



**REVIEW ARTICLE**

**MATERIALS USED IN TEMPORARY ANCHORAGE DEVICES (TADS)**

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**ABSTRACT**

**Background:** Tooth replacement concepts date back to the 18th century, but predictable skeletal anchorage was established only after Brånemark's discovery of osseointegration in 1964, making titanium the gold standard. Orthodontic miniscrews, first introduced by Kanomi in 1997, expanded anchorage options and applications. Implant biomaterials are broadly classified as biotolerant (stainless steel, cobalt–chromium), bioinert (titanium, carbon), and bioactive (hydroxyapatite, ceramics), each differing in tissue response from fibrous encapsulation to direct bone contact or chemical bonding, which directly influences the success of temporary anchorage devices.

**Materials and Methods:** A PRISMA-based systematic review was performed using PubMed, Google Scholar, and ScienceDirect (1913–2024), with manual reference checks. Eligible studies included experimental and clinical research on mini-implant materials and their properties. Two reviewers independently screened, extracted data, and assessed quality using CONSORT and STROBE. Owing to heterogeneity, results were qualitatively synthesized by material type and application.

**Results:** Mini-implants have advanced significantly, becoming reliable TADs for various orthodontic applications. Titanium and its alloys demonstrated the best stability, biocompatibility, and corrosion resistance, while stainless steel, cobalt–chromium, and ceramics offered alternative but less predictable outcomes. Success was influenced by implant design, bone quality, insertion torque, and surface modifications. Recent innovations, including nanotechnology-based surface treatments and digital placement methods, further improved osseointegration, antibacterial properties, and overall clinical predictability.

**Conclusion:** Mini-implants provide stable, compliance-free anchorage and have become essential in modern orthodontics. Titanium remains the gold standard, while advances in surface modifications and nanotechnology continue to improve their effectiveness and safety.

**Keywords:** TADs, Mini Implants, Stainless Steel, Titanium, Cobalt Chromium, Zirconia

**1. INTRODUCTION**

The concept of tooth replacement dates back to the 18th century, when John Hunter proposed implanting human teeth. Allografts failed due to immune rejection and infection. In 1809, Maggiolo placed a gold implant above the gingiva, and in 1911, Greenfield<sup>1</sup> introduced an endosseous implant design.

The idea of skeletal anchorage began with Gainsforth & Higley (1945)<sup>2</sup>, who inserted Vitallium screws in dog rami for orthodontic anchorage, but screws failed within a month. A major breakthrough came with Per Ingvar Brånemark (1964)<sup>3</sup>, who discovered osseointegration using titanium optical chambers in rabbit femurs. Subsequent animal studies showed titanium implants could remain stable for years without rejection,

establishing titanium as the gold standard. The first orthodontic miniscrew concept was proposed by Kanomi (1997)<sup>4</sup>, introducing a small implant (1.2 mm × 6 mm). This led to systems like the Aarhus Mini-Implant (Scandinavia)<sup>5</sup>, Spider Screw (Italy), and Abso-Anchor (Korea, 1999). The first marketed system was the K-1 (Dentsply Sankin, Japan)<sup>6</sup>. Wehrbein et al. (1997) tested titanium screw implants for anchorage, while Maino et al. (2003)<sup>7</sup> expanded applications to anterior retraction, open bite correction, distalization, and intrusion. Despite progress, much evidence still comes from case reports. Material science is central to implant success. Common biomaterials include titanium alloys, stainless steel, cobalt-chromium alloys, tantalum, zirconium, ceramics, and polymers. Titanium is most widely used in the form of commercially pure (cp) Ti or Ti-6Al-4V alloy, classified into six ASTM grades.

Implant biomaterials are broadly classified into three groups.

**Biotoberant materials**, such as stainless steel and cobalt–chromium alloys, are accepted by the body but become encapsulated in a fibrous tissue layer, limiting direct bone contact.

**Bioinert materials**, including titanium and carbon, allow close apposition of bone on their surface and promote contact osteogenesis, though they do not form a chemical bond with the host tissue<sup>8</sup>.

In contrast, **bioactive materials**, such as hydroxyapatite and bioactive ceramics, not only support new bone formation but also undergo ion exchange with the surrounding tissue, resulting in the formation of a strong chemical bond at the bone–implant interface, a process known as bonding osteogenesis<sup>9</sup>.

## 2.MATERIAL AND METHODS

### 2.1 Search Strategy and Data Sources

A structured and comprehensive systematic review was performed in accordance with PRISMA guidelines to collate existing literature on materials used in mini implants. An exhaustive electronic search was conducted across three major scientific databases: PubMed, Google Scholar, and ScienceDirect, covering a publication period from January 1913 to December 2024. The search strategy incorporated Boolean logic and truncation operators using the following terms: “Mini

implants” AND “Temporary anchorage devices” OR “TADs” OR “materials”. Additionally, manual reference mining of retrieved articles and reviews was performed to ensure inclusion of all pertinent studies.

### 2.2 Eligibility

Criteria Studies were selected based on pre-defined inclusion and exclusion criteria. Eligible studies included:

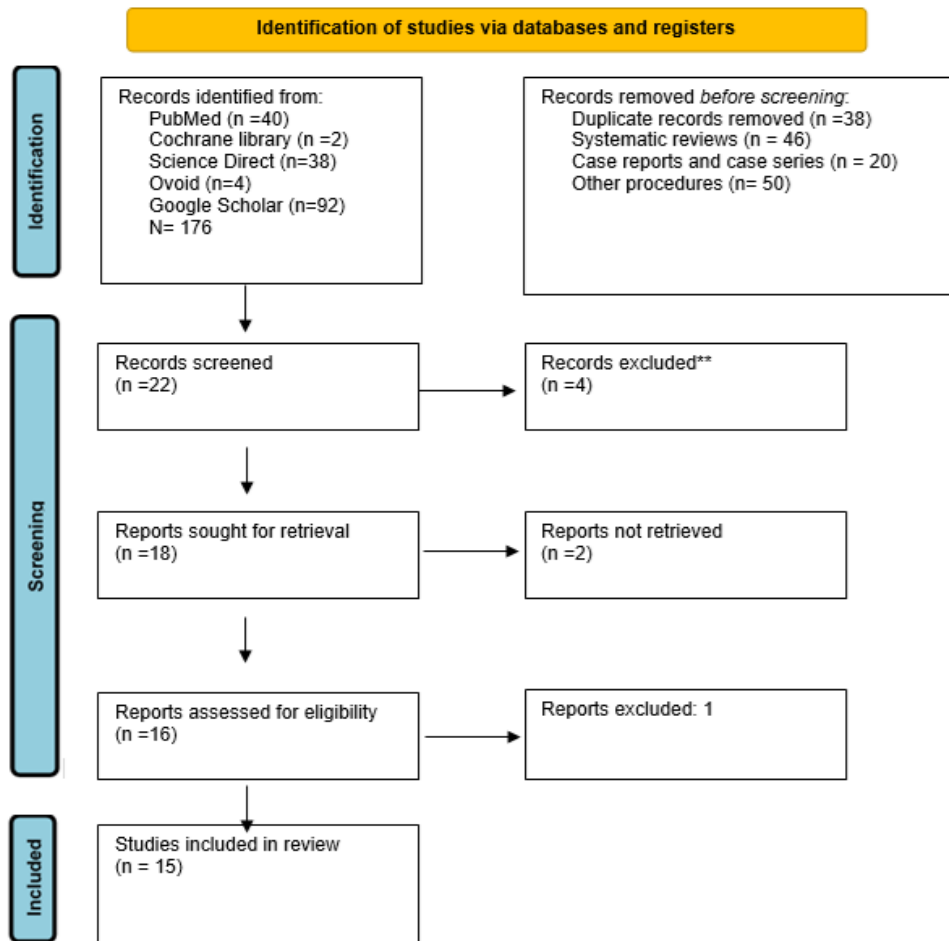
- Original experimental research involving in vitro, in vivo, or ex vivo models;
- Clinical investigations such as randomized controlled trials (RCTs), cohort studies, or case-control studies;
- Studies reporting on materials used in mini implants, surface modifications, biocompatibility, recent advances, physical properties, microscopic properties, corrosional properties of different mini implant materials.

