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Review Article

Temporary anchorage devices in orthodontics: Evolution, applications, and clinical insights

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Abstract

Anchorage control is fundamental to achieving stable and efficient orthodontic treatment outcomes. The development of Temporary Anchorage Devices (TADs) has revolutionized orthodontics by providing reliable, patient-independent anchorage for complex tooth movements. From early skeletal anchorage attempts to the modern use of mini-implants and miniplates, TADs have expanded treatment possibilities, especially in cases where conventional anchorage methods fall short. Understanding the biological and biomechanical principles, optimal placement techniques, and classification systems is vital for clinicians to maximize success rates. TADs play a critical role in applications such as anterior retraction, molar intrusion, distalization, midline correction, and vertical control. Although complications like screw loosening, inflammation, and root proximity exist, careful planning, patient education, and technological advances have improved predictability and patient comfort. Recent innovations including 3D-guided placement, bioactive surface treatments, and digital integration continue to enhance treatment efficiency and patient satisfaction. With ongoing research and interdisciplinary collaboration, TADs are poised to remain a cornerstone of modern orthodontic biomechanics. This review explores these developments comprehensively and highlights the promising future of skeletal anchorage in orthodontics.

Keywords: Complete Denture, Remedies, Troublesome dentures

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1. Introduction

Achieving optimal tooth movement without unwanted reciprocal effects is one of the greatest challenges in orthodontics.[1] A well-established anchorage system is the key to biomechanical control.[2] While traditional anchorage relies on dental units and appliances, their dependence on patient compliance limits their reliability.[3] With the development of skeletal anchorage using TADs, the scope of orthodontics has broadened to include complex movements without reciprocal loss.[4] TADs represent a shift toward predictable, non-compliant anchorage and have become integral in treating patients with high anchorage demands.[5] Detailed understanding of their biological principles and biomechanics is vital for every clinician aiming to provide evidence-based care.[2] Furthermore, the introduction of TADs has led to increased treatment options, improved patient satisfaction, and reduced reliance on invasive procedures.[6] Continuous research and innovation in this field will further refine clinical protocols and enhance treatment predictability, making TADs an indispensable part of modern orthodontic practice.[7] With the increasing popularity of TADs, training programs now emphasize their proper placement and management.[8] A strong grasp of anatomical considerations, insertion techniques, and potential complications is essential.[9] Additionally, patient education about TAD maintenance plays a crucial role in long-term success. The evolution of TADs also reflects the interdisciplinary collaboration between orthodontics and implantology, merging principles from both specialties to optimize outcomes. As research expands, clinicians must stay updated with the latest guidelines and best practices. Peer-reviewed case reports, systematic reviews, and meta-analyses contribute valuable data to refine treatment protocols. Professional societies and conferences increasingly focus on skeletal anchorage, providing platforms for knowledge exchange. Ethical considerations, such as informed consent and patient safety, must always be upheld. Finally, as digital

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dentistry evolves, the integration of digital planning tools with TAD placement is becoming more common, ensuring greater precision and predictability in treatment outcomes.[10]

