Review Article

Digital and Cone Beam Computed Tomography-Guided Miniscrew-Assisted Rapid Palatal Expansion: Workflows, Accuracy, and Clinical Outcomes: A Review of Literature

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Abstract

Background: Miniscrew-assisted rapid palatal expansion (MARPE) enables nonsurgical maxillary expansion in skeletally mature patients but is highly technique-sensitive. Inaccurate miniscrew placement and suboptimal planning may compromise skeletal outcomes. Digital and cone beam computed tomography (CBCT)–guided workflows have been introduced to improve anatomical assessment, placement accuracy, and treatment predictability. **Objective:** To provide a comprehensive and clinically relevant overview of digital and CBCT-guided MARPE workflows, with emphasis on planning protocols, miniscrew placement accuracy, anchorage strategies, and treatment outcomes. **Materials and methods:** A focused literature search was conducted to identify studies on digitally planned and CBCT-guided MARPE. Given heterogeneity in study designs and outcome measures, a narrative synthesis was performed in accordance with the principles of the Scale for the Assessment of Narrative Review Articles (SANRA). **Results:** Digital and CBCT-guided workflows enable three-dimensional, anatomy-driven planning and are associated with improved miniscrew placement accuracy and reproducibility, particularly regarding angular control and bicortical engagement. CBCT-based studies report predominantly skeletal expansion with limited dentoalveolar side effects. However, treatment response remains strongly influenced by patient age and midpalatal suture maturation. **Conclusion:** Digital and CBCT-guided MARPE enhance planning precision, anchorage stability, and clinical predictability. Nevertheless, lack of standardized protocols and limited high-quality clinical evidence highlight the need for well-designed trials to establish evidence-based guidelines.

Keywords: Cone beam computed tomography, Digital orthodontic workflow, Guided miniscrew placement, MARPE, Maxillary skeletal expansion

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Introduction

Maxillary transverse deficiency is a common dentofacial discrepancy associated with posterior crossbite, dental crowding, compromised occlusal function, and altered nasal airway dimensions, affecting approximately 8–18 % of referred orthodontic patients.[1] Conventional rapid palatal expansion (RPE) is effective in growing patients; however, increased midpalatal suture maturation in late adolescents and adults limits skeletal response and often results in predominantly dentoalveolar changes.[2,3] Surgically assisted rapid palatal expansion (SARPE) may overcome these limitations but is associated with increased invasiveness, cost, and morbidity.[4]

To achieve skeletal expansion while avoiding surgery, miniscrew-assisted rapid palatal expansion (MARPE) was developed.[5,6] MARPE delivers expansion forces directly to the maxillary basal bone through palatal miniscrews, producing greater skeletal expansion than conventional RPE.[7]

However, MARPE remains highly technique-sensitive, with treatment success dependent on accurate miniscrew placement, anchorage depth, and appliance positioning. The integration of cone beam computed tomography (CBCT) and intraoral scanning has enabled three-dimensional, anatomy-driven planning, virtual miniscrew positioning, and guided or appliance-integrated insertion techniques aimed at improving placement accuracy and reproducibility.[8,9]

Despite these advances, evidence supporting digital and CBCT-guided MARPE remains fragmented and methodologically heterogeneous, with limited prospective data and scarce long-term outcomes. Given the rapid evolution of digital technologies, a narrative synthesis is warranted to critically integrate current evidence, identify limitations, and outline directions for future research.

The aim of this narrative review is to provide a comprehensive and clinically relevant overview of CBCT-guided and digitally planned MARPE, with emphasis on clinical workflows, placement accuracy, treatment outcomes, and future perspectives.

Materials and methods

A focused literature search was conducted using PubMed, Scopus, and Google Scholar to identify publications related to digital workflows, CBCT-guided planning, and miniscrew-assisted rapid palatal expansion (MARPE). The search strategy combined keywords using Boolean operators as follows: (“MARPE” or “maxillary skeletal expander”) and (“CBCT” or “cone beam computed tomography”) and (“digital workflow” or “guided miniscrew placement”). The search was adapted for each database. Studies published between January 2017 and December 2025 and written in English were included to capture recent developments. The selected time frame (2017–2025) was chosen because significant developments in digital planning, CBCT-guided workflows, and guided miniscrew placement in MARPE have predominantly emerged during this period. Earlier studies predominantly described conventional MARPE without digital integration; the year 2017 marks the appearance of foundational CBCT-based anatomical quantification and early digital workflow descriptions in the MARPE literature,[8,9] making it an appropriate starting point for a review focused on digitally guided approaches.