Only articles published in peer-reviewed journals and written in English were considered. Exclusion criteria comprised commentaries, editorials, conference abstracts, duplicate reports, and review articles that did not provide new experimental data or systematic synthesis.

### 2.3 Study Selection and Data Extraction

All articles were independently screened in two stages by two reviewers (blinded to author identities). First, titles and abstracts were reviewed for relevance. Full texts of potentially eligible studies were then assessed in detail. Discrepancies were resolved through discussion or consultation with a third reviewer. The PRISMA flowchart guided the selection process as illustrated in **Figure 1**. After removing duplicates, titles and abstracts were screened for relevance. Full-text reviews of eligible studies followed, ensuring compliance with the inclusion criteria. Data were extracted using a standardized data extraction form designed to capture study characteristics, including:

- Authors, publication year, and journal;
- Study design and experimental setting;
- Materials used in mini implants
- Quantitative and qualitative outcomes;
- Findings, limitations, and conclusions.



**Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only**

\*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).

\*\*If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

#### 2.4 Quality and Risk of Bias Assessment

To evaluate the internal validity of included studies, two reviewers independently assessed the risk of bias using established tools:

- CONSORT 2010 checklist for clinical trials
- STROBE guidelines for observational and laboratory-based studies.

Assessment criteria included randomization, blinding, sample size justification, statistical rigor, reproducibility, and transparency in outcome reporting. Any discrepancies in assessment were resolved through consensus or adjudication by a senior investigator.

#### 2.5 Data Synthesis

Due to the heterogeneity of study designs, interventions, and outcomes, a qualitative synthesis was performed. Results were stratified by application domains (e.g., surface modifications, biocompatibility, recent advances, physical properties, microscopic properties, corrosional properties of different mini implant materials) and materials used in mini implants. Where applicable, outcome trends were highlighted and compared across studies.

### 3.1 History of mini implants

The development of Temporary Anchorage Devices (TADs)<sup>32</sup> is rooted in the broader history of dental and skeletal anchorage, progressing from early experimental implants to today's advanced mini-implant systems.

#### a) Early Foundations (18th–19th Century)

John Hunter's studies on bone healing laid the groundwork for implantology, while Maggiolo (1809)<sup>1</sup> attempted gold root implants for tooth replacement. Later, Greenfield (1909) introduced an iridioplatinum basket implant, and Strock tested Vitallium, improving biocompatibility but still limited by infection and poor integration.

#### b) Mid-20th Century – Osseointegration

The major breakthrough came when Brånemark (1950s–60s)<sup>3</sup> discovered osseointegration with titanium, enabling stable endosseous implants. Orthodontists like Linkow (1969) explored blade implants for anchorage, but these were large and invasive.

#### c) Birth of TADs (1980s–1990s)

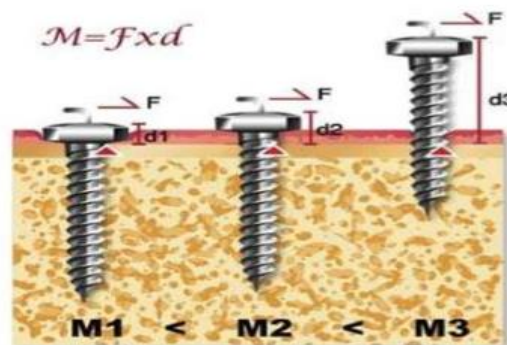
In 1983, Creekmore & Eklund first used a vitallium screw for incisor intrusion, proving skeletal anchorage feasible. Kanomi (1997)<sup>4</sup> then introduced the first dedicated orthodontic mini-implant (1.2 × 6 mm), sparking the development of smaller, less invasive systems such as Aarhus, Spider Screw, and Abso-Anchor.

#### d) 21st Century – Refinement & Adoption

Modern TADs feature self-drilling/self-tapping designs, surface modifications for stability, and titanium alloys for biocompatibility. With 3D imaging and guided placement, TADs are now routine for applications like molar intrusion, retraction, space closure, and skeletal expansion, offering predictable, minimally invasive anchorage<sup>32</sup>.

### 3.2 Anchorage in orthodontics

**Anchorage** in orthodontics refers to resistance against unwanted tooth movement and is essential for achieving controlled results. Traditionally, intraoral methods (reciprocal or reinforced anchorage) and extraoral appliances like headgear were used, but these relied heavily on patient compliance. The advent of **Temporary Anchorage Devices (TADs)**—including mini-implants and mini-plates—revolutionized anchorage by offering stable, independent support and reducing dependence on cooperation<sup>33</sup>. TADs are especially effective in cases needing maximum anchorage (e.g., molar intrusion, distalization, space closure) as they allow direct force application without affecting adjacent teeth. Their success depends on bone density, cortical thickness, implant design, and placement technique, while modern imaging tools like **CBCT** have enhanced placement accuracy and reduced failure risk.



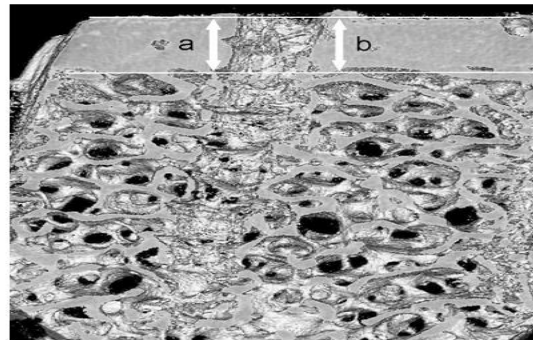
**Figure 2.** Extra anchorage potential can be gained when a contact surface of the screw to the bone exists - Paul et al (2024)<sup>32</sup>

The stability of TADs is critical for their success in orthodontic treatment. Stability can be divided into **primary stability**, which is the immediate mechanical retention after insertion, and **secondary stability**, which develops over time through biological adaptation. Unlike conventional dental implants that require osseointegration, TADs mainly rely on **mechanical interlocking with bone**<sup>30</sup>.

### Factors Affecting Stability

#### a) Bone Quality and Density

- Cortical bone thickness is one of the most important determinants of TAD success.
- Thicker, denser cortical bone provides stronger anchorage and reduces the risk of loosening, while low-density bone is associated with higher failure rates.
- Wilmes et al. (2011)<sup>13</sup> confirmed that areas with greater bone density significantly improve primary stability.



**Figure 3.** Micro CT for measurement of the compact thickness. Measurement at two sites next to implantation and calculation of average value (a and b)-  
Wilmes B et al. (2011)<sup>13</sup>

#### b) Mini-Implant Design and Diameter

- Design factors such as **diameter, length, and thread type** strongly influence stability.
- Larger diameters increase surface area and retention but risk damaging adjacent roots or overstressing bone<sup>10</sup>.
- Dual-thread and conical, self-drilling designs often provide greater mechanical retention compared to cylindrical or single-threaded implants.



