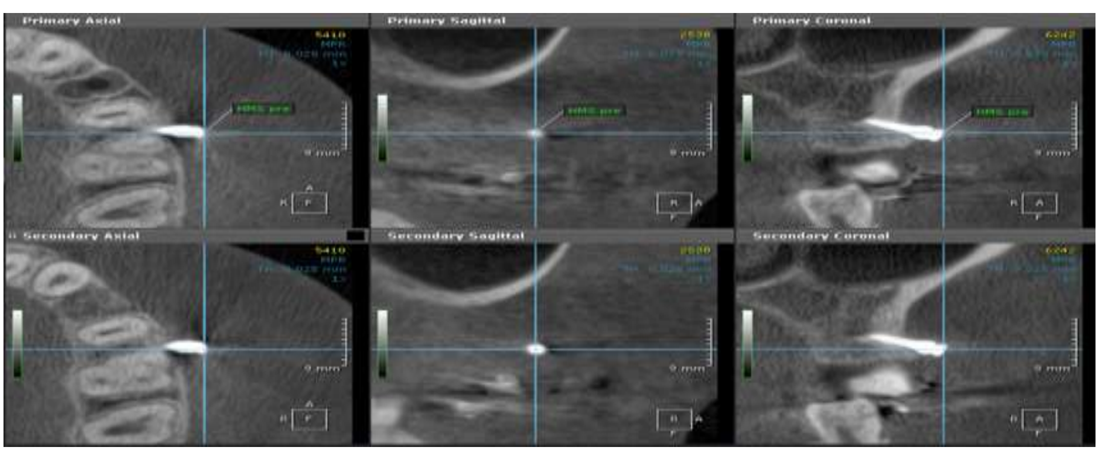

Fig 3. MPR images showing HMS landmark identification

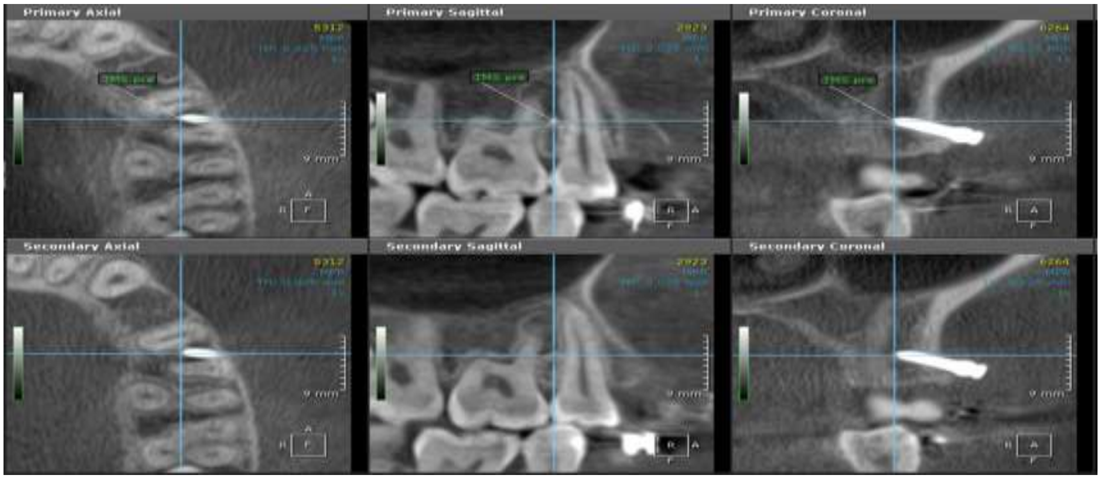

Fig 4. MPR images showing TMS landmark identification

Linear measurements:
After HMS and TMS landmarks identification, the "ruler" tool was used to measure the distances between each landmark and the CBCT planes (axial, sagittal, and coronal) that were previously adjusted at the head orientation step.
The observer starts the linear measurements with each landmark appearing in the three planes, then moving one plane at a time guided by the 3D image and the slice number to reach the previously identified plane level, and finally drawing a perpendicular line from the landmark to the orientation line denoting the plane. Three linear measurements were taken for each landmark to determine the spatial position of the screw in the three dimensions as follows;

- **Distance between landmark and axial plane (HMSA and TMSA):** measured from the coronal cut and represents the position of the screw head or tail in the vertical dimension.
- **Distance between landmark and sagittal plane (HMSS and TMSS):** measured from the coronal cut and represents the position of the screw head or tail in the mediolateral dimension.
- **Distance between landmark and coronal plane (HMSC and TMSC):** measured from the sagittal cut and represents the position of the screw head or tail in the anteroposterior dimension.

