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REVIEW ARTICLE

TEMPORARY ANCHORAGE DEVICES IN ORTHODONTICS: A SCOPING REVIEW OF CLINICAL APPLICATIONS, DIGITAL WORKFLOW, AND ARTIFICIAL INTELLIGENCE IN TREATMENT PLANNING

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Abstract

Background: Temporary anchorage devices (TADs) have transformed orthodontic treatment by providing reliable skeletal anchorage for complex tooth movements while reducing dependence on patient compliance. In recent years, advances in cone-beam computed tomography (CBCT), intraoral scanning, three-dimensional (3D) imaging, and artificial intelligence (AI) have introduced new possibilities for individualized TAD planning, improving insertion accuracy and biomechanical efficiency. Despite these developments, the available evidence remains scattered across different areas of orthodontic research.

Objective: This scoping review aimed to map the current evidence on the clinical applications of TADs, summarize factors influencing their success, and explore the emerging role of digital technologies and AI-assisted planning in optimizing orthodontic treatment.

Methods: A scoping review was conducted according to the PRISMA-ScR guidelines and JBI methodology. Electronic searches were performed in PubMed, Scopus, Web of Science, Embase, and Google Scholar for studies published between 2015 and 2026. Clinical studies, randomized trials, observational studies, systematic reviews, and relevant reports evaluating orthodontic TADs, digital workflows, or AI-assisted planning were included.

Results: The mapped evidence demonstrated that TADs provide predictable skeletal anchorage for space closure, molar distalization, intrusion, extrusion, open-bite correction, and management of complex malocclusions. Clinical success is influenced by anatomical site, cortical bone thickness, insertion technique, primary stability, loading protocol, and oral hygiene. Recent evidence indicates that AI-based image analysis, CBCT segmentation, automated anatomical landmark detection, and digital treatment planning may improve TAD positioning, reduce the risk of root injury, and support personalized biomechanical planning. However, clinical validation of AI-assisted systems remains limited.

Conclusions: Temporary anchorage devices remain an essential component of contemporary orthodontics, while digital technologies and artificial intelligence are expanding their clinical potential through more precise and individualized treatment planning. Future prospective studies should focus on validating AI-assisted planning systems and integrating them into routine orthodontic practice.

Keywords: temporary anchorage devices; orthodontic mini-implants; skeletal anchorage; artificial intelligence; digital orthodontics; Smartee S4 technology; CBCT; treatment planning.

INTRODUCTION

Orthodontic treatment has evolved considerably over the past decades, moving beyond simple correction of dental alignment toward a comprehensive approach focused on controlled tooth movement, skeletal relationships, and individualized biomechanical strategies. Among the factors determining treatment predictability, anchorage control remains one of the fundamental challenges in orthodontics. The ability to maintain stable anchorage while applying controlled orthodontic forces is essential for achieving predictable treatment outcomes, particularly in complex malocclusions requiring significant tooth movement [1].

Conventional anchorage methods, including extraoral appliances, transpalatal arches, and intermaxillary elastics, have contributed significantly to orthodontic treatment; however, their effectiveness may be limited by factors such as patient compliance, unwanted reciprocal tooth movement, and insufficient control during complex biomechanical procedures. These limitations have encouraged the development of alternative anchorage strategies capable of providing more reliable and predictable force control [2].

The introduction of temporary anchorage devices (TADs), including orthodontic mini-implants and miniscrews, has represented a major advancement in modern orthodontics by providing a reliable method of skeletal anchorage. Unlike conventional dental anchorage systems, TADs obtain support directly from the surrounding alveolar bone, allowing orthodontists to apply controlled forces without depending exclusively on adjacent teeth. This biomechanical concept has expanded the scope of orthodontic treatment and enabled predictable management of challenging clinical situations, including severe anchorage requirements, complex space closure, molar movement, and vertical control problems [3,4].

Clinical applications of TADs have progressively expanded and currently include anterior en-masse retraction, extraction space closure, molar distalization and mesialization, intrusion of anterior and posterior teeth, open-bite correction, and correction of asymmetric dental relationships. The clinical value of TAD-assisted mechanics extends beyond anchorage reinforcement, as these devices allow the application of forces from strategically selected anatomical locations, improving biomechanical efficiency and reducing undesirable dental effects. In selected cases, TAD-assisted approaches may also provide minimally invasive alternatives to more complex surgical procedures [5,6].

In clinical practice, skeletal anchorage can also be complemented by aligner mechanics, such as the Smartee S4 technology. The S4 framework utilizes strategically configured power arms—rigid levers attached to teeth or aligner structures—and precise touch-and-aligner contact dynamics to direct force vectors closer to the center of resistance, thereby enhancing root torque and bodily tooth movement during complex treatment phases (Figure 1).

Figure 1. S4 intelligent power arm & TADs

Despite their widespread clinical adoption, the success and predictability of TAD treatment remain dependent on multiple biological, anatomical, and mechanical variables. Factors including insertion site, cortical bone thickness, bone quality, implant dimensions, insertion torque, loading protocol, soft tissue characteristics, and peri-implant inflammation may influence primary stability and long-term success. Anatomical limitations such as inadequate interradicular space, unfavorable root proximity, insufficient cortical support, and proximity to critical structures represent important challenges during placement. Therefore, accurate preoperative assessment and individualized treatment planning are essential components of successful TAD-assisted orthodontic therapy [4–6].

Recent advances in digital orthodontics have provided new opportunities to improve the accuracy and predictability of TAD planning by enabling detailed assessment of patient-specific anatomy. Cone-beam computed tomography (CBCT), three-dimensional reconstruction, intraoral scanning, and computer-assisted treatment planning allow clinicians to evaluate dental roots, cortical bone morphology, and anatomical boundaries with greater precision than conventional two-dimensional imaging approaches. These technologies have contributed to a transition from experience-based placement toward a more systematic, anatomy-driven planning strategy [7–9].