2. Historical Evolution

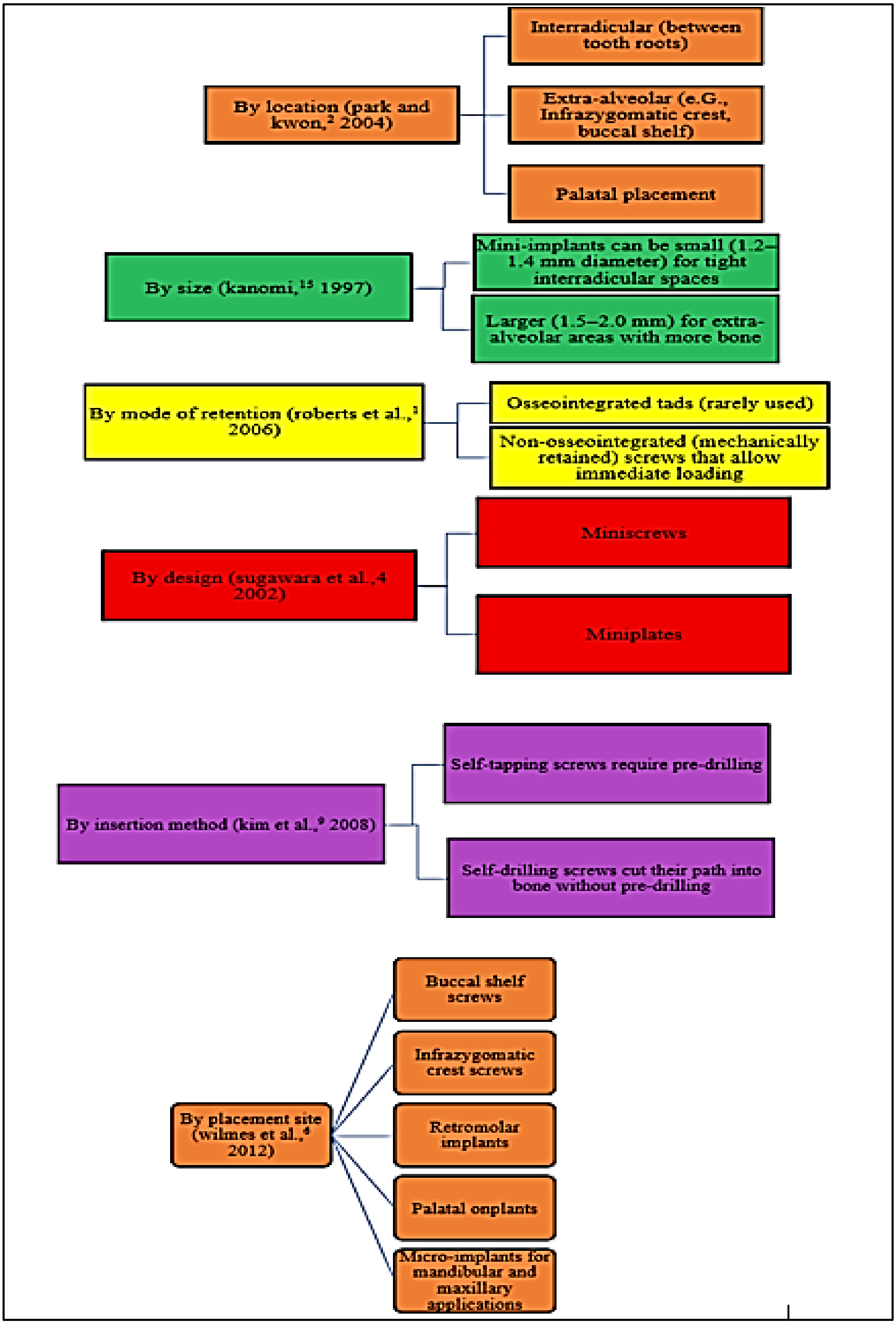
The concept of anchorage in orthodontics has evolved over centuries. Edward Angle laid the groundwork by defining anchorage types in the early 20th century,[1] recognizing the limits of intraoral anchorage. In 1945, Gainsforth and Higley[12] implanted vitallium screws in dogs, pioneering skeletal anchorage despite high failure rates due to poor aseptic techniques. In the 1960s, Per-Ingvar Branemark's[13] discovery of osseointegration transformed implantology, setting the stage for stable intraosseous devices. Creekmore and Eklund's3 landmark case in 1983 demonstrated the first use of a bone screw in a human for incisor intrusion. The 1990s saw the introduction of the Straumann Orthosystem and palatal implants, expanding placement sites.[1] Sugawara's4 Skeletal Anchorage System (SAS) used miniplates fixed to the zygomatic buttress, providing greater stability for open bite and molar intrusion cases. Kyung et al.[5] popularized miniscrews in the early 2000s, favoring self-drilling designs that allowed immediate loading. Research by Park,[2] Wilmes6 and Maino,8 refined insertion protocols and force mechanics. The history reflects a shift from prosthetic implants to temporary skeletal anchorage that minimizes osseointegration, favoring removal after treatment. Collaborative advances in implantology, materials science, and digital imaging have made TAD placement safer and more predictable. Today, TADs are a standard tool in modern orthodontic biomechanics, bridging the gap between conventional and surgical orthodontics while reducing dependence on patient compliance. This rich history underscores decades of trial, innovation, and clinical research that shaped contemporary skeletal anchorage. Additionally, advancements in CBCT imaging and digital workflow planning have further improved placement accuracy and patient outcomes.[10] International guidelines and consensus statements now offer clear protocols, ensuring uniformity in clinical practice. As awareness grows, ongoing studies continue to refine best practices, driving the next era of skeletal anchorage innovation. Training and workshops worldwide have made TAD techniques accessible even to general practitioners. Case studies continue to illustrate their success in challenging malocclusions. With interdisciplinary collaboration, the future of skeletal anchorage looks increasingly promising as newer materials and customized designs are developed.