By measuring these distances in both primary and secondary volumes, the difference between the pre- and the post-treatment spatial position of the screw could be obtained and the exact movement (displacement) of the screw could be assessed in three dimensions.
Statistical analysis: All the gathered data was collected, tabulated and statistically analyzed using SPSS.

3. RESULTS

The mean and standard deviation values were calculated for each group in each test. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests, data showed parametric (normal) distribution. Independent sample t-test was used to compare between two groups in non-related samples for quantitative data. Repeated measure ANOVA followed by Paired sample t-post hoc test was used to compare between more than two groups in related samples for quantitative data.
The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics Version 25 for Windows.

HMS

Coronal

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A statistically significant difference was found between (Control) and (Sand blasted and Acid etched) groups where ($p=0.006$).
The highest mean value of movement was found in (Control) group, while the least mean value of movement was found in (Sand blasted and Acid etched) group.

Table (1): The mean, standard deviation (SD) values of change of different Linear measurements.

Variables	HMS						
	Coronal						
	Mean	SD	S. Error	95% confidence interval for mean		Min	Max
				Lower bound	Upper bound		
Control (Titanium)	0.38	0.13	0.04	0.29	0.47	0.20	0.55
Sand blasted and Acid etched	0.25	0.02	0.01	0.23	0.26	0.21	0.28
p-value	**0.006***						

*; significant ($p<0.05$)