Artificial intelligence (AI) has recently emerged as a promising extension of digital orthodontic workflows. AI-based technologies have demonstrated potential applications in automated image interpretation, anatomical structure segmentation, landmark detection, predictive modeling, and clinical decision-support systems. Within TAD-assisted orthodontics, AI may provide additional value by analyzing CBCT-derived anatomical information, identifying potential insertion corridors, evaluating root–bone relationships, and assisting clinicians in selecting implant positions that optimize biomechanical requirements while maintaining anatomical safety [10–12].

However, despite increasing interest in AI applications within orthodontics, the specific role of artificial intelligence in TAD planning remains at an early stage of clinical development. Current evidence is mainly focused on algorithm development, image analysis, segmentation techniques, and preliminary technical validation, whereas clinical implementation and patient-centered outcome evaluation remain limited. Furthermore, important challenges include the absence of standardized AI-assisted planning protocols, the need for external validation across diverse patient populations, potential limitations related to training dataset variability, and incomplete integration into routine orthodontic workflows. Future studies are required to determine whether AI-assisted planning can provide clinically meaningful improvements in TAD placement accuracy, safety, treatment efficiency, and long-term outcomes compared with conventional approaches [13–15].

The convergence of temporary anchorage devices, three-dimensional imaging, and artificial intelligence represents a potential transition toward a more personalized model of orthodontic treatment planning. By integrating patient-specific anatomical information obtained from CBCT, biomechanical principles, and AI-based analytical tools, future digital workflows may improve insertion site selection, optimize miniscrew positioning, and reduce placement-related complications. Nevertheless, clinical implementation of these technologies requires stronger evidence regarding accuracy, reproducibility, external validity, and long-term effectiveness [16,17].

Therefore, this scoping review aims to comprehensively map the current evidence regarding the clinical applications of temporary anchorage devices in orthodontics, summarize factors influencing their stability and treatment outcomes, and explore the emerging role of digital workflows and artificial intelligence in personalized TAD-assisted treatment planning.

By integrating established principles of skeletal anchorage with recent advances in digital dentistry and AI technologies, this review seeks to identify current knowledge gaps and highlight future directions for safer, more predictable, and individualized orthodontic care.

2. METHODS

2.1 Study Design and Methodological Framework

This study was conducted as a scoping review following the methodological recommendations of the Joanna Briggs Institute (JBI) and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines [18-20]. A scoping review methodology was selected because the field of temporary anchorage devices (TADs) in orthodontics includes a wide range of clinical applications, biomechanical approaches, and rapidly emerging digital technologies. Unlike systematic reviews focusing on a narrowly defined clinical question, scoping reviews allow comprehensive mapping of available evidence, identification of knowledge gaps, and exploration of emerging concepts such as artificial intelligence-assisted treatment planning. The primary objective of this review was to characterize the current evidence regarding the clinical applications of orthodontic TADs, factors affecting their stability and success, and the integration of digital technologies, including three-dimensional imaging and artificial intelligence (AI)-based planning approaches, into contemporary orthodontic practice.

2.2 Review Question and PCC Framework

The research question was developed according to the Population–Concept–Context (PCC) framework recommended by the JBI methodology[18]. The PCC framework was selected to ensure a structured approach for identifying relevant evidence and defining the scope of the review.

The Population included patients undergoing orthodontic treatment who required skeletal anchorage for controlled tooth movement. The Concept focused on temporary anchorage devices, including orthodontic mini-implants and miniscrews, their clinical applications, biomechanical principles, treatment outcomes, complications, and emerging AI-assisted planning methods. The Context included conventional orthodontic approaches as well as modern digital workflows incorporating cone-beam computed tomography (CBCT), three-dimensional imaging, computer-assisted planning, and artificial intelligence technologies. The detailed eligibility framework based on the PCC approach is presented in **Table 1**.

Table 1. Eligibility Criteria According to the PCC Framework

Category	Description
Population	Patients receiving orthodontic treatment requiring skeletal anchorage
Concept	TADs, mini-implants, biomechanics, complications, AI planning
Context	CBCT, 3D imaging, guided placement, AI
Evidence sources	RCTs, observational studies, case series, reviews
Publication period	Jan 2015–Jul 2026
Language	English
Inclusion	Clinical TAD or AI studies
Exclusion	Animal/lab/non-orthodontic/abstracts

2.3 Literature Search Strategy

A comprehensive literature search was performed in the electronic databases PubMed/MEDLINE, Scopus, Web of Science, Embase, and Google Scholar. The search strategy was developed using a combination of controlled vocabulary terms (MeSH terms where applicable) and free-text keywords related to temporary anchorage devices, orthodontic applications, digital imaging, and artificial intelligence.

The following Boolean search strategy was applied:

("temporary anchorage device" OR "orthodontic mini-implant" OR "orthodontic miniscrew*" OR miniscrew* OR "skeletal anchorage")
AND
(orthodontic* OR malocclusion* OR "orthodontic treatment" OR "tooth movement")
AND
(CBCT OR "cone beam computed tomography" OR "three-dimensional imaging" OR "digital orthodontics" OR "computer-assisted planning" OR "artificial intelligence" OR "machine learning")**

Additional searches were performed using related terms and reference list screening of relevant publications to identify potentially eligible studies. The search was limited to English-language publications published between January 2015 and July 2026.