This review is narrative in nature and does not follow PRISMA guidelines. Studies were selected based on thematic relevance to digital workflows, CBCT-guided miniscrew placement, anatomical assessments, and clinical outcomes of MARPE, while those focusing solely on conventional tooth-borne expansion were excluded. Reference lists of selected studies were also manually reviewed.

Following title and abstract review and full-text assessment, 24 studies were ultimately selected based on their relevance to the review topic. This review is a traditional narrative review guided by SANRA principles and does not represent a systematic or semi-systematic review. To enhance transparency and methodological rigor, the review framework was guided by the Scale for the Assessment of Narrative Review Articles (SANRA).[10] The SANRA framework

Table 1 Representative Summary of Included Studies

Authors	Year	Study Type	Key Findings
Solano Mendoza et al.	2022	Clinical (CBCT)	MARPE produces skeletal expansion with minimal dentoalveolar effects
Angelieri et al.	2013	Methodological	Introduced midpalatal suture maturation classification
Lee et al.	2010	Case report	Early application of MARPE in severe cases
Brunetto et al.	2017	Clinical	Demonstrated nonsurgical MARPE in adults
Li et al.	2020	Clinical (CBCT)	Bicortical anchorage improves skeletal expansion
Wang et al.	2017	CBCT anatomical	Identified optimal palatal bone thickness
Cantarella et al.	2020	Technical	Digital planning workflow for MARPE
Thakkar et al.	2020	Clinical innovation	Digital MARPE workflow feasibility
Lo Giudice et al.	2020	Technical	CBCT-guided MARPE design
Hsu et al.	2023	Case report	Digital fabrication of MARPE appliance
Minervino et al.	2019	Case report	MARPE guide technique
Stursa et al.	2023	Cadaveric	High accuracy of guided miniscrew placement
Bellocchio et al.	2025	Clinical	Angular deviation ~3°, clinically acceptable accuracy
Wilmes et al.	2022	Clinical/Conceptual	Bone-first principle for MARPE
Hamanaka et al.	2024	In-vitro	Guide design influences accuracy
Vasoglou et al.	2022	Clinical	Accurate guided miniscrew placement
Ronsivalle et al.	2023	Clinical	Digital workflow accuracy consistent
Park et al.	2023	Clinical	Significant skeletal expansion outcomes
Thi Hong Thuy et al.	2025	Prospective	Increased nasal and skeletal dimensions
Oliveira et al.	2021	Clinical	Success linked to suture maturation
Burak & Hilmi	2024	CBCT anatomical	Palatal mucosal thickness variation
Andraws et al.	2024	CBCT study	Regional variation in palatal thickness
Andrei et al.	2025	Review	Digital customization of MARPE
Hoang et al.	2025	Scoping review	Clinical applications of digital MARPE

The majority of included studies were published between 2017 and 2025. A small number of foundational pre-2017 studies (Angelieri et al., 2013; Lee et al., 2010; Brunetto et al., 2017) were incorporated based on their seminal relevance to midpalatal suture classification and early MARPE development, which form the conceptual basis of this review.

consists of six domains: justification of the article's importance, description of the literature search, appropriate referencing, scientific reasoning, appropriate presentation of data, and balanced interpretation. These criteria were considered during manuscript preparation to ensure methodological quality. The application of SANRA criteria in the present review is summarized in Supplementary.

Results

This narrative review, guided by SANRA principles, included studies identified from PubMed, Scopus, and Google Scholar (2017–2025). A total of 24 studies were included based on their relevance to digitally planned and CBCT-guided MARPE, encompassing in-vitro studies, cadaveric investigations, technical workflow reports, and clinical studies. The review addressed the six SANRA domains, as summarized in Supplementary. A representative summary of key included studies is presented in Table 1.

Digital Workflow for MARPE Planning

The overall digital workflow for CBCT-guided MARPE planning—from imaging and virtual planning to appliance fabrication and placement—is summarized in Figure 1.

CBCT acquisition protocols

CBCT imaging represents the initial step in digitally planned MARPE, and most studies recommend a limited field-of-view scan focused on the maxilla to balance diagnostic requirements with radiation exposure in accordance with the as low as reasonably achievable (ALARA) principle.[8] Purpose-driven imaging of the midpalatal suture and adjacent palatal anatomy facilitates assessment of bone thickness and identification of potential miniscrew insertion sites.[9] CBCT use in MARPE should be selectively justified in accordance with the ALARA principle, particularly for evaluating palatal bone thickness, midpalatal suture maturation, and safe miniscrew positioning, as it improves placement accuracy and reduces complications.[8,9]