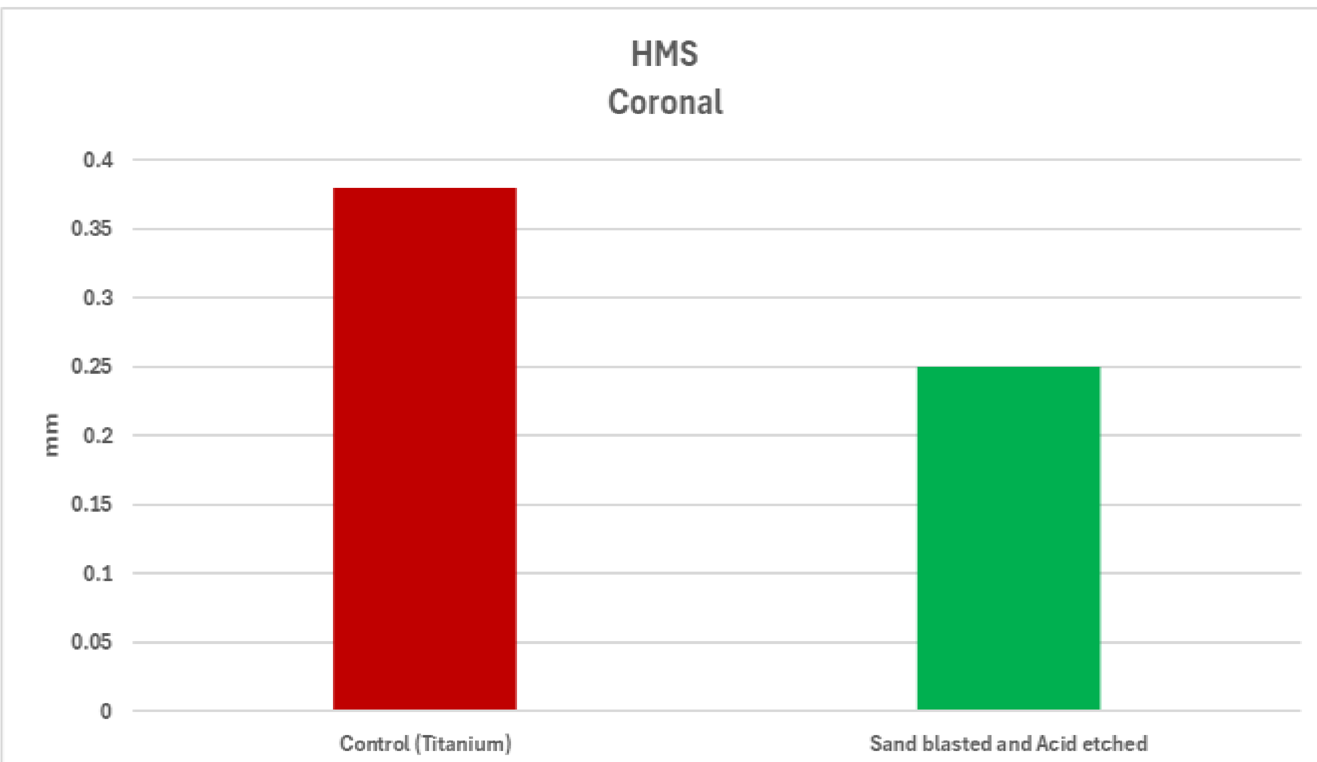

Figure (5): Bar chart representing HMS in Coronal plane

Axial

A statistically significant difference was found between (Control) and (Sand blasted and Acid etched) groups where ($p<0.001$).
While no statistically significant difference was found between any other pair.
The highest mean value of movement was found in (Control) group, while the least mean value of movement was found in (Sand blasted and Acid etched) group.

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Table (2): The mean, standard deviation (SD) values of change of different Linear measurements.

Variables	HMS						
	Axial						
	Mean	SD	S. Error	95% confidence interval		Min	Max
				Lower bound	Upper bound		
Control (Titanium)	0.35	0.07	0.02	0.30	0.40	0.20	0.45
Sand blasted and Acid etched	0.23	0.04	0.01	0.20	0.26	0.15	0.28
p-value	<0.001*						

*; significant (p<0.05)

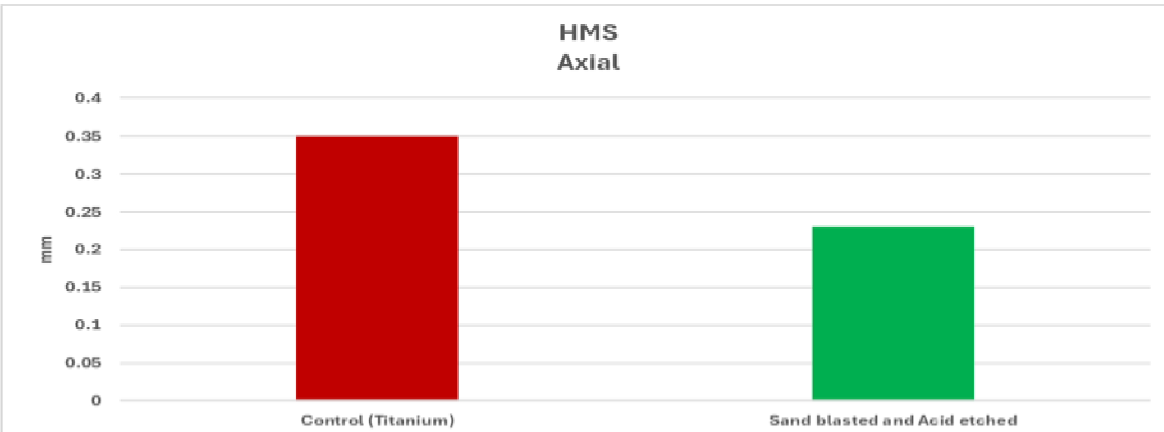

Figure (6): Bar chart representing HMS in Axial plane

Sagittal

A statistically significant difference was found between (Control) and (Sand blasted and Acid etched) groups where (p=0.001).

The highest mean value of movement was found in (Control) group, while the least mean value of movement was found in (Sand blasted and Acid etched) group.

Table (3): The mean, standard deviation (SD) values of change of different Linear measurements.

Variables	HMS						
	Sagittal						
	Mean	SD	S. Error	95% confidence interval		Min	Max
				Lower bound	Upper bound		
Control (Titanium)	0.30	0.05	0.01	0.27	0.33	0.23	0.37
Sand blasted and Acid etched	0.22	0.04	0.01	0.19	0.25	0.18	0.29
p-value	0.001*						

*; significant (p<0.05)