2.4 Study Selection Process

All retrieved records were collected and screened after removal of duplicates. Two independent reviewers performed title and abstract screening according to predefined eligibility criteria. Potentially relevant studies were subsequently assessed through full-text evaluation. Studies were included when they provided clinical information regarding TAD application, treatment outcomes, biomechanical considerations, or digital and AI-based approaches related to orthodontic anchorage. Any disagreement between reviewers was resolved through discussion and consensus.

2.5 Data Extraction and Charting

Data extraction was performed using a standardized data-charting form developed according to the objectives of the review. Extracted variables included bibliographic information, study characteristics, patient demographics, TAD-related parameters, clinical indications, treatment outcomes, complications, and digital technologies used. For studies involving artificial intelligence, additional information was collected regarding the type of AI application, imaging modality, algorithmic function, clinical purpose, and reported advantages or limitations.

The complete data extraction framework is summarized in **Table 2**.

Table 2. Data Extraction Framework for Included Studies

Data domain	Extracted variables
Bibliographic information	Author, year, country
Study characteristics	Design, sample, follow-up
Patient characteristics	Age, sex, diagnosis
TAD characteristics	Type, dimensions, site
Clinical application	Retraction, intrusion, distalization
Biomechanical factors	Force direction, anchorage
Treatment outcomes	Success, stability, complications
Digital/AI	CBCT, 3D, segmentation, prediction

2.6 Data Synthesis

Due to the expected heterogeneity among included studies regarding clinical protocols, patient populations, TAD designs, and outcome measures, a qualitative descriptive synthesis was performed rather than a quantitative meta-analysis. The findings were organized into major thematic categories, including clinical applications of TADs, factors influencing treatment success, complications, digital orthodontic workflows, and emerging AI-based approaches for personalized TAD planning.

3. RESULTS

3.1 Study Selection and Characteristics of Included Evidence

The literature search identified studies investigating the clinical applications of temporary anchorage devices (TADs), their biomechanical performance, treatment outcomes, complications, and recent developments in digital orthodontic planning. The study selection process was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) framework (**Figure 1**). The initial search identified 96 records. After removal of 24 duplicate records, 72 studies remained for title and abstract screening. Following the screening process, 28 records were excluded due to irrelevance to the review objectives or failure to meet the predefined eligibility criteria. Subsequently, 44 full-text articles were assessed for eligibility, and 8 articles were excluded because of insufficient clinical information, inappropriate study design, or lack of relevance to TAD applications and AI-assisted orthodontic planning. Finally, 36 studies were included in the qualitative synthesis.

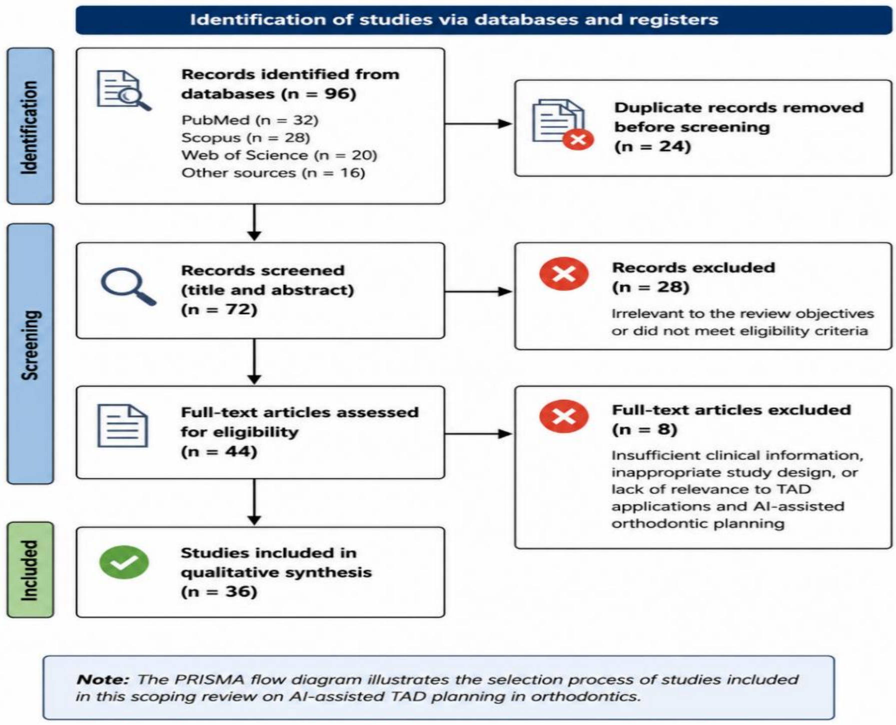

Figure 2. PRISMA-ScR flow diagram illustrating the study selection process.

The included evidence comprised randomized clinical trials, prospective and retrospective clinical studies, observational investigations, case series, and evidence-based reviews. The selected studies evaluated different orthodontic indications, including anterior retraction, molar distalization, intrusion, open-bite correction, asymmetric tooth movement, and anchorage reinforcement.

The main characteristics of the included studies, including study design, population, TAD application, digital technologies, and reported outcomes, are summarized in **Table 3**.

Table 3. Overview of the Characteristics of Included Studies

Evidence domain	Characteristics of included evidence
Study design	RCTs, prospective, retrospective, observational, reviews
Population	Adolescent and adult orthodontic patients
Applications	Retraction, distalization, intrusion, open bite
Outcomes	Anchorage, stability, complications
Biomechanics	Insertion site, cortical bone, loading
Digital/AI	CBCT, 3D planning, AI

3.2 Clinical Applications of Temporary Anchorage Devices

The analyzed evidence demonstrates that TADs have become an important component of contemporary orthodontic treatment by providing stable skeletal anchorage for complex tooth movements. The most frequently reported applications included anterior en-masse retraction, molar distalization, posterior intrusion, correction of open bite, management of asymmetric malocclusions, and reinforcement of anchorage during comprehensive orthodontic therapy.