3. Biological and Biomechanical Principles

The biological and biomechanical principles underlying TADs are crucial for their successful use in clinical practice.[14] TADs achieve stability primarily through mechanical retention in the cortical bone rather than full osseointegration, allowing immediate loading in most cases.[1] The thickness of cortical bone, insertion angle, screw diameter, and thread design all play vital roles in achieving primary stability.[9] Denser cortical bone offers better anchorage and reduces the risk of screw loosening.[5] Biomechanically, TADs provide absolute anchorage, eliminating unwanted reciprocal forces that can compromise treatment goals.[2] Forces can be applied with precision to achieve controlled tooth movement in three dimensions, including complex movements like molar intrusion and en-masse retraction.[6] Factors such as optimal force levels, vector direction, and stress distribution are carefully considered to prevent micro-movements and ensure long-term stability.[8] Root proximity, soft tissue type, and patient-specific bone density must be evaluated through CBCT imaging before placement.[10] A strong understanding of bone remodeling dynamics helps clinicians anticipate how forces will be transferred to surrounding structures during treatment. Additionally, emerging concepts like micro-implant surface treatments aim to enhance bone contact and reduce micro-movement under load. Advances in thread design and surface coatings, such as sandblasting and acid etching, have shown promise in improving mechanical retention. Proper biomechanical planning ensures that TADs act as reliable anchors without compromising adjacent anatomical structures. Finite element analysis and biomechanical modeling contribute valuable insights into stress distribution and force systems, helping clinicians optimize treatment mechanics.[1] Understanding these principles also assists in troubleshooting failures and planning re-insertion if mobility occurs. Long-term studies continue to refine insertion protocols, insertion torque recommendations, and surface modifications to enhance stability and patient comfort.

3.1. Classification of TADs

TADs have been classified by various authors using different criteria to better guide clinical use


By location (park and kwon,2 2004)
Interradicular (between tooth roots)
Extra-alveolar (e.G., Infrazygomatic crest, buccal shelf)
Palatal placement
By size (kanomi,15 1997)
Mini-implants can be small (1.2–1.4 mm diameter) for tight interradicular spaces
Larger (1.5–2.0 mm) for extra-alveolar areas with more bone
By mode of retention (roberts et al.,1 2006)
Osseointegrated tads (rarely used)
Non-osseointegrated (mechanically retained) screws that allow immediate loading
By design (sugawara et al.,4 2002)
Miniscrews
Miniplates
By insertion method (kim et al.,9 2008)
Self-tapping screws require pre-drilling
Self-drilling screws cut their path into bone without pre-drilling
By placement site (wilmes et al.,4 2012)
Buccal shelf screws
Infrazygomatic crest screws
Retromolar implants
Palatal onplants
Micro-implants for mandibular and maxillary applications

4. Discussion

4.1. Clinical applications

Temporary Anchorage Devices (TADs) have a wide range of applications that have greatly expanded over time. This section explains each major clinical application in detail, highlighting how TADs are used, why they are preferred, and what clinical outcomes can be expected.