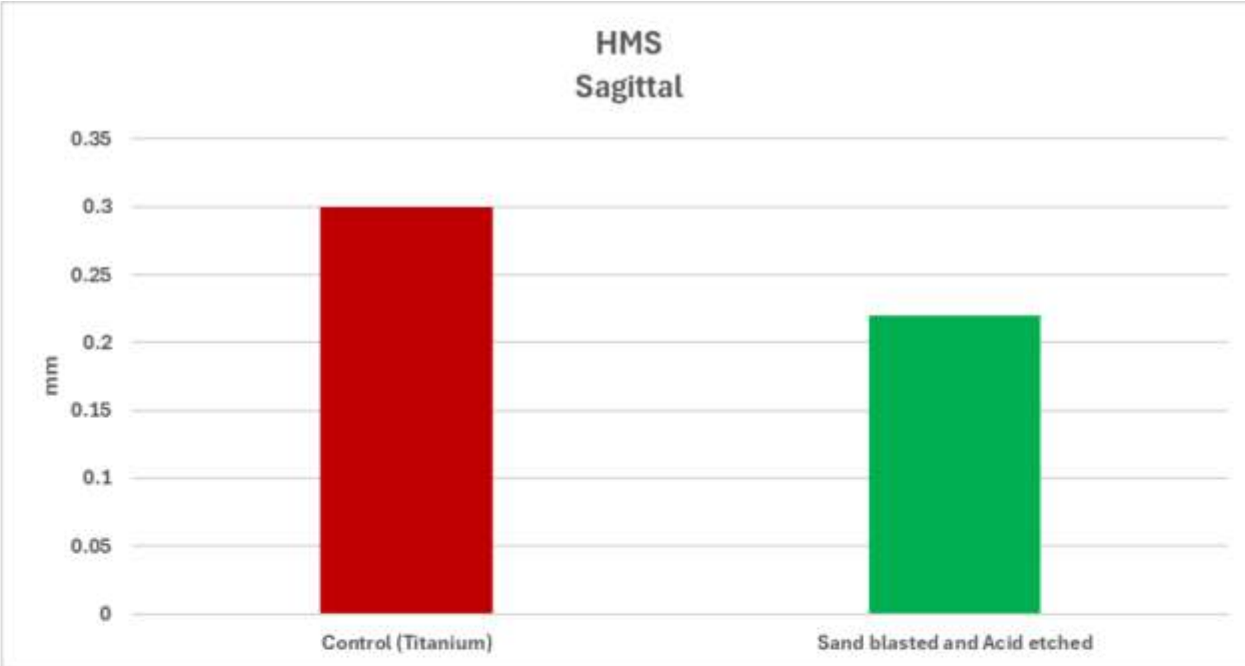

Figure (7): Bar chart representing HMS in Sagittal plane

i) Relations between different planes:

a) Control:

There was no statistically significant difference between (Coronal), (Axial) and (Sagittal) groups where (p=0.181).

b) Sand blasted and Acid etched:

There was no statistically significant difference between (Coronal), (Axial) and (Sagittal) groups where (p=0.190).

TMS

Coronal

There was no statistically significant difference between (Control) and (Sand blasted and Acid etched) groups where (p=0.050).

The highest mean value of movement was found in (Control) group, while the least mean value of movement was found in (Sand blasted and Acid etched) group.

Table (4): The mean, standard deviation (SD) values of change of different Linear measurements.

Variables	TMS						
	Coronal						
	Mean	SD	S. Error	95% confidence interval		Min	Max
				Lower bound	Upper bound		
Control (Titanium)	0.30	0.05	0.02	0.26	0.33	0.20	0.40
Sand blasted and Acid etched	0.24	0.02	0.01	0.22	0.25	0.20	0.28
p-value	**0.050ns**						

ns; non-significant (p>0.05)