The major advantage of TAD-assisted mechanics is the ability to apply orthodontic forces from a stable skeletal base, reducing unwanted reciprocal tooth movement and improving biomechanical control. The clinical applications and their treatment objectives are summarized in **Table 4**.

Table 4. Clinical Applications and Biomechanical Objectives of Temporary Anchorage Devices

Clinical application	Treatment objective	Biomechanical advantage
Anterior retraction	Correct protrusion	Absolute anchorage
Molar distalization	Sagittal correction	Controlled movement
Posterior intrusion	Open bite	Intrusive force
Molar mesialization	Space closure	Skeletal support
Asymmetry	Unilateral correction	Differential forces
Complex mechanics	Anchorage	Predictability

3.3 Factors Influencing TAD Stability and Clinical Outcomes

The clinical performance of TADs is influenced by a combination of mechanical, anatomical, and patient-related factors. The reviewed studies emphasized that successful placement depends not only on implant characteristics but also on careful evaluation of the surrounding anatomical environment.

Important factors include cortical bone thickness, insertion site selection, implant dimensions, loading protocol, peri-implant tissue condition, and operator experience. In particular, three-dimensional assessment of root position and available bone volume has become increasingly important for reducing placement-related complications.

The main factors affecting TAD success are summarized in **Table 5**.

Table 5. Factors Influencing Clinical Success and Failure Risk of Orthodontic Temporary Anchorage Devices

Factor	**Influence on Clinical Outcome**	Clinical relevance
Cortical bone thickness and density	Determines the primary mechanical stability of the temporary anchorage device after insertion	Adequate cortical bone improves initial stability and reduces the likelihood of early failure
Root proximity and interradicular space	Influences the availability of a safe insertion corridor and the risk of root injury	Preoperative CBCT evaluation facilitates accurate site selection and minimizes iatrogenic complications
Implant dimensions (diameter and length)	Affect bone engagement, mechanical retention, andresistance to orthodontic loading	Appropriate implant dimensions enhance stability while reducing the risk of loosening or fracture
Insertion site selection	Determines the quality of surrounding bone and soft tissues as well as biomechanical efficiency	Proper anatomical site selection contributes to predictable force application and long-term clinical success
Insertion technique and angulation	Influence placement accuracy, primary stability, and stress distribution around the implant	Correct insertion technique minimizes surgical complications and improves treatment outcomes
Orthodontic loading protocol	Determines the magnitude and direction of forces transmitted to the implant–bone interface	Appropriate loading protocols help maintain implant stability throughout treatment
Peri-implant soft tissue health and oral hygiene	Influence the development of peri-implant inflammation and soft tissue complications	Good oral hygiene reduces inflammation and contributes to long-term clinical success
Treatment planning and operator experience	Affect placement accuracy, biomechanical planning, and overall clinical decision-making	Careful planning supported by digital imaging improves treatment predictability and reduces failure risk

3.4 Digital Workflow and Artificial Intelligence-Assisted Personalized TAD Planning

The integration of digital technologies has introduced new possibilities for individualized orthodontic anchorage planning. CBCT-based three-dimensional reconstruction allows detailed visualization of dental roots, cortical bone morphology, and anatomical limitations before TAD placement.

Artificial intelligence-based systems may further enhance this process by assisting with automated segmentation of anatomical structures, identification of relevant landmarks, and analysis of patient-specific characteristics.

By integrating CBCT-derived information with orthodontic treatment objectives, AI-assisted platforms may support personalized selection of insertion sites, trajectories, and implant parameters. The proposed AI-assisted digital workflow for personalized TAD planning is illustrated in Figure 3.