**Figure 3.a** Dual thread TAD- Durrani Z et al (2017)<sup>21</sup>

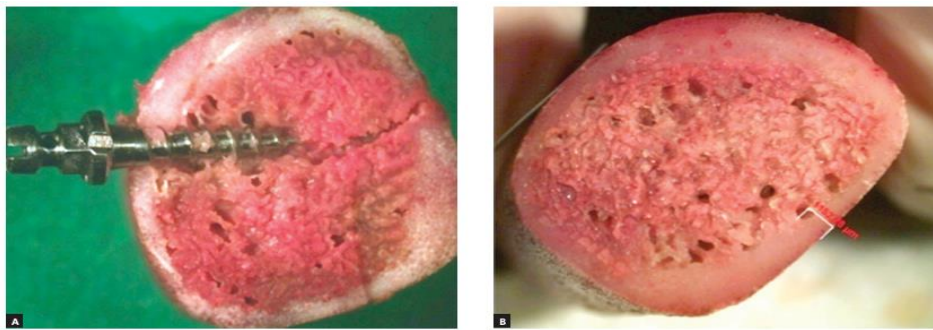
**Figure 3.b** Single thread TAD- Durrani Z et al (2017)<sup>21</sup>



**Figure 3.c** Predrilling, cylindrical miniscrews and self-drilling, conical miniscrew implants- Sandler PJ et al(2014)<sup>17</sup>

**c) Insertion Torque and Technique**

- Correct insertion torque is vital: **5–10 Ncm** provides the best stability.
- Excessive torque may cause bone microfractures and implant failure, while too little torque results in early loosening<sup>20</sup>.
- Self-drilling miniscrews in areas of sufficient cortical thickness often provide more reliable retention than predrilled screws.



**Figure 4.** Mini-implant position in pork rib (A) and cortical bone thickness of pork rib block used in the insertion test of mini-implants (B) - Assad-Loss TF(2016)<sup>20</sup>

**d) Placement Location**

- Anatomical site influences success.
- **Palatal and interradicular sites** are preferred for their dense bone support.
- The **mandible** generally offers higher stability than the maxilla due to thicker cortical bone<sup>31</sup>.
- Conversely, maxillary posterior regions with thin bone show higher failure rates.

**e) Surface Coating and Modifications**

- Surface treatments such as **titanium anodization** or **hydroxyapatite coatings** enhance bone-implant interaction and reduce bacterial colonization.
- These coatings improve corrosion resistance and increase the lifespan of the implant<sup>30</sup>.

**f) Load Application and Force Direction**

- The magnitude and direction of orthodontic force affect long-term stability.
- **Light, continuous forces (50–150 g)** are best tolerated.
- Forces applied along the long axis of the implant are more stable, whereas oblique or lateral forces can induce tipping or loosening<sup>29</sup>.

**g) Patient-Related Factors**

- Oral hygiene is critical: poor hygiene can lead to peri-implantitis and early failure.
- Parafunctional habits such as bruxism increase loading and micro-movement.
- Smoking is associated with impaired healing and higher failure rates<sup>32</sup>.

Orthodontic mini-implants, also known as Temporary Anchorage Devices (TADs), are essential tools that provide stable anchorage during tooth movement. In 2024, a study conducted by Sana et al<sup>34</sup> showed that the materials used in their construction significantly influence their performance, biocompatibility, and success rates. Here's a detailed overview of these materials:

#### **a) Titanium and Titanium Alloys**

##### **Properties and Advantages:**

- **Biocompatibility:** Titanium is renowned for its excellent compatibility with human tissues, minimizing adverse reactions.
- **Mechanical Strength:** It possesses a high strength-to-weight ratio, ensuring durability without adding excessive weight.
- **Corrosion Resistance:** Titanium naturally forms a protective oxide layer, safeguarding it against corrosion in the oral environment.

##### **Common Variants:**

- **Commercially Pure (Cp) Titanium:** Available in grades 1 to 4, with increasing strength. Grade 4 is frequently used for mini-implants due to its optimal balance of strength and ductility.
- **Titanium Alloys (e.g., Ti-6Al-4V):** This alloy incorporates 6% aluminum and 4% vanadium, enhancing its mechanical properties, including fatigue resistance, making it particularly suitable for orthodontic applications.

##### **Clinical Significance:**

Titanium's ability to osseointegrate, or bond directly with bone, ensures the stability of mini-implants under orthodontic forces. Studies by Saranya et al (2024)<sup>35</sup>, Bucur et al (2021)<sup>36</sup> emphasized that osseointegration is crucial for the long-term success of the implant.

#### **b) Stainless Steel (316L)**

##### **Properties and Advantages:**

- **Mechanical Strength:** 316L stainless steel offers substantial strength, making it resistant to deformation under load.
- **Corrosion Resistance:** The inclusion of chromium and molybdenum provides a protective layer against corrosion, essential for the moist oral environment.
- **Cost-Effectiveness:** Generally more affordable than titanium, making it an attractive option in certain scenarios.

##### **Clinical Considerations:**

A study by Padmini et al (2016)<sup>37</sup> confirmed that while stainless steel mini-implants provide robust mechanical properties, they lack the osseointegration capabilities of titanium. This absence means there's no direct bone-implant bonding, which might affect the long-term stability of the implant.

#### **c) Cobalt-Chromium Alloys**

##### **Properties and Advantages:**

- **High Wear Resistance:** These alloys are exceptionally resistant to wear, extending the implant's lifespan.
- **Mechanical Strength:** They offer excellent mechanical properties, suitable for withstanding significant forces.

**Clinical Considerations:**

A study by Lolage et al(2018)<sup>38</sup> showed that despite their strengths, cobalt-chromium alloys are less commonly used in mini-implants due to their higher stiffness, which can lead to stress shielding, and concerns about biocompatibility compared to titanium.

**d) Ceramic Materials (e.g., Zirconia)**

**Properties and Advantages:**

- **Biocompatibility:** Ceramics like zirconia are highly compatible with human tissues, reducing the risk of adverse reactions.
- **Aesthetics:** Their tooth-like color makes them preferable in situations where implant visibility is a concern.
- **Corrosion Resistance:** Ceramics are inherently resistant to corrosion, ensuring longevity in the oral cavity.

**Clinical Considerations:**

The brittleness of ceramics poses a challenge, as they are more susceptible to fractures under excessive forces. Advancements in material science were aimed to enhance their toughness, a study by Sana et al (2024)<sup>34</sup> revealed that careful case selection is essential when considering ceramic mini-implants.

**Table 1. Properties of different mini implant materials**

Property	Titanium Alloy (Ti-6Al-4V)	Cp Titanium (Grades 1-4)	Stainless Steel (316L)	Zirconia-Coated Titanium
<b>Biocompatibility</b>	High (good osseointegration)	Very High (pure metal)	Moderate (Ni and Cr may cause allergies)	Very High (bio-inert coating)
<b>Strength</b>	High (strongest among all)	Moderate (lower than alloy)	High (but more brittle)	High (due to titanium core)
<b>Corrosion Resistance</b>	Excellent (except in fluoride)	Excellent (except in fluoride)	Low (prone to pitting in saliva)	Very High (zirconia prevents corrosion)
<b>Fracture Resistance</b>	High (resistant to bending and cyclic loading)	Lower (may bend under load)	Low (higher risk of brittle fracture)	High (similar to Ti-6Al-4V)
<b>Insertion Torque</b>	15-25 Ncm (ideal for primary stability)	Lower than Ti-6Al-4V	Higher but prone to cracking	Similar to Ti-6Al-4V
<b>Ion Release Risk</b>	Minimal	Minimal	High (Ni, Fe, Cr ions can leach)	Minimal (zirconia barrier)
<b>Cost</b>	Moderate to High	Moderate	Low	Higher due to coating
<b>Common Use</b>	Most widely used	Alternative for sensitive patients	Less common (short-term use)	Used for improved biocompatibility

Mini-implants, or Temporary Anchorage Devices (TADs), have transformed orthodontics by providing reliable anchorage. Their clinical success depends largely on surface modifications, which enhance stability, osseointegration, and biocompatibility.