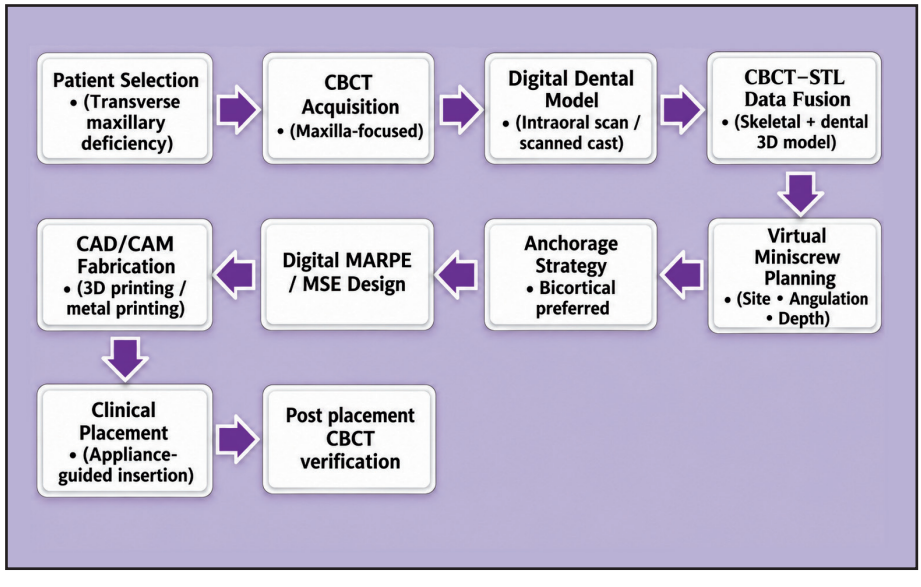


Figure 1 Schematic representation of the digital and CBCT-guided MARPE workflow, illustrating patient selection, CBCT acquisition, CBCT–STL data fusion, virtual miniscrew planning, anchorage strategy, CAD/CAM fabrication, appliance-guided insertion, and post-placement CBCT verification. [CBCT: cone beam computed tomography; STL: stereolithography; MARPE: miniscrew-assisted rapid palatal expansion; MSE: maxillary skeletal expander; CAD/CAM: computer-aided design/computer-aided manufacturing.]

DICOM–STL merging (CBCT + intraoral scans)

A critical step in digital MARPE planning is the integration of skeletal and dental datasets. All the workflows assessed relied on merging CBCT DICOM data with STL files derived from intraoral scans or scanned dental casts. Surface-based registration and dental landmark alignment were commonly employed to ensure accurate superimposition. Cantarella's methodology involved conversion of CBCT data into STL format followed by alignment with optical scans, facilitating precise spatial relationships between the maxilla and the expander.[9]

Virtual miniscrew planning

Virtual planning of miniscrew placement represents a major advantage of digitally guided MARPE workflows. Across reviewed studies, miniscrew sites were selected based on assessment of palatal bone availability and surrounding anatomical structures to minimize root proximity and optimize insertion trajectories.[11,12] Quantitative approaches incorporating regional bone thickness mapping have further supported refinement of angulation and insertion depth.[9] However, most planning protocols remain operator-dependent, and objective validation of virtual planning accuracy in routine clinical settings remains limited.

Bicortical versus monocortical anchorage

Digitally planned MARPE workflows commonly favor bicortical anchorage to enhance miniscrew stability and skeletal force transmission. Virtual planning facilitates deliberate selection of screw length and trajectory to engage both palatal and nasal cortical plates, and several authors have incorporated this strategy to reduce miniscrew loosening and optimize expander positioning.[9,12,13] CBCT-based outcome studies further associate bicortical engagement with improved skeletal expansion and anchorage stability compared with monocortical insertion. Studies also report that reliable bicortical engagement is influenced by individual anatomical variation and biological factors.

Digital design of MARPE/ maxillary skeletal expander (MSE) appliances

Digital design of MARPE appliances aims to translate virtual miniscrew planning into a clinically deliverable appliance. CAD/CAM-based workflows allow customization of connector arms, miniscrew insertion rings, and expansion screws based on skeletal anatomy. Several authors have described digital frameworks integrating appliance design with virtual miniscrew positioning, enabling individualized appliance fabrication and improved transfer accuracy.[9,12,13]

CAD/CAM and 3D printing workflows

CAD/CAM technologies enable fabrication of customized MARPE appliances and transfer guides through methods such as metal laser sintering and three-dimensional printing. Although these approaches may improve planning transfer accuracy, protocols vary widely and standardization of digitally guided MARPE workflows remains limited.[9,14]