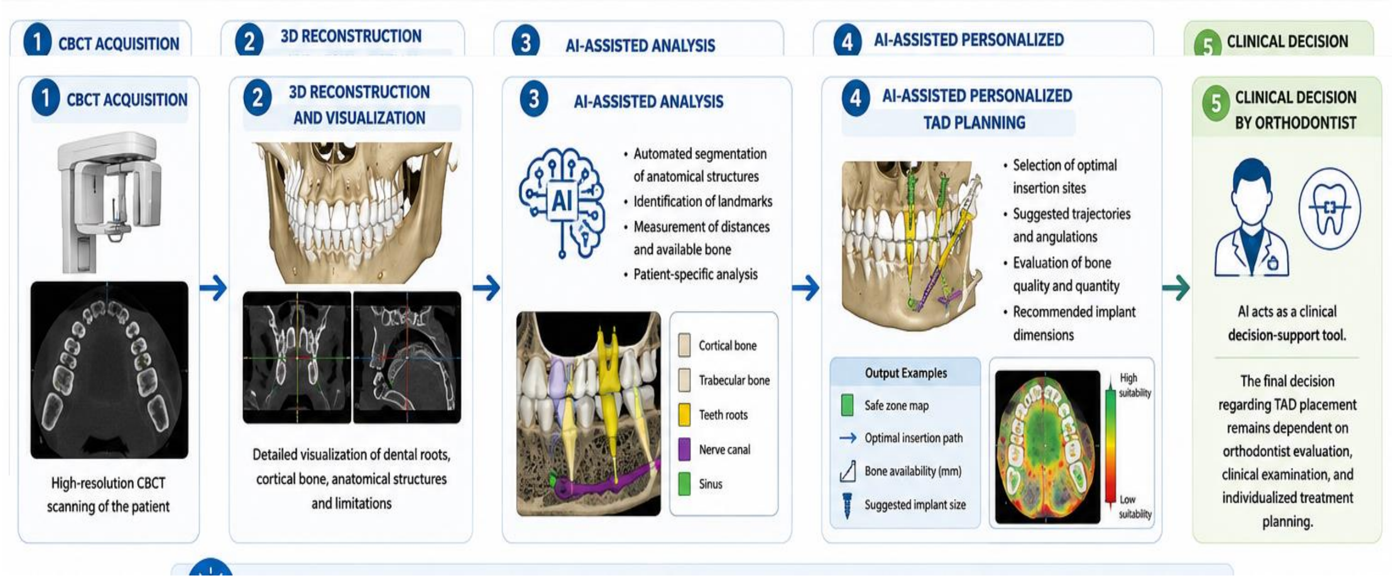

Figure 3. Digital Workflow of Artificial Intelligence–Assisted Personalized Temporary Anchorage Device (TAD) Planning.

Importantly, AI functions as a clinical decision-support tool rather than an autonomous treatment system. The final decision regarding TAD placement remains dependent on orthodontist evaluation, clinical examination, and individualized treatment planning.

The proposed AI-assisted personalized planning parameters are summarized in **Table 6**.

3.5 AI-Assisted Risk Stratification for Prevention of TAD-Related Complications

Beyond treatment planning, artificial intelligence may provide additional value through patient-specific risk assessment. By analyzing CBCT-derived anatomical information, AI-assisted systems may help identify conditions associated with increased risk of complications, including insufficient interradicular space, unfavorable root proximity, inadequate cortical support, or inappropriate insertion trajectories. Rather than applying universal placement rules, AI-assisted risk stratification allows individualized evaluation of anatomical variations and supports safer clinical decision-making. The proposed AI-assisted risk stratification framework for prevention of TAD-related complications is presented in Figure 4**.**

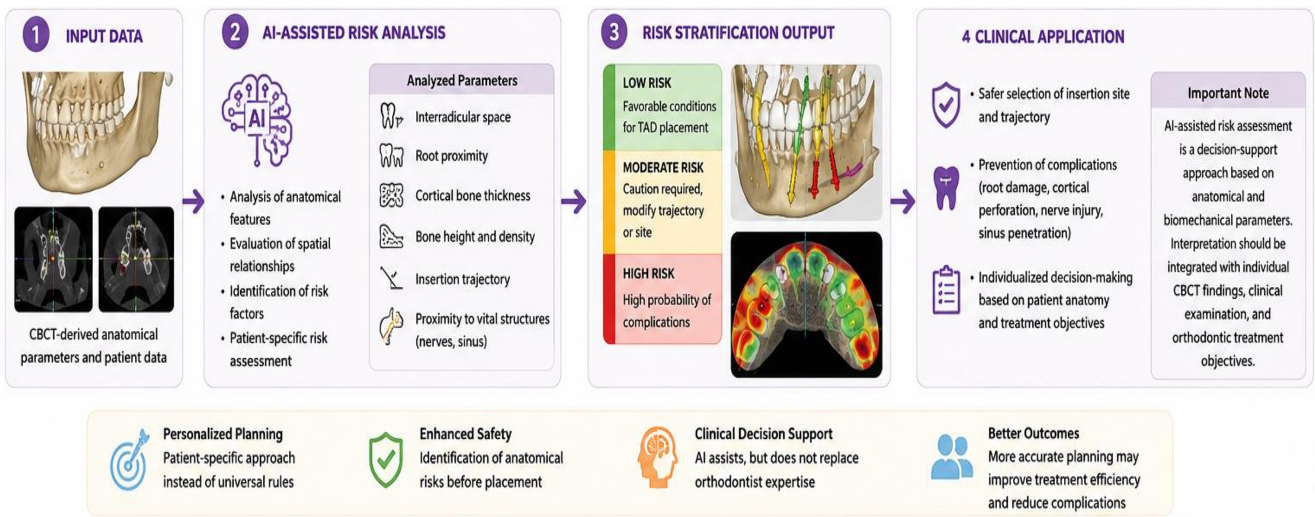

Figure 4. Artificial Intelligence–Assisted Risk Stratification Framework for Prevention of Temporary Anchorage Device (TAD)-Related Complications.

The potential safety parameters used for personalized risk assessment are summarized in **Table 7**.

Table 6. CBCT-Based Anatomical Parameters for AI-Assisted Personalized TAD Planning

CBCT Parameter	Clinical Importance	Role in AI-Assisted Planning
Interradicular space	Determines the availability of a safe insertion corridor between adjacent tooth roots	AI identifies optimal insertion pathways while minimizing the risk of root contact
Cortical bone thickness	Influences primary mechanical stability and implant retention	AI quantifies cortical bone dimensions to improve site selection and predict implant stability
Bone volume and morphology	Determines whether sufficient bone support is available for TAD placement	AI reconstructs three-dimensional bone anatomy and identifies suitable insertion sites
Root morphology and orientation	Influences insertion angulation and the likelihood of root interference	Automated segmentation enables precise localization of dental roots before implant placement
Maxillary sinus, nasal cavity, and neurovascular structures	Identifies critical anatomical structures that should be avoided during insertion	AI detects anatomical boundaries and supports safer treatment planning
Soft tissue thickness	Influences implant head position, patient comfort, and peri-implant tissue health	AI integrates soft tissue measurements into personalized placement planning
Three-dimensional insertion trajectory	Determines the optimal insertion angle and depth for biomechanical stability	AI simulates implant positioning to optimize accuracy and minimize procedural risks

Table 7. AI-Assisted Anatomical Risk Assessment Framework for Personalized TAD Placement