1. **Anterior En-masse retraction:** TADs provide a stable, non-compliant anchorage point for retracting anterior segments after premolar extractions. This prevents unwanted mesial movement of posterior teeth, ensuring maximum space closure and ideal incisor inclination. They are especially useful in high anchorage cases such as bimaxillary protrusion.14[14]
2. **Molar intrusion for anterior open bite correction**: TADs can intrude supra-erupted molars by applying vertical forces directly to molar crowns. This promotes mandibular autorotation, improving facial aesthetics and achieving stable closure of anterior open bites without surgery.[4]

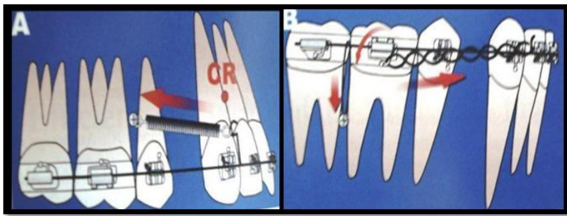


Figure 1: Anterior en-masse retraction using TADs

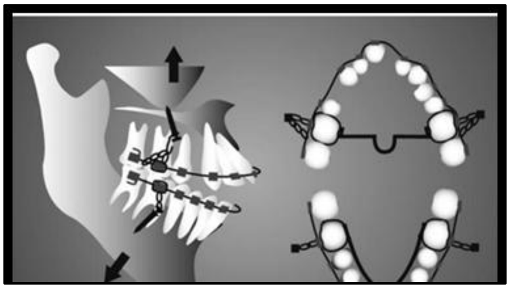


Figure 2: Molar intrusion for anterior open bite correction using titanium screw anchorage

4.2. Molar distalization in Class II malocclusion treatment

TADs provide absolute anchorage to distalize upper molars and premolars, reducing the need for headgear. Distalization can be performed with coil springs or sliding jigs connected to palatal or buccal screws, maintaining arch form.[6]

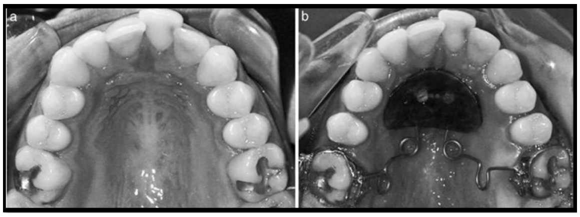


Figure 3: Bone-anchored pendulum appliance (BAPA)

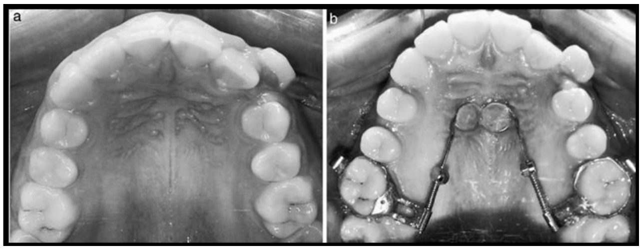


Figure 4: Miniscrew implant supported distalization system (MISDS)

4.3. Total arch distalization

Using systems like the Beneslider, TADs placed in the palate can distalize the entire maxillary arch en-masse, minimizing side effects like molar tipping. This approach provides excellent control for non-extraction Class II corrections.[6]

Figure 5: Beneslider* distalization appliance

4.4. Vertical dimension control

Anterior teeth can be intruded to manage deep overbites or reduce excessive gingival display. TADs make this possible by resisting reactive forces, ensuring precise vertical movement without unwanted extrusion elsewhere.[14]

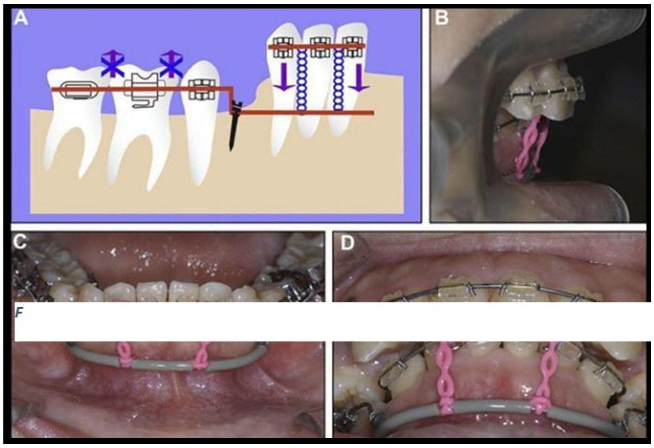


Figure 6: Indirect usage of miniscrew anchorage to intrude over erupted mandibular incisor