CBCT-guided miniscrew placement and surgical guides

Rationale for guided miniscrew insertion

Successful MARPE depends on accurate miniscrew placement, as deviations in site, angulation, or depth may compromise skeletal expansion and anchorage stability. Conventional freehand insertion, guided primarily by clinical landmarks and two-dimensional imaging, is limited by complex palatal anatomy and inter-individual variability. CBCT-guided virtual planning enables three-dimensional assessment of palatal morphology and identification of optimal insertion trajectories.[9,11] Inaccurate placement has been associated with monocortical engagement, screw tipping, and asymmetric expansion.[12] Current studies report reduced angular deviations and clinically acceptable accuracy with guided techniques compared with freehand insertion.[15,16]

Table 2 Overview of surgical guide types used in CBCT-guided miniscrew placement for MARPE, highlighting support mechanisms, key characteristics, advantages, and limitations.[9,12,13,17]

Category	Support	Key Characteristics	Main Advantages	Limitations
Tooth-borne guides	Dentition	Expander- or tooth-supported transfer of planned miniscrew sites	Good stability; improved angular accuracy	Influenced by dental inclination and scan errors
Bone-borne guides	Palatal bone / mucosa	Placement guided by skeletal anatomy (bone-first approach)	Independent of dentition; suitable for adults	Requires precise CBCT planning
Hybrid guides	Dental + skeletal	Laboratory-based transfer templates	Improved appliance positioning accuracy	Semi-digital; added lab steps
Appliance-integrated guides	MARPE/MSE appliance	Prefabricated screw channels act as insertion guide	Simplified clinical workflow	Dependent on appliance fit

Types of guides: tooth-borne, bone-borne, and hybrid

CBCT-guided miniscrew placement can be achieved using tooth-borne, bone-borne, hybrid, or appliance-integrated guides, each differing in their support mechanism and clinical application.

Tooth-borne guides are supported by the dentition and enable transfer of digitally planned miniscrew positions with good positional stability.[14,15] Bone-borne guides rely on palatal bone or mucosal support and follow the bone-first concept, allowing miniscrew placement to be guided primarily by skeletal anatomy.[17] Hybrid guides combine dental and skeletal or mucosal support to improve stability during transfer of the virtual plan to the clinical setting.[9,13] Appliance-integrated guides use prefabricated screw channels within the MARPE or MSE appliance itself to guide miniscrew insertion without a separate surgical guide.[12] The key characteristics, advantages, and limitations of these guide types are summarized in Table 2.

Bone-first principle

The bone-first principle, introduced by Wilmes et al.,[17] describes an anatomy-driven approach to miniscrew placement, in which CBCT-based identification of optimal skeletal anchorage sites precedes appliance design. Instead of adapting miniscrew position to a prefabricated expander, the appliance or guide is designed according to the selected insertion sites. Wilmes et al. reported that appliance-first approaches may result in placement in less optimal bone regions. Studies by Stursa et al.[15] and Bellocchio et al.[16] report clinically acceptable accuracy when transferring bone-driven virtual plans using guided systems.

Clinical protocols for guide use

Clinical protocols for CBCT-guided miniscrew placement generally involve maxilla-focused CBCT acquisition, integration with intraoral scan data, and virtual definition of miniscrew position, angulation, and depth.[12,14,16] Digitally designed surgical guides or appliance-integrated insertion channels are then used to transfer the virtual plan to the clinical setting.

Dedicated guide-based protocols, including metal-sleeved guides and controlled predrilling, have demonstrated acceptable transfer accuracy under clinical conditions.[16] In contrast, appliance-guided workflows enable simplified, single-visit insertion but may offer less control over insertion depth and trajectory.

Accuracy and reliability of guided MARPE techniques

Linear, angular, and depth deviations

Accuracy of guided MARPE miniscrew placement is commonly evaluated using linear, angular, and depth deviations. Among these, angular deviation is the most clinically relevant, as excessive angulation can compromise bicortical engagement, risk nasal floor perforation, and alter force vectors.

Clinical and experimental studies support the reliability of CBCT-guided techniques. Bellocchio et al. reported mean angular deviations of about 3°, with linear deviations within clinically acceptable limits using 3D-printed palatal guides.[16] A study by Stursa et al. showed significantly lower angular deviations with guided placement compared with freehand insertion, though minor depth discrepancies persisted.[15] In vitro, Hamanaka et al. demonstrated that longer guide sleeves improved linear accuracy, underscoring the influence of guide design on placement precision.[18]

While deviations of approximately 2–3° are generally considered clinically acceptable, angular deviations exceeding 5–7° may compromise bicortical engagement, reduce miniscrew stability, and influence expansion symmetry, thereby affecting overall skeletal outcomes.[15,16,19]

In-vitro, cadaveric, and clinical accuracy studies

Evidence on guided miniscrew accuracy across different experimental and clinical models is summarized in Table 3.