### **Types of Surface Modifications**

- **Sandblasted and Acid-Etched (SLA):** Large-grit blasting plus acid-etching creates roughness, improving bone contact. Schätzle et al. (2009)<sup>11</sup> reported faster implant stability with chemically modified SLA surfaces.
- **Nanocoatings:** Nanoparticles improve biocompatibility, antibacterial activity, and osseointegration<sup>39</sup>.
- **Hydrophilic Surfaces:** Promote protein absorption and cell adhesion, enhancing early bone healing<sup>11</sup>.
- **Plasma-Sprayed & Titanium Oxide Coatings:** Increase roughness and corrosion resistance, supporting stronger bone integration<sup>30</sup>.
- **Fluoride Treatment:** Stimulates bone cell activity, accelerates bone formation, and improves retention.

### **Benefits of Surface Modifications**

- **Enhanced Osseointegration:** Promotes rapid bone formation and higher stability.
- **Increased Implant Stability:** Surface-treated implants resist dislodgement more effectively<sup>14</sup>.
- **Reduced Healing Time:** Chemically modified surfaces enable earlier orthodontic loading<sup>11</sup>.
- **Improved Biocompatibility:** Better cell interaction reduces inflammation and rejection<sup>22</sup>.
- **Greater Corrosion & Wear Resistance:** Extends implant lifespan and lowers infection risk<sup>15</sup>.
- **Antibacterial Properties:** Nanocoatings and fluoride reduce bacterial adhesion and peri-implantitis risk<sup>39</sup>.

### **3.6 Mechanical Properties of Mini-Implants**

The mechanical properties of orthodontic mini-implants are fundamental to their ability to resist forces during insertion, orthodontic loading, and removal. These properties influence both their primary stability and their long-term clinical success. Key aspects include insertion torque, fracture resistance, and resistance to dislodgement.

#### **a. Insertion Torque and Primary Stability**

Insertion torque is a critical indicator of the mechanical engagement between the implant threads and cortical bone. It reflects primary stability, which is essential for immediate loading in orthodontics.

- The optimal insertion torque lies between 10–25 Ncm.
- Excessive torque may cause bone microfractures and microdamage to cortical bone, reducing secondary stability.
- Conversely, low torque values may result in early loosening and implant failure due to inadequate interlocking.
- Giri et al. (2020)<sup>26</sup> compared different mini-implant designs and reported that zirconia-coated implants showed insertion torque values comparable to uncoated titanium implants, without compromising structural integrity, indicating that surface coating does not negatively affect mechanical engagement.

#### **b. Fracture Resistance**

Mini-implants undergo continuous cyclic loading during orthodontic treatment, which can result in fatigue fractures over time.

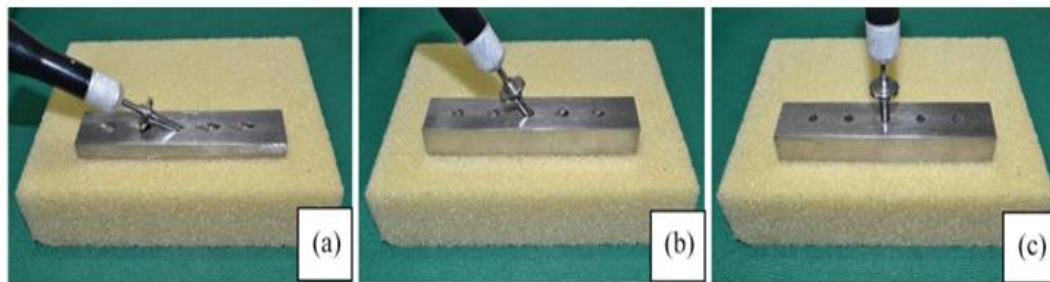
- The implant neck is the most common site of fracture due to stress concentration in this region.
- Titanium alloys demonstrate superior fatigue resistance and ductility, making them more reliable under long-term loading.

- Stainless steel implants, although strong, are more prone to brittle fractures when subjected to repeated stress<sup>34</sup>.
- Patwari et al. (2019)<sup>16</sup> confirmed that most fractures occur at the neck of the implant, highlighting the need for proper design and material selection to minimize this risk.

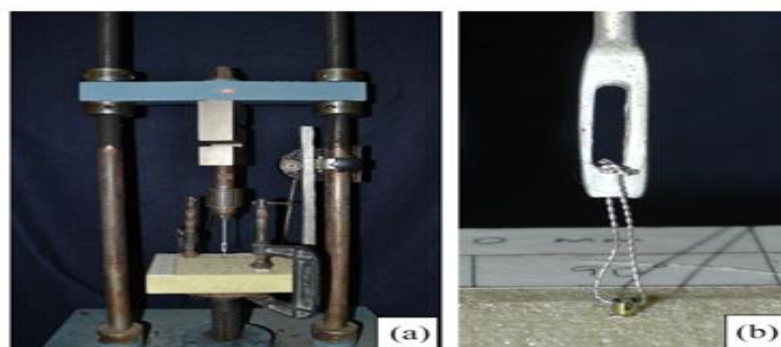
### c. Resistance to Dislodgement and Mechanical Stability

Dislodgement resistance represents the ability of a mini-implant to resist pull-out forces and maintain anchorage under orthodontic loading. Multiple factors influence this property:

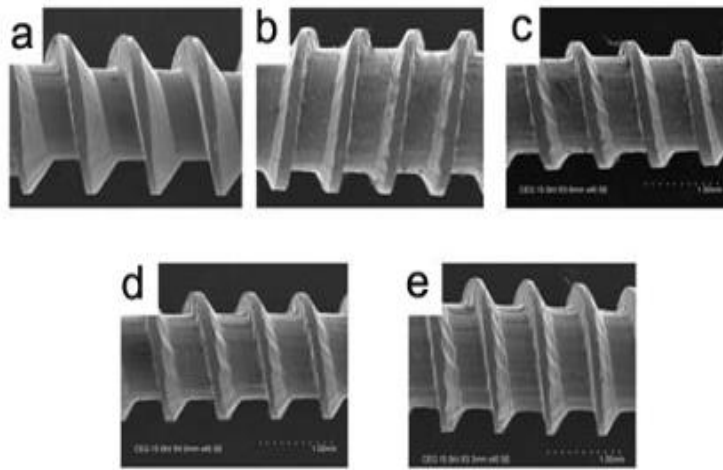
- **Bone conditions:**
  - John et al. (2012)<sup>14</sup> showed that mini-implants inserted in thicker cortical bone required significantly higher forces for removal, confirming the role of cortical thickness in stability.
  - Denser cortical bone provides a more secure interlock for threads.
- **Implant design & thread shape:**
  - Yashwant et al. (2017)<sup>45</sup> demonstrated that trapezoidal fluted thread designs produced the highest pull-out strength, ensuring superior stability compared to conventional thread forms.
- **Self-tapping vs. self-drilling designs:**
  - Favero et al. (2010)<sup>12</sup> found that self-tapping implants achieved better retention than self-drilling screws because pre-drilling allowed more precise engagement with cortical bone, though clinical choice often depends on site accessibility.
- **Implant dimensions & placement angle:**
  - Santhosh et al. (2022)<sup>44</sup> evaluated placement variables and concluded that longer implants and higher insertion angles significantly improved pull-out strength and stability. Interestingly, implant diameter and bone density had less influence compared to length and angle.