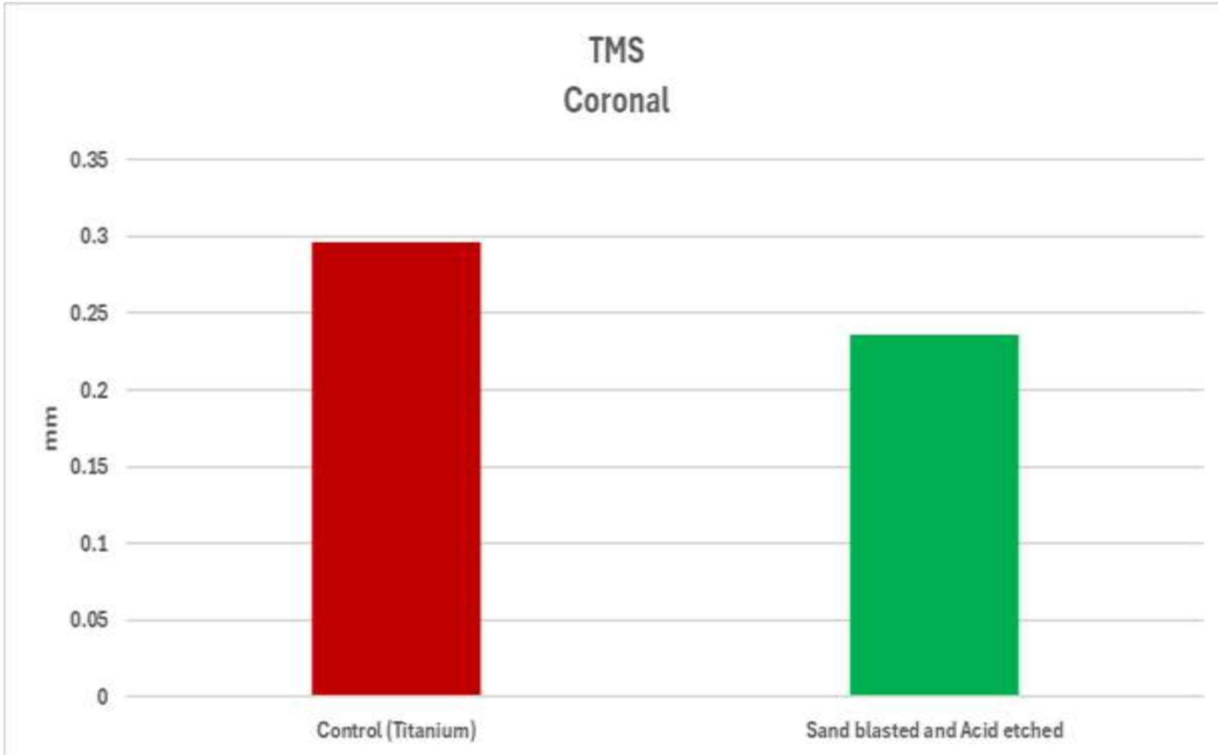

Figure (8): Bar chart representing TMS in Coronal plane

Axial

There was no statistically significant difference between (Control) and (Sand blasted and Acid etched) groups where (p=0.212).

The highest mean value of movement was found in (Control) group, while the least mean value of movement was found in (Sand blasted and Acid etched) group.

Table (5): The mean, standard deviation (SD) values of change of different Linear measurements.

Variables	TMS						
	Axial						
	Mean	SD	S. Error	95% confidence interval		Min	Max
				Lower bound	Upper bound		
Control (Titanium)	0.24	0.07	0.02	0.19	0.29	0.11	0.38
Sand blasted and Acid etched	0.21	0.02	0.01	0.20	0.22	0.18	0.23
p-value	**0.212ns**						

ns; non-significant (p>0.05)

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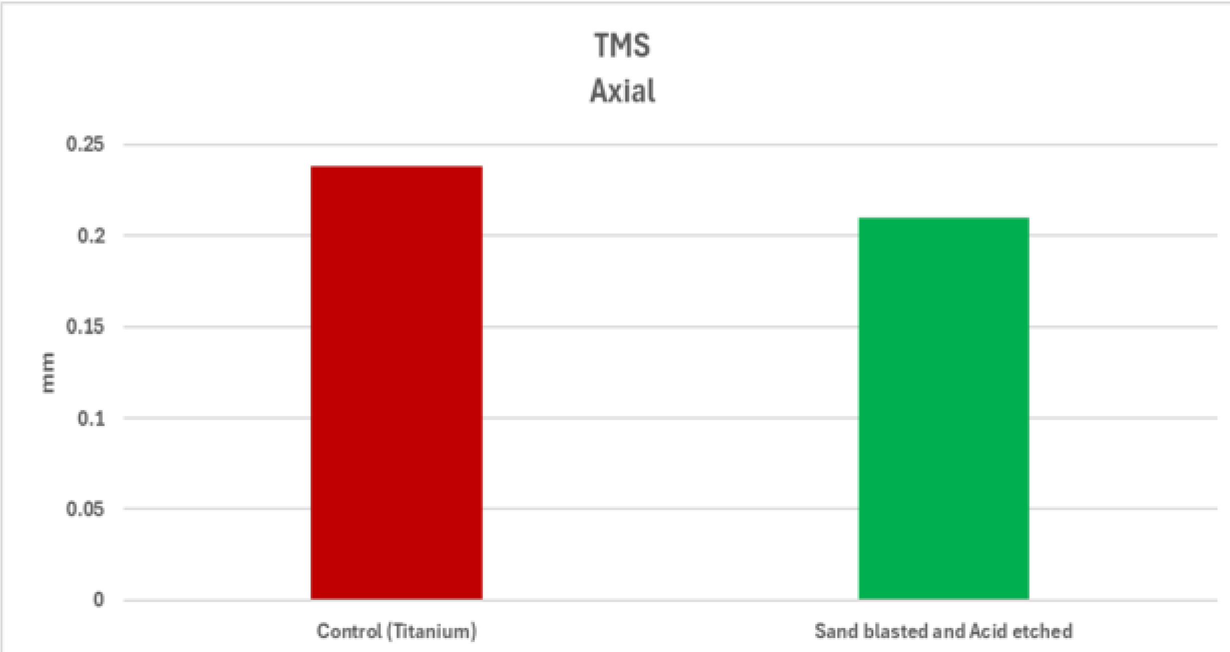