Comparison with freehand placement

Across study designs, guided miniscrew placement demonstrates superior accuracy and

Table 3 Summary of in-vitro, cadaveric, and clinical evidence on the accuracy of guided miniscrew placement for MARPE.

Study model	Key purpose	Reported accuracy	Main findings	Clinical implications
In-vitro studies	Controlled evaluation of mechanical factors (e.g., sleeve length, drill tolerance)	Angular deviation ~2–3°, linear deviation ~0.5–1 mm	Hamanaka et al.[18] showed guided drilling consistently outperformed freehand insertion under controlled conditions	Demonstrates mechanical advantage of guides, but may underestimate deviations seen clinically due to absence of soft tissue and patient movement
Cadaveric studies	Simulation of clinical anatomy without patient-related variables	Angular deviation ~2–3°	Stursa et al.[15] found superior angular accuracy with professionally manufactured guides compared with in-house 3D-printed guides	Highlights cumulative errors from planning, fabrication, and handling; underscores need for workflow standardization
Clinical studies	Assessment of real-world accuracy and reliability	Angular deviation ~5–7°	Vasoglou et al.[20] reported lower angular deviations with CBCT-integrated (DICOM–STL) guide design; Ronsivalle et al.[19] found mean angular deviations of 5–7° irrespective of planning software	Suggests that accurate data integration and guide design are more critical than the specific software platform used

Table 4 Comparison of guided versus freehand miniscrew placement in MARPE.

Aspect	Guided miniscrew placement	Freehand miniscrew placement
Planning basis	CBCT-based 3D virtual planning.[9] Anatomy-driven trajectory selection.[13,17]	Clinical landmarks only.[13] No 3D anatomical assessment.[17]
Placement accuracy	Reduced angular and linear deviations.[15,16] Superior accuracy in direct comparisons.[19]	Greater angular deviations, especially sagittal.[15] Inferior in all direct comparisons.[19]
Mean angular deviation	~3° clinically (Bellocchio et al.[16]). ~2–3° in cadaveric/in-vitro models (Stursa et al.[15]; Hamanaka et al.[18]).	Sagittal angular deviation of 5.34° reported for freehand insertion.[15] Guided consistently outperformed freehand in all direct comparisons.[15,19]
Reproducibility	High reproducibility.[15] Reduced operator dependence with standardized protocols.[13]	Operator-dependent.[13] Variable across cases and clinicians.
Anchorage engagement	Predictable bicortical engagement via pre-planned trajectory and screw length.[13]	Frequently monocortical.[7] Especially unreliable in posterior palate.[13]
Risk of complications	Reduced risk of tipping, asymmetry, and nasal floor perforation.[13,15,16]	Higher risk of screw tipping, asymmetry, and suboptimal engagement.[13]
Suitability for posterior palate	Reliable due to CBCT-based safe-zone identification.[17]	Less reliable due to reduced bone availability and limited 2D visualization.[17]
Overall clinical predictability	High, due to pre-validated digital trajectories.[9,13,17]	Variable, dependent on operator skill and anatomy.[13,17]

reproducibility compared with freehand insertion. Direct comparisons have shown significantly greater angular deviations with freehand techniques, particularly in the sagittal plane, underscoring the value of CBCT-based three-dimensional planning in improving placement precision.[15,20] Although freehand insertion is still commonly used in the anterior palate where bone availability is favorable, anatomical variability—especially in posterior regions—limits its reliability in many MARPE cases.[17] Inaccurate freehand placement may result in monocortical engagement, screw tipping, or asymmetric expansion, whereas guide-assisted or appliance-integrated workflows constrain miniscrew trajectories to pre-validated digital plans, thereby improving clinical predictability.[12] The key differences between guided and freehand miniscrew placement are summarized in Table 4.

Sources of error in digital workflows

Despite demonstrable improvements over freehand techniques, guided MARPE workflows are not immune to error. Cumulative inaccuracies may arise at multiple stages of the digital chain, including CBCT acquisition, DICOM–STL superimposition, guide design, manufacturing, and clinical application. Stursa et al. reported that laboratory-related factors significantly influenced placement accuracy, with in-house fabricated guides showing inferior performance compared with commercially produced templates.[15] Bellocchio et al. similarly observed residual deviations

even with high-quality guides, reporting that complete elimination of placement error was not achieved in clinical practice.[16]

Guide design parameters also affect accuracy, with inadequate sleeve length compromising drilling precision.[18] Additional clinical variables, including mucosal resilience, incomplete guide seating, insertion torque, and operator handling, may further influence final miniscrew position. Ronsivalle et al. reported the presence of residual accuracy errors even in optimized workflows.[19]