**Figure 5.** Mini-implant drive positioned at (a) 30°, (b) 60° and (c) 90° in metal jig over synthetic bone surface- Mohan S et al (2022)<sup>44</sup>



**Figure 6.** (a) The bone block clamped to the customised platforms using a metal clamp and attached to the Instron machine. (b) Ligature wires used to attach mini-implant and the load arm- Mohan S et al (2022)<sup>44</sup>



**Figure 7.** (a) SEM view of reverse buttress thread design; (b) SEM view of buttress thread design; (c) SEM view of 750 joint profile with flutes thread design; (d) SEM view of trapezoidal thread design; (e) SEM view of trapezoidal fluted thread design- Yashwant AV et al (2017)<sup>45</sup>.

### 3.7 Microscopic Properties of Mini-Implants

Mini-implants (TADs) are small titanium or stainless-steel screws whose **surface morphology, elemental composition, and nanostructure** determine their biocompatibility, stability, and corrosion resistance. Various microscopic techniques are used to study these properties before and after clinical use<sup>30</sup>.

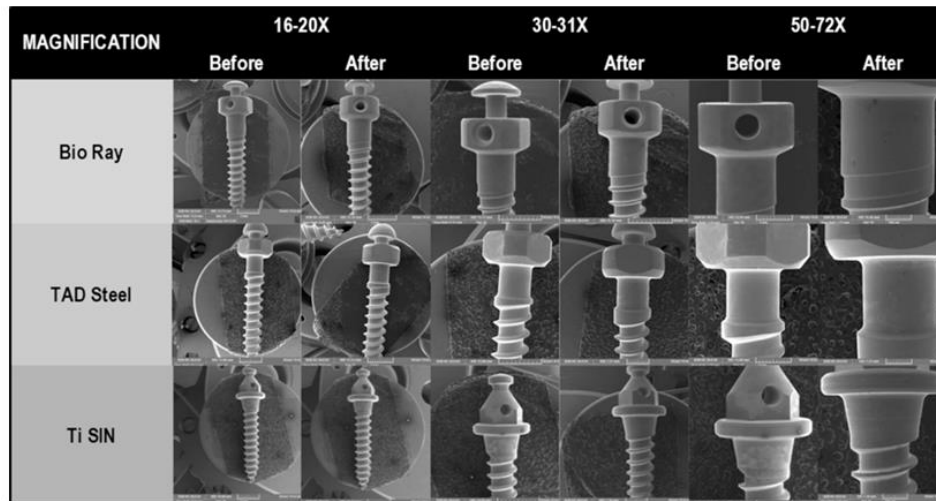
- **Scanning Electron Microscopy (SEM):** Provides high-resolution images of implant surfaces, revealing machining marks, porosity, and roughness. After clinical use, SEM shows irregularities, pitting, biofilm, and microfractures. Moderate surface roughness improves bone interlocking and primary stability, while excessive roughness promotes bacterial adhesion and peri-implantitis.
- **Energy-Dispersive X-ray Spectroscopy (EDS/EDX):** Analyzes elemental composition and ion release. Titanium alloys (Ti-6Al-4V) provide excellent strength but may release Ti, Al, and V ions, especially in fluoride-rich environments<sup>19</sup>. Stainless steel implants contain Fe, Cr, and Ni, making them more prone to corrosion and ion leaching.
- **Atomic Force Microscopy (AFM):** Evaluates nanostructure and 3D surface topography, allowing precise measurement of nanoscale roughness. Surface modifications like **sandblasting, acid etching, or plasma spraying** enhance osseointegration and stability by improving bone adhesion<sup>30</sup>.
- **Optical Microscopy:** Detects gross morphological changes such as wear, discoloration, and micro-pitting. Retrieved implants often show biofilm deposits and surface deterioration, especially in high-stress regions (e.g., infrazygomatic crest, palate)<sup>30</sup>, where mechanical loading accelerates wear and corrosion.

### 3.8 Corrosion Properties of Mini-Implants

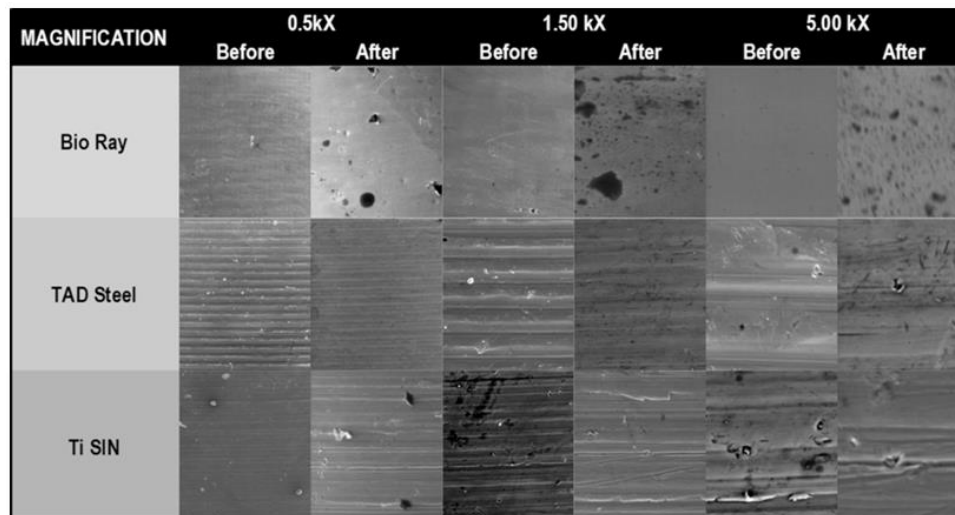
Corrosion is a major factor influencing the **longevity and performance** of mini-implants, as they are constantly exposed to saliva, biofilms, fluoride products, and temperature changes. It results from chemical/electrochemical reactions, leading to **implant weakening, loss of stability, and ion release**<sup>23</sup>.

#### Titanium alloys (Ti-6Al-4V):

- Favored for their biocompatibility, strength, and natural **TiO<sub>2</sub> protective layer**.
- However, fluoride exposure degrades this passive layer, causing **pitting and crevice corrosion**<sup>25</sup>.
- Ion release of Ti, Al, and V occurs over time but generally at low, controlled levels<sup>19</sup>.



**Figure 8.a** Representative photomicrographs of the transmucosal TAD profile region before and after immersion in artificial saliva at lower magnifications- Assis do Nascimento C et al(2017)<sup>25</sup>



**Figure 8.b** Representative photomicrographs of the transmucosal TAD profile region before and after immersion in artificial saliva at higher magnifications- Assis do Nascimento C et al(2017)<sup>25</sup>

**Stainless steel:**

- Less corrosion resistant, especially in acidic or fluoride-rich conditions.
- Electrochemical tests show significantly reduced resistance compared to titanium<sup>15</sup>.
- Higher susceptibility to **localized corrosion** and greater ion leaching.

**Types of corrosion<sup>24</sup>:**

- **Pitting corrosion:** deep pits weaken implant structure, often fluoride-related.
- **Crevice corrosion:** occurs under plaque or soft tissue deposits where localized acidity accelerates degradation.
- **Galvanic corrosion:** arises when dissimilar metals (e.g., titanium + stainless steel) are present in the oral cavity, accelerating breakdown.