4.5. Crossbite correction

TADs provide skeletal anchorage for expansion appliances and springs to correct posterior or anterior crossbites. They prevent molar tipping and enhance skeletal expansion effects.[8]

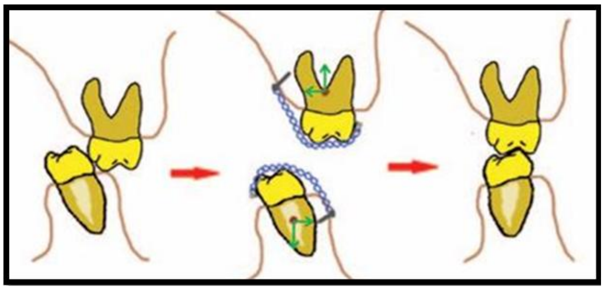


Figure 7: scissor-bite correction after bite raising with bonded composite turbos.

4.6. Molar uprighting

When molars are tipped due to long-term edentulous spaces, TADs serve as anchorage to apply uprighting springs or coil mechanics, restoring occlusal contacts and space for prosthetics.[2]

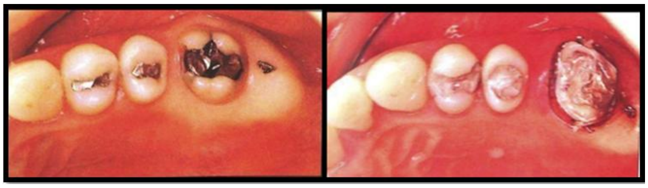


Figure 8: Implant on the maxillary tuberosity molar uprighted

4.7. Space closure and protraction

In cases of missing teeth, TADs help protract posterior teeth mesially to close spaces, avoiding prosthetic replacement. This is especially valuable when alveolar ridge conditions allow controlled bodily movement.[1]

Figure 9: Molar Mesialization with mini implants

4.8. Occlusal cant correction

Vertical anchorage with TADs enables selective intrusion or extrusion of teeth to correct occlusal plane cants, enhancing smile aesthetics and functional balance.[4]

Figure 10: Correction of canted occlusal plane

4.9. Expansion mechanics

Palatal or buccal TADs can anchor expanders like the Hybrid Hyrax, delivering skeletal expansion in adolescents and adults while minimizing dental tipping.[10]

Figure 11: Miniscrew assisted palatal expansion

4.10. Impacted teeth traction

TADs provide fixed points for elastics or coil springs to guide impacted canines or premolars into the arch, reducing unwanted reciprocal effects on adjacent teeth.[9]

Figure 12: Extrusion of impacted canines using TADs

5. Complications and Risk Management

While Temporary Anchorage Devices (TADs) generally demonstrate high success rates, various complications have been documented in clinical studies.[9,16]

5.1. Screw loosening

One of the most common complications reported is screw loosening, which can significantly compromise anchorage control. This often occurs due to inadequate primary stability during placement, insufficient cortical bone thickness at the insertion site, or excessive orthodontic forces applied before osseointegration or mechanical retention is adequate. Studies have shown that overloading TADs, poor bone quality, or micro-movements under functional forces can all contribute to screw loosening and subsequent failure.[17]

5.2. Soft tissue overgrowth & irritation

When TADs are placed in areas with non-keratinized mucosa, the surrounding soft tissue may proliferate over the screw head, leading to irritation and inflammation. This overgrowth can trap plaque and food debris, increasing the risk of local infection and patient discomfort. Soft tissue irritation is more prevalent in cases where hygiene is poor or where the screw head design does not adequately maintain clearance from soft tissues.[14]