CBCT-based clinical outcomes of MARPE

Skeletal expansion patterns

CBCT-based studies indicate that MARPE produces predominantly skeletal maxillary expansion in late adolescents and young adults, with significant increases in maxillary width and mean skeletal expansion of approximately 2–3 mm.[21] Suture opening is generally parallel on axial and coronal views, while a characteristic triangular expansion pattern, with greater inferior maxillary separation, reflects effective transmission of orthopedic forces through skeletal anchorage.[22]

Dentoalveolar effects

Although MARPE is intended to minimize dentoalveolar side effects, CBCT studies indicate that minor dental and alveolar changes may still occur. Small reductions in buccalbone thickness (< 0.5 mm) with corresponding increases in palatal thickness suggest adaptive remodeling rather than destructive change.[21] Dental effects are generally limited to mild posterior tooth inclination, minimal molar tipping, and partial relapse during retention; studies report that these dentoalveolar changes are modest and better controlled than those associated with conventional RPE.[22,23]

Miniscrew stability and bone response

Miniscrew stability is a key determinant of MARPE success. CBCT studies suggest that bicortical or posterior bicortical engagement may enhance skeletal expansion and reduce dentoalveolar effects compared with monocortical anchorage by improving force transmission and appliance stability.[7] However, stability is multifactorial; patient age and midpalatal suture maturation strongly influence outcomes. Oliveira et al. reported that failures are more frequent in patients with advanced suture maturation (Angelieri stages D–E), regardless of miniscrew configuration.[24]

Airway and nasal cavity changes

CBCT-based assessments indicate that MARPE produces favorable increases in nasal and airway dimensions, including significant widening of the nasal cavity and extension of expansion into the zygomaticomaxillary region.[22] Prospective studies further demonstrate increased nasal base and cavity width with minimal relapse.[23] Functional respiratory outcomes were variably reported across the included studies; however, CBCT morphologic data from these studies consistently document nasal dimensional gains following MARPE.

Relationship between planning accuracy and outcomes

Although most CBCT outcome studies emphasize morphologic changes rather than planning accuracy, indirect associations suggest that precise control of miniscrew site and insertion depth—particularly with bicortical engagement—supports greater skeletal expansion and improved suture parallelism.[7] Studies report that advanced suture maturation may limit skeletal response despite optimal digital placement planning.[24] CBCT outcome studies report associations between bicortical engagement and increased skeletal expansion, although outcomes vary with suture maturation.[24]

Anatomic considerations for CBCT-guided MARPE

CBCT-based anatomical studies demonstrate considerable variation in palatal bone and mucosal thickness, which directly influences miniscrew

placement in MARPE. The anterior paramedian palate, particularly near the second premolars, generally provides the most favorable cortical thickness and is widely considered a predictable insertion site, although bone thickness decreases posteriorly and varies among individuals.[8,25] Facial growth pattern may further influence palatal morphology, with thinner bone often observed in high-angle patients. In addition to bone thickness, palatal mucosal thickness—typically increasing posteriorly—must also be considered, as excessive soft tissue may compromise effective cortical engagement despite adequate bone availability.[26] CBCT studies report that progressive midpalatal suture interdigitation with increasing age is associated with greater skeletal resistance, and several authors indicate this may influence MARPE outcomes.[25]

Discussion

Advantages of digital and CBCT-guided MARPE

Digital and CBCT-guided MARPE workflows offer several potential advantages over conventional planning approaches. Three-dimensional visualization enables more accurate assessment of skeletal anatomy and facilitates controlled adjustment of appliance position, angulation, and insertion depth, thereby reducing operator dependence and improving planning reproducibility.[9,12] Integration of CBCT and intraoral scan data also supports simulation of miniscrew trajectories, reducing the risk of root proximity and enabling bone-first placement strategies.[17] Accurate evaluation of palatal bone thickness and palatal–nasal floor distance further enhances miniscrew stability through optimized cortical engagement and appropriate screw length selection.[12] In addition, digital workflows allow individualized appliance customization based on skeletal morphology and planned force vectors, contributing to improved appliance adaptation and treatment efficiency.[9,12,27] From a clinical perspective, three-dimensional visualization enhances treatment predictability. Nevertheless, these advantages remain dependent on data quality, software reliability, and operator expertise, underscoring the need for standardized protocols and further clinical validation.