Risk Assessment Parameter	AI-Based Evaluation	Clinical Significance
Interradicular space availability	Automated three-dimensional measurement of the space between adjacent roots	Identifies safe insertion corridors and reduces the risk of root injury
Root proximity	Automatic root segmentation and distance analysis	Minimizes accidental root contact during TAD placement
Cortical bone thickness	Quantitative assessment of cortical bone dimensions	Predicts primary stability and assists in selecting the optimal insertion site
Bone morphology and	Three-dimensional	Supports personalized

Note: The proposed AI-assisted risk assessment framework represents a clinical decision-support approach based on anatomical and biomechanical parameters. These factors should be interpreted together with individual CBCT findings, clinical examination, and orthodontic treatment objective

5. DISCUSSION

Temporary anchorage devices have fundamentally changed modern orthodontic treatment by providing a reliable method of skeletal anchorage and expanding the range of predictable tooth movements. The findings of this scoping review demonstrate that TADs are now widely incorporated into orthodontic practice for managing complex clinical situations, including anchorage reinforcement, molar movement, intrusion mechanics, and correction of challenging malocclusions [21–24].

The increasing application of TADs reflects a shift from conventional anchorage concepts toward more controlled and individualized biomechanical approaches. In modern practice, skeletal anchorage can be integrated alongside specialized aligner solutions, such as the Smartee S4 technology. By employing rigid power arms and optimizing touch-and-aligner interface dynamics, clinicians can achieve precise control over force vectors and root torque, complementing the anchorage benefits provided by TADs [24–26]. Unlike traditional anchorage methods, miniscrews provide clinicians with the ability to apply forces from strategically selected skeletal locations, reducing unwanted dental effects and improving treatment efficiency. However, successful outcomes depend on appropriate case selection, anatomical assessment, insertion technique, and maintenance of peri-implant health [24–26].

One of the important observations from the current evidence is the growing importance of three-dimensional treatment planning. Conventional two-dimensional radiographic assessment provides limited information regarding root proximity, cortical bone morphology, and anatomical restrictions. In contrast, CBCT-based evaluation enables more precise analysis of patient-specific anatomy and facilitates safer selection of insertion sites [9,27].

The integration of artificial intelligence into orthodontic workflows represents a further evolution of this personalized approach. Current literature suggests that AI-assisted systems may support clinicians by improving anatomical analysis, automated segmentation, landmark identification, and prediction of treatment-related outcomes. In the context of TAD placement, AI has particular potential for risk stratification by analyzing three-dimensional imaging data, identifying unfavorable anatomical conditions, and assisting clinicians in selecting safer and more biomechanically appropriate insertion pathways [10–12]. However, AI should be considered an assistive technology rather than a replacement for clinical expertise. Orthodontic treatment involves complex biological responses, mechanical considerations, and patient-specific objectives that cannot be fully determined by automated systems alone. The most appropriate future model is likely to involve collaboration between AI-based analytical tools and clinician decision-making, where artificial intelligence provides quantitative information while the orthodontist determines the final treatment strategy [12,28–30].

Furthermore, the clinical performance of AI-based systems depends strongly on the quality, accuracy, and diversity of the datasets used for model development. Algorithms trained on specific patient populations or limited imaging datasets may demonstrate reduced generalizability when applied to different clinical environments. The absence of external validation and multicenter evaluation remains an important challenge before AI-assisted orthodontic planning can be widely implemented in routine clinical practice. Future research should focus on developing standardized datasets, validating AI models across diverse populations, and determining whether AI-supported planning provides measurable improvements in treatment safety, efficiency, and clinical outcomes [31–33].

Another important aspect identified in this review is the need for standardization. Current studies evaluating TAD success frequently use different definitions of stability, failure criteria, insertion protocols, loading conditions, and outcome measures. This methodological heterogeneity limits direct comparison between studies and highlights the need for standardized reporting criteria. Future investigations should incorporate consistent parameters, including CBCT-based anatomical measurements, biomechanical variables, loading protocols, and long-term clinical outcomes to improve the reliability and comparability of evidence regarding TAD effectiveness [34–36].

6. Limitations

This scoping review has several limitations. First, the included studies demonstrated considerable heterogeneity regarding study design, patient populations, TAD characteristics, insertion protocols, and outcome assessment methods. Due to this variability, quantitative meta-analysis was not performed. Second, although digital orthodontics and artificial intelligence represent rapidly developing fields, the available evidence regarding AI-assisted TAD planning remains limited compared with conventional clinical research. Many AI-related studies are focused on technical development, image analysis, or preliminary validation rather than large-scale clinical implementation. Third, most available evidence originates from specialized orthodontic centers with experienced clinicians, which may limit generalizability to different clinical environments. Additional multicenter studies involving diverse patient populations are required to validate the effectiveness and reliability of AI-assisted planning systems.Finally, the proposed AI-assisted risk assessment approach should be interpreted as a conceptual clinical decision-support approach based on current evidence rather than a universally validated algorithm. Further prospective studies are necessary to determine whether AI-guided planning leads to measurable improvements in safety, efficiency, and treatment outcomes.

7. Future Perspectives and Emerging Trends

The future development of TAD-assisted orthodontics is expected to be closely associated with advances in digital dentistry, artificial intelligence, and personalized treatment planning.

One emerging direction is the development of fully integrated digital orthodontic platforms combining CBCT imaging, intraoral scanning, three-dimensional simulation, and AI-based analysis. Such systems may allow automated evaluation of anatomical conditions and generation of patient-specific anchorage strategies.

Another promising area is the application of machine learning models for prediction of TAD stability and failure risk. By analyzing large datasets containing anatomical, mechanical, and patient-related variables, future AI systems may identify individuals at higher risk of complications and recommend preventive strategies.