5.3. Peri-implantitis

Similar to dental implants, TADs can develop peri-implantitis, which is characterized by inflammation and progressive bone loss around the implant site. This complication is most commonly associated with inadequate oral hygiene and plaque accumulation, which lead to bacterial colonization around the screw. If not managed early, peri-implantitis can result in implant mobility and complete failure of anchorage.[10]

5.4. Root contact

Accidental contact between the TAD and the root of an adjacent tooth during insertion is another significant complication. Root damage can lead to root resorption, pulp necrosis, or periodontal ligament trauma, all of which jeopardize both the TAD's stability and the affected tooth's vitality. Meticulous pre-insertion imaging and careful angulation during placement are critical to minimizing this risk.[1]

5.5. Insertion errors

Technical errors such as improper insertion angles, choosing an inappropriate screw length or diameter, or placing the screw in regions with insufficient cortical bone thickness can increase the likelihood of failure. Misplacement in high-mobility bone regions may also result in micro-movements under load, eventually leading to screw loosening or failure. Clinician experience and precision are key factors in avoiding these errors.[9]

5.6. Allergic reactions

Though rare, hypersensitivity reactions to implant materials like titanium or its alloys have been reported in some patients. Symptoms may include localized swelling, discomfort, or even systemic reactions in highly sensitive individuals. Thorough medical history taking and awareness of patient allergies are necessary to minimize this risk.[16]

To minimize these complications, thorough pre-treatment planning with CBCT scans is essential to identify optimal insertion sites with sufficient bone and safe root distances.[17] Using surgical guides improves placement accuracy, while appropriate selection of screw length, diameter, and insertion torque ensures better primary stability. Regular follow-up visits and patient education on strict oral hygiene help prevent peri-implant inflammation. If early mobility is detected, timely repositioning or replacement can salvage treatment outcomes. Innovations like surface-treated and bioactive coated miniscrews further enhance bone retention. Ultimately, clinician training in proper insertion techniques, understanding anatomical risks, and prompt complication management are key to maintaining high success rates and patient comfort when using TADs for orthodontic anchorage.

6. Recent Advances and Future Directions

Recent years have seen remarkable innovations aimed at improving the predictability, comfort, and success rates of TADs. New surface treatments, such as nano-texturing, sandblasting, acid etching, and bioactive coatings, are being developed to enhance bone contact and stability.[17] 3D CBCT-guided surgical templates allow clinicians to plan optimal insertion sites and angles, minimizing root contact risks.[16] Digital workflows now integrate CAD/CAM technology for custom-made appliances that connect directly to TADs, improving biomechanics and patient comfort. Researchers are exploring bioresorbable anchorage devices made of polylactide materials, which eliminate the need for removal surgery and improve patient acceptance. Robotic-assisted insertion and navigation systems are being tested to provide ultra-precise placement, especially in anatomically challenging regions. Artificial intelligence is also finding its place by predicting optimal sites based on individual bone density maps and providing decision support for force vectors. Future directions include smart TADs with embedded sensors that monitor load, micro-movements, and tissue healing, giving real-time feedback to clinicians for timely intervention. Interdisciplinary collaboration with implantology, periodontology, and biomaterials science promises the development of advanced titanium alloys, antibacterial coatings, and bioactive surfaces that resist infection and promote faster osseointegration when needed. Studies on patient-reported outcomes, such as discomfort levels, speech impact, and long-term satisfaction, are helping to establish evidence-based protocols and improve patient-centered care. As clear aligner therapy evolves, TADs will continue to play a vital role by providing supplemental skeletal anchorage in complex hybrid treatments that combine fixed appliances and aligners.

7. Conclusion

TADs have revolutionized the concept of anchorage in orthodontics, providing reliable, versatile, and patient-independent solutions for complex tooth movements. As technology evolves, the integration of digital workflows, advanced biomaterials, and precision-guided placement will continue to enhance the success and scope of TADs in modern orthodontic practice.

8. Source of Funding

None.

9. Conflict of Interest

None.

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