Clinical considerations for optimizing MARPE Outcomes

Treatment outcomes in MARPE are influenced by appliance design, activation protocol, miniscrew characteristics, and insertion site. Bone-borne or hybrid appliances provide greater skeletal expansion and reduced dentoalveolar effects compared with tooth-borne designs, due to more efficient force transfer to basal bone.[6,7]

Direct skeletal force transmission in MARPE is optimized using bone-borne or hybrid appliances that position the expander close to the palatal vault, minimizing dental anchorage.[7] CBCT-guided planning further improves accuracy of miniscrew insertion depth and angulation, reducing force dissipation.[9,12] Activation rates of 0.2–0.5 mm/day are commonly used; however, slower activation may enhance skeletal adaptation and reduce complications, particularly in patients with increased suture maturation.[22,23]

The anterior paramedian palate is considered the most favorable miniscrew insertion site due to greater cortical bone thickness and reduced risk of root proximity, while posterior regions show reduced bone availability.[8,25]

Miniscrews with diameters of 1.5–2 mm and lengths of 10–14 mm are generally recommended to achieve adequate primary stability and facilitate bicortical engagement, which improves skeletal expansion and anchorage stability.[7]

Accurate miniscrew placement is critical, as angular deviations exceeding 5–7° may compromise bicortical engagement, reduce stability, and affect expansion symmetry, highlighting the importance of guided insertion techniques.[15,16,19]

Limitations and challenges of digital and CBCT-guided MARPE

Digital and CBCT-guided MARPE workflows are

associated with several important limitations. Additional radiation exposure remains a concern, particularly in younger patients, necessitating selective CBCT use, limited field-of-view protocols, and strict adherence to the ALARA principle.[9,12,17] Implementation of digital workflows also requires substantial investment in imaging equipment, planning software, and CAD/CAM facilities, raising concerns regarding the cost–benefit balance in routine clinical practice.[9,12] Furthermore, digital planning is associated with a significant learning curve and remains highly operator-dependent, with potential for errors related to CBCT interpretation, data integration, and virtual planning.[12,17] Another important limitation is the considerable variability in digital planning protocols, including differences in CBCT acquisition parameters, miniscrew positioning strategies, appliance design, and guide fabrication methods, which complicates direct comparison across studies.[9,12,14] Importantly, available evidence is largely derived from low-level study designs, with few randomized controlled trials and limited long-term or patient-centered outcome data.[28] Collectively, these limitations highlight that digital MARPE technologies remain in an evolving phase and should be applied judiciously until supported by more robust clinical evidence.

The key advantages and limitations of digital and CBCT-guided MARPE workflows are summarized in Figure 2.

Future directions in digital and CBCT-guided MARPE

Artificial intelligence has the potential to streamline MARPE planning by automating miniscrew site selection, angulation, insertion depth, and safe-zone identification from CBCT data. Hoang et al. reported that digital MARPE workflows may improve planning precision, standardization, and clinical efficiency, while highlighting the need for further clinical validation of these technologies.[28] Dynamic navigation systems represent another emerging approach, providing real-time guidance during miniscrew insertion and potentially overcoming limitations associated with guide seating and mucosal resilience, although cost and technical complexity currently limit widespread adoption.[19] In parallel, advances in CAD/CAM technology, intraoral scanning, and rapid 3D printing support the development of fully chairside MARPE workflows. Wilmes et al. described bone-first planning combined with same-day guide and appliance fabrication, while recent digital design approaches further enable individualized appliance customization

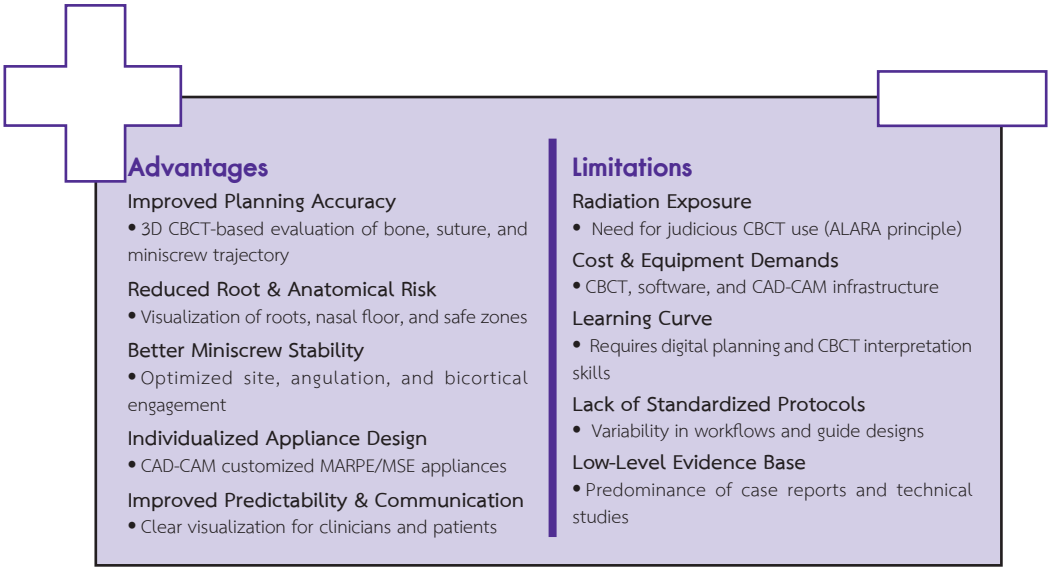


Figure 2 Schematic summary of the advantages and limitations of digital and CBCT-guided MARPE workflows.