**Testing methods:**

- **Electrochemical studies**<sup>19</sup>, mass loss analysis, and ion release assays (ICP-OES) assess material performance.
- Titanium consistently shows **superior resistance** to stainless steel but still suffers in harsh fluoride/acidic environments.

**3.9 Biocompatibility and Tissue Response of Mini-Implants**

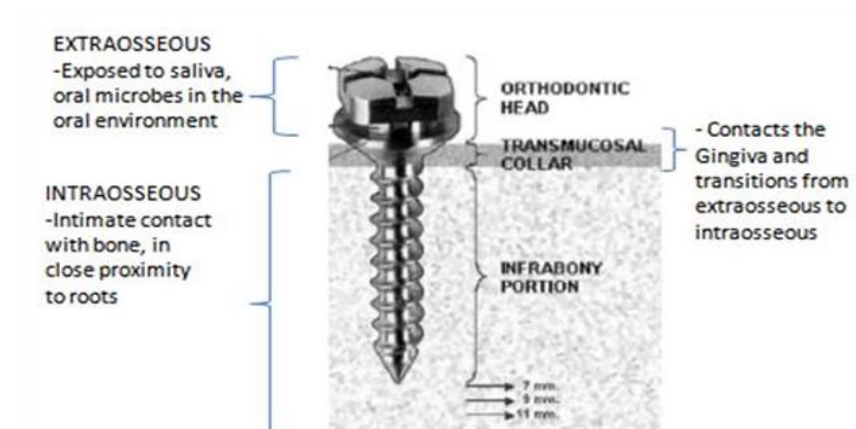
Biocompatibility is essential for the success of mini-implants, ensuring safety, tissue compatibility, and long-term stability. Most are made of **titanium or Ti-6Al-4V alloys**, known for excellent corrosion resistance and biological safety<sup>34</sup>.

**a) Biocompatibility and Cytotoxicity**

In vitro studies have consistently shown minimal cytotoxic effects of mini-implants. **Birg et al. (2015)**<sup>18</sup> and **Finke et al. (2018)**<sup>22</sup> reported >90% cell viability in gingival fibroblasts and osteoblasts, while found no significant damage to PDL fibroblasts, confirming their clinical safety<sup>16</sup>.



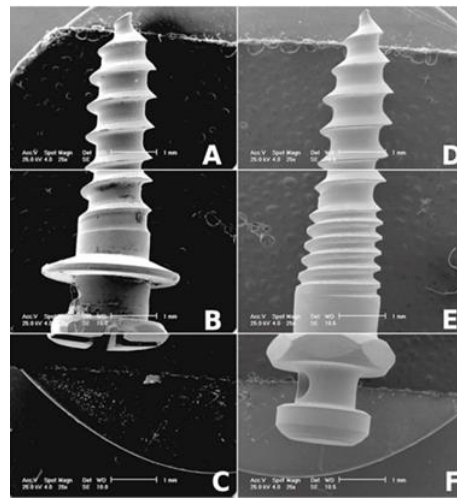
**Figure 9.** Specimens in the agar overlay assay. Cytotoxic activity would induce decoloration of the cells under and next to the specimen. A decolorized zone would be apparent macroscopically- Finke C et al (2018)<sup>22</sup>



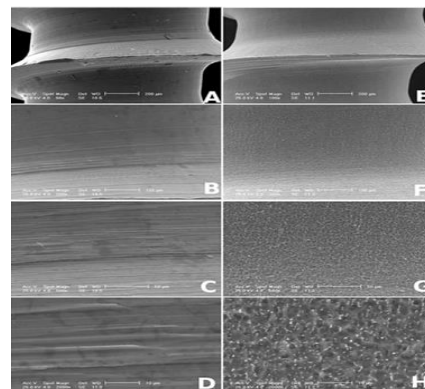
**Figure 10.** The different host- material interfaces of mini-screws- Patwari M (2013)<sup>16</sup>

**b) Tissue Response**

Mini-implants rely on **mechanical stability** rather than osseointegration, but surface features influence tissue adaptation. **Bourzgui et al. (2015)**<sup>40</sup> showed roughened/anodized surfaces improved soft tissue adaptation and reduced bacterial adhesion. **Moldoveanu et al. (2021)**<sup>28</sup> demonstrated that custom-made titanium alloy implants had comparable safety and low cytotoxicity to commercial types.



**Figure 11.a** Scanning electron micrographs (25×) presenting active tip, body and head of custom-made mini-implant (A–C) and commercial mini-screw (D–F)- Moldoveanu A et al(2021)<sup>28</sup>



**Figure 11.b** Scanning electron micrographs (100×, 200×, 500×, 2000×) showing the surface morphology of custom made mini-implant (A–D) and commercial mini-screw (E–H) Moldoveanu A et al(2021)<sup>28</sup>

**c) Corrosion and Ion Release**

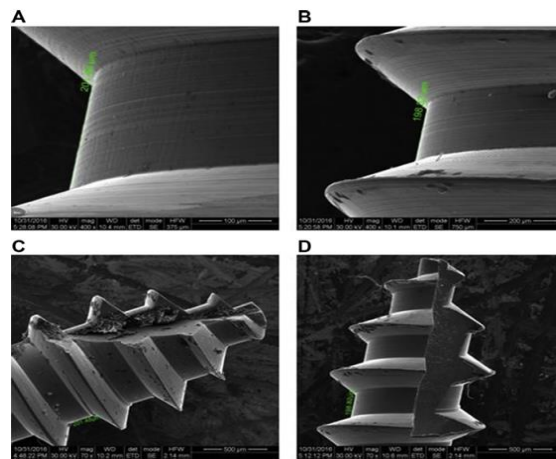
Although corrosion is limited, small amounts of Ti, Al, and V ions can leach into surrounding tissues. High concentrations of Al and V may affect bone metabolism, but studies such as Bucur et al. (2021)<sup>36</sup> confirm levels remain below toxic thresholds, ensuring long-term safety.

**3.10 Recent Advances in Mini Implants**

Continuous research has improved the design, materials, placement techniques, and clinical applications of mini-implants, making them indispensable in orthodontics.

a) Nanotechnology

Nanoparticle coatings (e.g., silver, TiO<sub>2</sub>, ZnO) enhance antibacterial properties, reducing peri-implantitis and improving osseointegration. Nanorobotics is being explored for targeted tooth movement and reduced root resorption, aiming to improve stability and patient comfort.