Computer-guided TAD placement represents another important trend. Integration of AI-assisted planning with three-dimensional printing technologies may enable customized surgical guides that transfer virtual planning into clinical practice with improved accuracy. Furthermore, future research may focus on real-time clinical decision-support systems capable of continuously integrating treatment progress, orthodontic force application, and biological response. Such approaches could contribute to adaptive orthodontic treatment, where therapeutic strategies are modified according to individual patient response. Nevertheless, successful implementation of AI in orthodontics will require rigorous clinical validation, ethical considerations, data security protection, and collaboration between orthodontists, engineers, and data scientists.

8. CONCLUSION

Temporary anchorage devices have become an essential component of contemporary orthodontic treatment by providing predictable skeletal anchorage for a wide range of complex tooth movements. Their clinical success depends on appropriate anatomical evaluation, biomechanical planning, and careful management of patient-specific factors. The integration of CBCT-based three-dimensional assessment and artificial intelligence introduces a new direction toward personalized TAD planning. AI-assisted systems may improve anatomical risk assessment, optimize insertion strategies, and support individualized treatment decisions while maintaining the essential role of orthodontic clinical expertise. Although current evidence demonstrates promising potential, further prospective and multicenter clinical studies are required to validate AI-based TAD planning systems and establish standardized protocols. The future of orthodontic anchorage is likely to involve a combination of advanced imaging, artificial intelligence, and clinician-guided personalized treatment approaches, leading toward safer, more predictable, and individualized orthodontic care.

DECLARATIONS

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Not applicable.
Competing Interests
The authors declare no conflict of interest.
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REFERENCES

1. Kyung HM, Ly NT, Hong M. Orthodontic skeletal anchorage: up-to-date review. *Orthodontic Waves*. 2019;76(3):123–132. doi:10.1016/j.odw.2017.06.002.
2. Diar-Bakirly S, Feres MF, Saltaji H, Flores-Mir C, El-Bialy T. Effectiveness of the transpalatal arch in controlling orthodontic anchorage in maxillary premolar extraction cases: a systematic review and meta-analysis. *The Angle Orthodontist*. 2017;87(1):147–158. doi:10.2319/021216-120.1.
3. Papageorgiou SN, Zogakis IP, Papadopoulos MA. Failure rates and associated risk factors of orthodontic miniscrew implants: a meta-analysis. European Journal of Orthodontics. 2012;34(6):656–666. doi:10.1093/ejo/cjr056.
4. Alharbi F, Almuzian M, Bearn D. Miniscrews failure rate in orthodontics: systematic review and meta-analysis. *European Journal of Orthodontics*. 2018;40(5):519–530. doi:10.1093/ejo/cjx093.
5. Ritchie C, McGregor S, Bearn DR. Temporary anchorage devices and the forces and effects on the dentition and surrounding structures during orthodontic treatment: a scoping review. *European Journal of Orthodontics*.2023;45(3):324–337. doi:10.1093/ejo/cjac072.
6. Patel KS, Parmar I, Digumarthi UK, Parmar J, Quraishi A, Patel K, Shah A, Shah K, Jani B, Arora MA. Temporary Anchorage Device: A Narrative Review. *Cureus*. 2025;17(4):e81617. doi:10.7759/cureus.81617.
7. Alshammery FA. Three dimensional (3D) imaging techniques in orthodontics—An update. *Journal of Family Medicine and Primary Care*. 2020;9(6):2626–