Figure (9): Bar chart representing TMS in Axial plane

Sagittal

There was no statistically significant difference between (Control) and (Sand blasted and Acid etched) groups where (p=0.069).

The highest mean value of movement was found in (Control) group, while the least mean value of movement was found in (Sand blasted and Acid etched) group.

Table (6): The mean, standard deviation (SD) values of change of different Linear measurements.

Variables	TMS						
	Sagittal						
	Mean	SD	S. Error	95% confidence interval		Min	Max
				Lower bound	Upper bound		
Control (Titanium)	0.24	0.06	0.02	0.19	0.28	0.12	0.30
Sand blasted and Acid etched	0.20	0.03	0.01	0.18	0.21	0.15	0.22
p-value	**0.069ns**						

ns; non-significant (p>0.05)

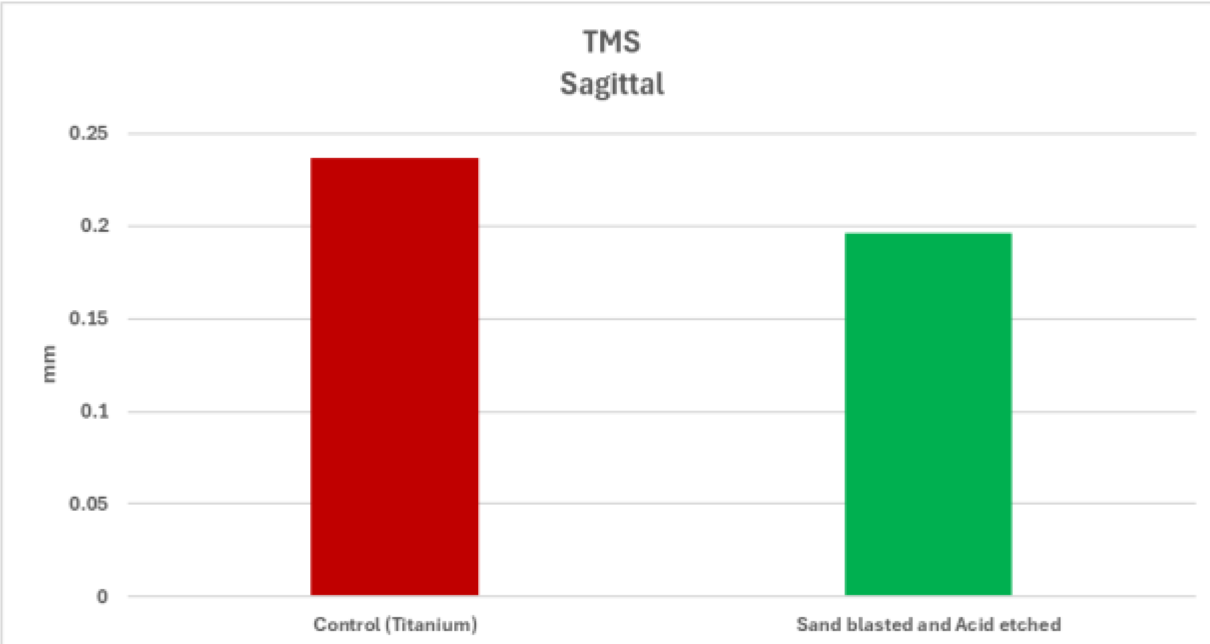

Figure (10): Bar chart representing TMS in Sagittal plane

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i) Relations between different planes:

a) Control:
There was no statistically significant difference between (Coronal), (Axial) and (Sagittal) groups where (p=0.106).