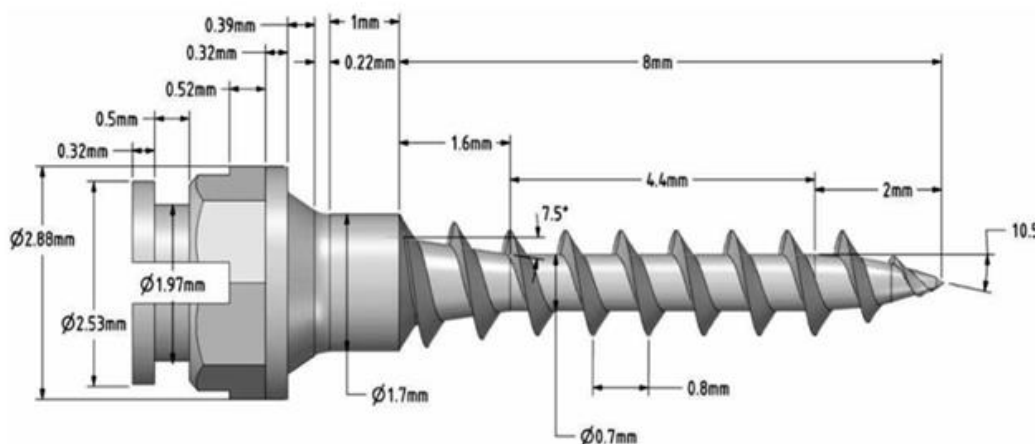
**Figure 12.** SEM analysis. (A) Noncoated titanium implant (control) before insertion. (B) Zirconia-coated titanium implant (experimental) before insertion. (C) Noncoated titanium implant (control) after insertion. (D) Zirconia-coated titanium implant (experimental) after insertion- Giri J et al(2020)<sup>26</sup>

b) Innovative Materials & Surface Modifications

**Titanium alloys (Ti-6Al-4V)** remain the standard for strength and biocompatibility, while stainless steel screws are preferred in dense bone for higher fracture resistance. Surface modifications such as acid etching and sandblasting increase bone-to-implant contact and mechanical interlocking, improving primary stability.

c) Placement Techniques

Digital tools like CBCT, CAD, and 3D-printed surgical guides enable precise placement, minimizing root proximity risks. Extra-radicular screws in areas like the infrazygomatic crest (IZC) and buccal shelf (BS) provide robust anchorage for complex malocclusions.



**Figure 13.** Three-dimensional rendering of the custom-made mini-implant design- Popa D et al(2020)<sup>27</sup>

d) Expanded Clinical Applications

Mini-implants are now central to treatments like molar distalization, maxillary protraction, intrusion of overerupted molars, and Class II/III correction,

reducing dependence on headgear or orthognathic surgery and allowing more conservative treatment plans.

## e) Success Rates & Challenges

High success rates are reported, but issues such as gingival overgrowth, early loosening, and soft tissue irritation persist. Bone screws in dense cortical bone show greater stability than smaller implants. Research is also exploring self-adaptive implants responsive to mechanical forces.

## f) Future Directions

Emerging technologies include drug-eluting implants for local drug delivery, smart implants with sensors for real-time monitoring, and bioengineered resorbable implants that may eliminate removal procedures. Integration with biotechnology and AI promises further breakthroughs in safety and predictability.

## 4. CONCLUSION

Mini-implants, or Temporary Anchorage Devices (TADs), have transformed orthodontics by providing absolute, patient-independent anchorage, unlike traditional methods such as headgear or intraoral appliances. The concept of skeletal anchorage began with Gainsforth and Higley (1945), who placed vitallium screws in dogs, but the first clinical use was reported by Creekmore and Eklund (1983) for deep bite correction. Since then, advances in materials, surface modifications, and insertion techniques have made mini-implants integral to modern orthodontics<sup>32</sup>. Anchorage control, the ability to resist unwanted tooth movement, was traditionally achieved with intraoral devices (transpalatal arch, Nance) or extraoral appliances (headgear), both limited by compliance. TADs overcome this by engaging cortical bone, offering predictable and efficient results, especially in complex cases.

Their stability is crucial—primary stability depends on bone density, implant design, and insertion torque, while secondary stability develops through bone remodelling. Self-drilling screws typically provide superior stability. Factors such as insertion angle, cortical thickness, and patient habits (oral hygiene, smoking) also affect success rates.

Mini-implants are commonly fabricated from titanium (cp titanium, Ti-6Al-4V alloy) for its strength, light weight, corrosion resistance, and biocompatibility.

**Stainless steel (AISI 316L)** is also used for its strength and lower cost, though it may release nickel ions, causing allergic reactions in sensitive patients. Other materials like cobalt-chromium and zirconia are being explored but remain less common. To enhance performance, **surface modifications** such as acid etching, sandblasting, and nanocoatings improve osseointegration and stability. Antimicrobial coatings with chitosan or silver nanoparticles further reduce peri-implant infection risks<sup>40</sup>.

**Corrosion resistance** is critical for longevity. Titanium naturally forms a protective TiO<sub>2</sub> layer that prevents ion release, whereas stainless steel is more prone to localized corrosion in chloride-rich saliva. Titanium implants induce minimal inflammation and show long-term stability, as confirmed by biocompatibility studies<sup>41</sup>. Microscopic studies have shown that alpha-phase titanium offers greater corrosion resistance, while beta-phase provides higher mechanical strength. Increased microporosity also enhances bone integration, further supporting implant stability.

Recent innovations include low-level laser therapy (LLLT) to stimulate bone remodelling and shorten healing, bicortical engagement for improved stability in low-density bone, and 3D-printed custom implants for better anatomical adaptation. CBCT-guided placement has improved insertion precision, minimizing root damage and optimizing positioning<sup>42</sup>.

Overall, mini-implants have revolutionized orthodontic anchorage by offering stable, reliable, and compliance-free solutions. Titanium and its alloys remain the gold standard, while ongoing research into nanotechnology, antimicrobial coatings, and biomechanical optimization continues to refine their safety and effectiveness, ensuring their role as a cornerstone of modern orthodontics<sup>43</sup>.

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### Competing Interests

The authors have no competing interests to declare.

### Ethical Approval

The study was approved by the appropriate ethics committee and conducted according to relevant guidelines and regulations.

### Informed Consent

Not applicable.