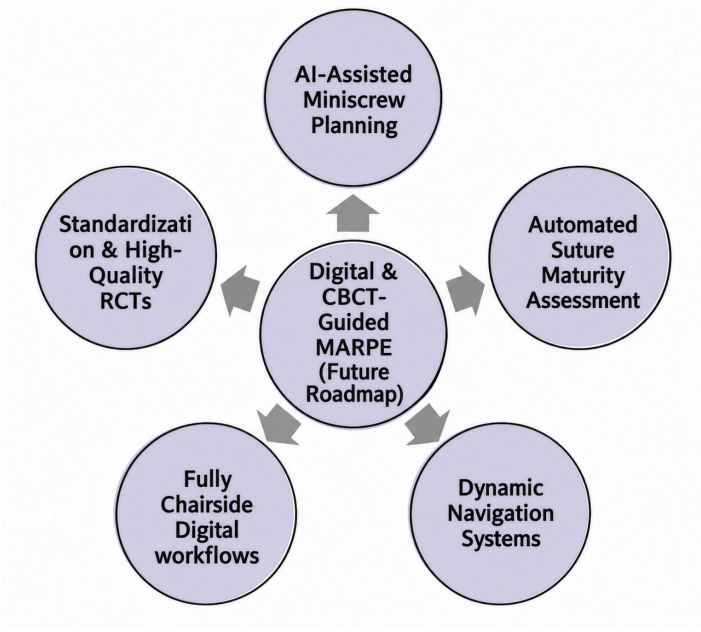


Figure 3 Conceptual overview of future directions in digital and CBCT-guided MARPE.

and improved workflow efficiency.[17,27] Despite these technological developments, the current evidence base remains limited, and well-designed clinical studies are needed to evaluate the impact of digital planning and guided insertion on placement accuracy, skeletal expansion outcomes, miniscrew stability, and patient-reported measures. These emerging directions are schematically illustrated in Figure 3.

Strengths and limitations of this review

While recent scoping and narrative reviews have summarized clinical efficacy and outcomes of MARPE, the present review uniquely focuses on the accuracy and reliability of CBCT-guided and digitally planned workflows, with particular emphasis on quantitative deviations in miniscrew placement and factors affecting transfer fidelity. This narrative review provides a comprehensive synthesis of current evidence on digital and CBCT-guided MARPE, integrating anatomical, biomechanical, clinical, and workflow-related data across diverse study designs.

However, the non-systematic nature of the review and the narrative study selection process may introduce potential selection bias, as studies were identified through targeted database searches and manual thematic review rather than a predefined systematic protocol. Consequently, some relevant studies may not have been captured, and the interpretation of available evidence should be considered exploratory rather than exhaustive. Additionally, rapid technological advancements in digital planning, imaging, and manufacturing may outpace the available clinical evidence, necessitating cautious interpretation of findings.

Conclusion

Digital and CBCT-guided MARPE has emerged as a clinically relevant advancement for the management of maxillary transverse deficiency, particularly in skeletally mature patients. By enabling three-dimensional, anatomy-driven planning, these workflows improve miniscrew positioning, anchorage stability, appliance customization, and overall treatment predictability compared with conventional approaches.

Although available evidence supports favorable skeletal and nasal outcomes with reduced dentoalveolar side effects, current literature is limited by heterogeneous methodologies, lack of standardized protocols, and a predominance of low-level evidence. Future investigations should focus on prospective clinical trials evaluating the impact of digital planning on placement accuracy, skeletal expansion stability, and patient-centered outcomes. With continued technological refinement and robust clinical validation, digital and CBCT-guided MARPE has the potential to become an evidence-based standard in contemporary transverse maxillary expansion.

Author contributions

Sakshi Santoshkumar Jain: Conceptualization, Investigation, Data Curation, Writing – Original Draft, Visualization; **Jyoti Sunny Manchanda:** Conceptualization, Writing – Review & Editing, Supervision; **Santosh Jetu Chavan:** Methodology, Writing – Review & Editing,

Supervision; **Vaibhav Sunil Zanwar:** Investigation; **Vedant S.:** Investigation, Data Curation, Writing – Review & Editing.

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