2630. doi:10.4103/jfmpc.jfmpc_64_20.
8. Pandey R, Kamble R, Kanani H. Revolutionizing Smiles: Advancing Orthodontics Through Digital Innovation. *Cureus*. 2024;16(7):e64086. doi:10.7759/cureus.64086.
9. Kapila SD, Nervina JM. CBCT in orthodontics: assessment of treatment outcomes and indications for its use. *Dentomaxillofacial Radiology*. 2015;44(1):20140282. doi:10.1259/dmfr.20140282.
10. Liu J, Zhang C, Shan Z. Application of Artificial Intelligence in Orthodontics: Current State and Future Perspectives. *Healthcare (Basel)*. 2023;11(20):2760.doi:10.3390/healthca11202760.
11. Bichu YM, Zou B, Chaudhari PK, Adel SM, Vaiid N. Artificial intelligence applications in orthodontics. In: Schwendicke F, Chaudhari PK, Dhingra K, Uribe SE, Hamdan M, editors. *Artificial Intelligence for Oral Health Care: Applications and Future Prospects*. Cham: Springer Nature Switzerland; 2025. p.81–97.
12. Sedaghat B, Heidari A. Artificial intelligence-driven orthodontics: current applications, emerging trends, and key limitations. *Discover Artificial Intelligence*. 2026;6:570. doi:10.1007/s44163-026-01291-3.
13. Kazimierczak N, Kazimierczak W, Serafin Z, Nowicki P, Nożewski J, Janiszewska-Olszowska J. AI in Orthodontics: Revolutionizing Diagnostics and Treatment Planning—A Comprehensive Review. *Journal of Clinical Medicine*. 2024;13(2):344. doi:10.3390/jcm13020344.
14. Nordblom NF, Büttner M, Schwendicke F. Artificial Intelligence in Orthodontics: Critical Review. *Journal of Dental Research*. 2024;103(6):577–584. doi:10.1177/00220345241235606.
15. Tucci I, Gimondo E, Jovanova E, Angjelova A, Isola G, Grippaudo C. Present and Future of the Use of Artificial Intelligence in Orthodontics. *Bioengineering (Basel)*. 2026;13:263. doi:10.3390/bioengineering13030263.
16. Olawade DB, Leena N, Egbon E, Rai J, Mohammed APEK, Oladapo BI, Boussios S. AI-Driven Advancements in Orthodontics for Precision and Patient Outcomes. *Dentistry Journal*. 2025;13(5):198. doi:10.3390/dj13050198.
17. Roy P, Vedavathi HK. The role of artificial intelligence in modern orthodontics: transforming diagnosis and treatment planning – a narrative review. *Journal of Pierre Fauchard Academy(India Section)*.2025;39(4):102–111. doi:10.18231/j.jpfa.14145.1764140475.
18. Peters MDJ, Marnie C, Tricco AC, Pollock D, Munn Z, Alexander L, McInerney P, Godfrey CM, Khalil H. Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis*.2020;18(10):2119–2126. doi:10.11124/JBIES-20-00167.
19. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*. 2018;169(7):467–473. doi:10.7326/M18-0850.
20. Peters MDJ, Godfrey C, McInerney P, Munn Z, Tricco AC, Khalil H. Chapter 11: Scoping Reviews. In: Aromataris E, Munn Z, editors. *JBI Manual for Evidence Synthesis*. Adelaide: Joanna Briggs Institute; 2020. doi:10.46658/JBIMES-20-12.
21. Sanap MU, Karandikar A, Jatania A. Temporary anchorage devices in orthodontics: A brief review. *J Interdiscip Dent Sci*. 2019;8:10–14.
22. Verma SK, Aiswareya G, Yadav PK, MP AA, Brij D. Enhancing orthodontic precision: a comprehensive review of temporary anchorage devices. J Dent Panacea. 2024;6:92–102.
23. Jain S, Kumari S, Chutia J, Sen S. Anatomic site consideration in placement of TADs: a literature review.. https://cdronline.org/4.TAD%2023-31.pdf Chron Dent Res. 2022;11:23–31.
24. Bungau TC, Marin RC, Țenț A, Ciavoi G. Temporary Anchorage Devices in Orthodontics: A Narrative Review of Biomechanical Foundations, Clinical Protocols, and Technological Advances. *Appl Sci*. 2025;15:13035. doi:10.3390/app152413035.
25. Park KH, Choi JY, Kim KA, Kim SJ, Chung KR, Kim SH. Critical issues concerning biocreative strategy in contemporary temporary skeletal anchorage device orthodontics: a narrative review. Orthodontics & Craniofacial Research. 2021;24(Suppl 1):39–47. doi:10.1111/ocr.12444.
26. Bucur S.-M., Vaida L.L., Olteanu C.D., Checchi V. A Brief Review on Micro-Implants and Their Use in Orthodontics and Dentofacial Orthopaedics. Appl. Sci. 2021;11:10719. doi: 10.3390/app112210719.
27. Caetano GR, Soares MQ, Oliveira LB, Junqueira JL, Nascimento MC. Two-dimensional radiographs versus cone-beam computed tomography in planning mini-implant placement: A systematic review. J Clin Exp Dent. 2022 Aug 1;14(8):e669-e677. doi: 10.4317/jced.59384.
28. La Rosa S, Uzunçibuk H, Almeida LE, et al. *The impact of artificial intelligence on orthodontics: a systematic review of applications and implications.* Minerva Dental and Oral Science. 2025;74(3):195–208. doi: 10.23736/S2724-6329.24.04930-1
29. Sharp C. Orthodontics in the city: artificial intelligence in orthodontics. BDJ Team. 2025;12(4):168–71. https://doi.org/10.1038/s41407-025-2969-z
30. Baxmann B, Zsoldos M, Kárpáti K. AI in orthodontic treatment planning: a systematic review comparing learning approaches. BMC Oral Health. 2026. doi: 10.1186/s12903-026-08854-x
31. Heribanová B, Janáková K, Tomášik J, Tichá D, Harsányi Š, Thurzo A. Current Applications and Future Perspectives of Artificial Intelligence in Face-Driven Orthodontics: A Scoping Review. *Biomimetics (Basel)*.

2026;11(2):146. doi:10.3390/biomimetics11020146.

32. Tomášik J, Zsoldos M, Oravcová Ľ, Lifková M, Pavleová G, Strunga M, Thurzo A. AI and Face-Driven Orthodontics: A Scoping Review of Digital Advances in Diagnosis and Treatment Planning. *AI*. 2024;5:158–176. doi:10.3390/ai5010009.

33. Du W, Bi W, Liu Y, Zhu Z, Tai Y, Luo E. Machine Learning-Based Decision Support System for Orthognathic Diagnosis and Treatment Planning. *BMC Oral Health*. 2024;24:286. doi:10.1186/s12903-024-04063-6.

34. Dalessandri D, Salgarello S, Dalessandri M, Lazzaroni E, Piancino M, Paganelli C, Maiorana C, Santoro F. Determinants for success rates of temporary anchorage devices in orthodontics: a meta-analysis (n > 50). *European Journal of Orthodontics.*2014;36(3):303–313. doi:10.1093/ejo/cjt049

35. Jaramillo-Bedoya D, Villegas-Giraldo G, Agudelo-Suárez AA, Ramírez-Ossa DM. A Scoping Review about the Characteristics and Success-Failure Rates of Temporary Anchorage Devices in Orthodontics. *Dent J (Basel)*. 2022;10(5):78. doi:10.3390/dj10050078.

36. Gardner JD, Ha A, Lee S, Mohajeri A, Schwartz C, Hung M. Where You Place, How You Load: A Scoping Review of the Determinants of Orthodontic Mini-Implant Success. *Appl Sci*. 2025;15(17):9673. doi:10.3390/app15179673.

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