## REFERENCES

1. Greenfield EJ. Implantation of artificial crown and bridge abutments. *Dent Cosmos*. 1913;55:364-9.
2. Gainsforth BL, Higley LB. A study of orthodontic anchorage possibilities in basal bone. *Am J Orthod Oral Surg*. 1945;31(8):406-17.
3. Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallén O, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scand J Plast Reconstr Surg Suppl*. 1977;16:1-132.
4. Kanomi R. Mini-implant for orthodontic anchorage. *J Clin Orthod*. 1997;31(11):763-7.
5. Melsen B, Verna C. Miniscrew implants: the Aarhus anchorage system. *Semin Orthod*. 2005;11(1):24-31.
6. Wehrbein H, Glatzmaier J, Yildirim M, Diedrich P. The use of short mid-palatal implants as a means of reinforcing anchorage in orthodontics. *Int J Oral Maxillofac Implants*. 1996;11(5):627-31.
7. Maino BG, Mura P, Bednar J. The Spider Screw for skeletal anchorage. *J Clin Orthod*. 2003;37(2):90-7.
8. Lemons JE. Biomaterials, biomechanics, tissue healing, and immediate-function dental implants. *J Oral Implantol*. 2004;30(5):318-24.
9. Albrektsson T, Brånemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. *Acta Orthop Scand*. 1981;52(2):155-70.
10. Morarend C, Qian F, Marshall SD, Southard KA, Grosland NM, Southard TE. Effect of screw diameter on orthodontic skeletal anchorage. *Am J Orthod Dentofacial Orthop*. 2009;136(2):224-9.
11. Schätzle M, Männchen R, Zwahlen M, Lang NP. Stability changes of chemically modified sandblasted/acid-etched (modSLA) titanium palatal implants: A randomized controlled trial. *Clin Oral Implants Res*. 2009;20(5):489-95.
12. Favero L, Brollo P, Bressan E. Orthodontic anchorage systems: A review of biomechanical and clinical applications. *Orthod Craniofac Res*. 2010;13(3):197-203.
13. Wilmes B, Drescher D. Impact of bone quality, implant type, and implantation site preparation on insertion torques of orthodontic mini-implants. *J Orofac Orthop*. 2011;72(4):263-73.
14. John S, Uthappa R, Krishna NR, Manikandan R. Biomechanical evaluation of different temporary anchorage devices (TADs) in orthodontics. *J Clin Diagn Res*. 2012;6(5):901-5.
15. Knutson K, Katona TR, Paydar NH, Eckert GJ. Electrochemical properties of orthodontic miniscrews in artificial saliva with and without fluoride. *Am J Orthod Dentofacial Orthop*. 2012;142(5):547-56.
16. Patwari M, Rao NR, Jain A, Patel M, Chandrasekaran SC. Cytotoxicity evaluation of four different brands of orthodontic Temporary Anchorage Devices (TADs). *J Clin Diagn Res*. 2013;7(12):2993-6.
17. Sandler PJ, Allen M, Murray A, Hodges SJ. Anchorage reinforcement with temporary anchorage devices vs. Nance palatal arches and headgear: A comparative study. *Am J Orthod Dentofacial Orthop*. 2014;145(5):603-11.
18. Birg J, Wheeler M, Patel MP, Wilson DA. Biocompatibility assessment of five orthodontic miniscrews using human gingival fibroblasts. *J Biomed Mater Res B Appl Biomater*. 2015;103(6):1232-8.
19. Ananthanarayanan P, Gopalakrishnan M, Singh N, Ahuja R. Composition, surface characterization, and corrosion resistance of orthodontic mini-implants: An in vitro study. *J Indian Prosthodont Soc*. 2016;16(2):134-40.
20. Assad-Loss TF, Pithon MM, Hennig E, Oliveira DD. Design, dimensions, and torsional fracture strength of five orthodontic mini-implant brands. *Prog Orthod*. 2016;17(1):29.
21. Durrani Z, Waring D, Ghaffar KA, Horrocks EN. Failure rates of single-thread and dual-thread temporary anchorage devices in orthodontics: A clinical study. *Eur J Orthod*. 2017;39(6):601-7.
22. Finke C, Sader R, Landes C, Schmelzeisen R. In vitro biocompatibility of orthodontic miniscrews with human gingival fibroblast and SAOS-2 osteoblast cultures. *Clin Oral Investig*. 2018;22(2):747-56.
23. Carllin K, Meyer B, Schneider GA. Corrosion properties of orthodontic temporary anchorage devices in artificial saliva with and without fluoride. *J Mater Sci Mater Med*. 2018;29(6):78.
24. Chen YJ, Huang YS, Lin HY, Chen LK. Cytotoxic effects of orthodontic temporary anchorage devices on human periodontal ligament fibroblasts. *Angle Orthod*. 2019;89(4):571-9.
25. Assis do Nascimento C, Paranhos LR, de Medeiros IS, da Silva RA, Simamoto PC, Vasconcellos WA. Surface micromorphology and corrosion resistance of titanium

- alloy and stainless steel temporary anchorage devices. *J Prosthet Dent.* 2020;124(2):270.e1-270.e7.
26. Giri J, Kumar S, Chaturvedi TP. Evaluation of insertion torque and surface integrity of zirconia-coated titanium mini screw implants: An in vitro study. *J Indian Orthod Soc.* 2020;54(1):17-23.
27. Popa D, Toma M, Ivan M, Teodorescu AC, Neacsu IM, Mihai AI. Impact of insertion angle and cortical bone thickness on stress distribution in custom-made orthodontic mini-implants: A 3D finite element analysis. *J Clin Med.* 2020;9(11):3482.
28. Moldoveanu A, Nicoară AI, Martu I, Danila S, Savin C, Ioanid N. In vitro biocompatibility evaluation of titanium alloy orthodontic mini-implants. *Materials (Basel).* 2021;14(17):5011.
29. Song BJ, Kim HJ, Lee JY, Baek SH. Stability of maxillary and mandibular total arch distalization using temporary anchorage devices (TADs) in adults: A retrospective study. *Angle Orthod.* 2022;92(1):98-106.
30. Ioana TR, Vasilescu A, Popescu E, Mitroi MF. Surface analysis of orthodontic mini-implants after their clinical use. *Rom J Morphol Embryol.* 2022;63(1):45-51.
31. Ceratti DP, Fagundes NCF, Souza RS, Karam FK. Effectiveness of maxillary molar distalization using temporary anchorage devices: A systematic review and meta-analysis. *Angle Orthod.* 2024;94(1):57-71.
32. Paul R, Yadav D, Gulia V, Sairal A. History, Design and Evolution of Mini Implants. 1st ed. Innovation Online Training Academy; 2024. 103 p.
33. Ferrillo M, Nucci L, Gallo V, Bruni A, Montrella R, Fortunato L, Giudice A, Perillo L. Temporary anchorage devices in orthodontics: a bibliometric analysis of the 50 most-cited articles from 2012 to 2022. *IOSR J Dent Med Sci.* 2013;7(2):15-20.
34. Sana S, Manjunath G. Mini-implant materials: An overview. *IOSR J Dent Med Sci.* 2024;23(8 Suppl 4):24-9. doi:10.9790/0853-2308042429.
35. Saranya V, Tripathi T. Primary stability of orthodontic mini-implants “The Forgotten Frontier”: A narrative review. *IOSR J Dent Med Sci.* 2024;23(8 Suppl 4):24-9.
36. Bucur SM, Vaida LL, Olteanu CD, Checchi V. A brief review on micro-implants and their use in orthodontics and dentofacial orthopaedics. *Appl Sci.* 2021;11(22):10719. doi:10.3390/app112210719.
37. Padmini MN, Bharathi, Smitha, Hamsa PR. Mini screws as temporary anchorage device in orthodontics: A narrative review. *IOSR J Dent Med Sci.* 2016;15(10 Suppl 9):55-62.
38. Lolage G, Gore K, Jaju K, Patil T, Mahamuni A. Mini-screws in orthodontics: A review. *Sch J Dent Sci.* 2018;5(6):346-51.
39. Paul R. Latest advancement in mini implants. In: *Futuristic Trends in Medical Sciences. IIP Series, Volume 3, Book 12, Part 1, Chapter 30.* e-ISBN: 978-93-6252-091-3.
40. Bourzgui F, Aghoutan H, Sebbar M, Diouny S, Aazzab B. The Temporary Anchorage Device (TAD): A surface characterization study using optical microscopy. *Microscopy: Advances in Scientific Research and Education.* Oct 2015:356-64.
41. Birg J, Wheeler M (2015) Biocompatibility of Temporary Anchorage Devices Using an in vitro Cell Culture Model. *J Dent Oro Surg* 1(1): 102.
42. Mohamed AM, Yang Y, Yaosen C, Badawy R, Alaa M, Maher A. Effect of operator-related factors on failure rate of orthodontic mini implants (OMIS) used as temporary anchorage devices (TAD): A systematic review. *J Dent Oral Care Med.* Sept 2018;4(2):1-11.
43. Jasoria G, Shamim W, Rathore S, Kalra A, Manchanda M, Jaggi N. Miniscrew implants as temporary anchorage devices in orthodontics: A comprehensive review. *J Contemp Dent Pract.* 2013;14(5):993-9.
44. Mohan S, Srinivasan D, Devasahayam D, Kannan R, Arumugam E. Effect of placement angle, diameter, length and bone density on the pull-out strength of orthodontic mini-implants: An in vitro study. *J Orthod.* 2022;49(2):143-150. doi:10.1177/14653125211053338.
45. Yashwant AV, Dilip S, Krishnaraj R, Ravi K. Does change in thread shape influence the pull-out strength of mini implants? An in vitro study. *J Clin Diagn Res.* 2017 May;11(5):ZC17-ZC20.