b) Sand blasted and Acid etched:
There was a statistically significant difference between (Coronal), (Axial) and (Sagittal) groups where (p=0.004).
A statistically significant difference was found between (Coronal) and each of (Axial) and (Sagittal) groups where (p=0.019) and (p=0.005).
No statistically significant difference was found between (Axial) and (Sagittal) groups where (p=0.213).

DISCUSSION

Our research demonstrated that the precision of Cone Beam Computed Tomography (CBCT) facilitated the detection of mini-screw displacement. By conducting both CBCT 1 and CBCT 2 for 3D reconstruction orientation and landmark marking simultaneously, we ensured that reference planes and landmarks were consistently positioned. This approach minimized errors and enhanced measurement accuracy for the operator.
The goal of this randomized clinical trial was to compare the displacement of two types of mini-screws: titanium mini-screws and those that were sandblasted and acid-etched. The displacement rate was assessed across three planes—coronal, axial, and sagittal for both the head and tail of the mini-screw groups.
Since Liou et al. (2004)[9] raised concerns regarding the stability of mini-screws under orthodontic forces, only a handful of studies have evaluated whether mini-screws actually experience dislocation when subjected to load. In a related study, Santiago et al. (2009)[12] analyzed 451 oblique lateral cephalometric radiographs and found no changes in mini-implant positions during canine retraction. However, the authors noted that the statistically insignificant variation in initial mini-implant positioning may have been due to distortions in the radiographic images.

El-Beialy et al. (2009)[4] reported average displacement values of 1.08 mm for the head and 0.82 mm for the tail while examining mini-implant movement during canine retraction with CT. They noted a minimum displacement of 0.17 mm for the head and 0.34 mm for the tail. In contrast, our findings differed, which may be attributed to El-Beialy et al.'s method of overlapping CT volumes, whereas we employed fixed planes in CBCT to assess mini-screw displacements.
The displacement rate was also analyzed across all three dimensions (transverse, antero-posterior, and vertical) for both the head and tail of the buccal and palatal mini-implants, as noted by Alves (2011)[2]. Liu et al. (2011)[8] identified several factors influencing mini-screw displacement, including loading duration, cortical thickness, mini-screw characteristics, magnitude of forces, and direction of forces. Consequently, additional research on the long-term stability of mini-screws is warranted.
Seker et al. (2022)[13] concluded that sandblasted, large-grit, and acid-etched mini-screws exhibited significantly greater stability when subjected to heavy forces during the healing process. In a study by Sreenivasagan et al. (2021)[14], it was found that no displacement occurred of the mini-implants when loaded for orthodontic treatment, challenging the alternative hypothesis that suggested there would be displacement under such conditions.
The current study supports these observations, indicating that safe assessments of mini-implant positioning and potential prognosis can be achieved through the dynamic visualization offered by CBCT, as suggested by Batista Junior et al. (2022)[3].
There is a notable lack of studies specifically examining the impact of CBCT on treatment planning and prognosis in orthodontics, as pointed out by Garib et al. (2014)[6]. Existing scientific literature has shown that two-dimensional imaging may not provide sufficient clarity for visualizing mini-implant surgical sites, recommending the use of CBCT for this purpose (Abbassy et al., 2015)[1].
In conclusion, our findings reveal that interradicular mini-screws, utilized as a stable skeletal anchorage unit, experienced some displacement when subjected to forces during enmasse retraction over a 6-month period. However, we uphold the hypothesis that this observed displacement holds limited clinical significance for this mini-screw system concerning the magnitude and mechanics of forces applied.
Conclusions:
1. Although miniscrews are regarded as clinically stable anchorage units, they do experience some displacement under loading, as observed through 3D evaluations.
2. Orthodontic miniscrews that are sandblasted and acid-etched exhibit greater stability compared to those with smooth surfaces during en masse retraction.

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