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Three-Dimensional Evaluation of Skeletal and Dentoalveolar Changes Following Miniscrew-Assisted Rapid Palatal Expansion (MARPE) in Young Adults: A Prospective Clinical Study

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Abstract

Objective: To evaluate three-dimensional (3D) skeletal, dentoalveolar, and periodontal changes following miniscrew-assisted rapid palatal expansion (MARPE) in skeletally mature young adults using cone-beam computed tomography (CBCT).

Materials and Methods: Thirty-two young adults (13 males, 19 females; mean age: 21.4 ± 2.6 years; Cervical Vertebral Maturation Stage V–VI) with maxillary transverse deficiency (>4 mm) received a custom hybrid MARPE appliance anchored by four bicortical palatal miniscrews (1.8 × 11–13 mm). Activation proceeded at two turns/day (0.52 mm/day) until overcorrection, followed by a 6-month retention phase. CBCT scans acquired pre-expansion (T0) and post-retention (T1) were analyzed using paired t-tests ($\alpha = 0.05$).

Results: Midpalatal suture separation succeeded in 29 of 32 patients (90.6%). Mean sutural opening was 3.42 ± 0.78 mm at the anterior nasal spine (ANS) and 2.89 ± 0.71 mm at the posterior nasal spine (PNS), yielding an 84.5% posterior-to-anterior opening ratio. Nasal cavity width and maxillary basal width increased by 2.38 ± 0.64 mm and 3.12 ± 0.81 mm, respectively ($p < 0.001$). Intermolar width increased by 5.46 ± 1.12 mm ($p < 0.001$), with pure skeletal expansion accounting for 57.1% of transverse dental gain. Maxillary first molars exhibited mild buccal tipping (3.64° ± 1.45° right; 3.81° ± 1.52° left, $p < 0.001$) and minimal buccal cortical thinning (-0.42 ± 0.21 mm right; -0.45 ± 0.23 mm left, $p < 0.001$).

Conclusion: MARPE predictably achieves substantial, nearly parallel skeletal maxillary expansion in young

adults while limiting dentoalveolar tipping and buccal alveolar bone loss to clinically acceptable levels.

Keywords: Cone-Beam Computed Tomography, Maxillary Transverse Deficiency, Midpalatal Suture, Miniscrew-Assisted Rapid Palatal Expansion, Young Adults.

Introduction

Maxillary transverse deficiency (MTD) affects approximately 8% to 23% of adolescents and nearly 10% of adult orthodontic patients, manifesting clinically as posterior crossbite, dental crowding, narrow palatal vault, dark buccal corridors, and elevated nasal airway resistance [1–4]. While conventional tooth-borne rapid palatal expansion (RPE) reliably separates the midpalatal suture in pre-pubertal patients, progressive tortuous interdigitation and osseous bridging of the midpalatal and circummaxillary sutures during late adolescence severely restrict skeletal opening [5–7]. In skeletally mature patients, heavy tooth-borne orthopedic forces predominantly induce dentoalveolar compensation, resulting in buccal crown tipping, alveolar bone bending, buccal cortical dehiscence, gingival recession, and post-treatment relapse.[8,9]

Surgically assisted rapid palatal expansion (SARPE) has traditionally been indicated to release sutural resistance in adults.[10] However, surgical morbidity, neurosensory risks, general anesthesia requirements, and high costs frequently deter patient acceptance.[11,12] Consequently, miniscrew-assisted rapid palatal expansion (MARPE) has emerged as a minimally invasive orthopedic alternative[13,14]. By anchoring a rigid expansion jackscrew directly to the palatal vault via four bicortical miniscrews, MARPE transmits expansion forces straight into the maxillary basal bone, reducing periodontal strain on anchor teeth[15,16].

Although recent clinical studies report encouraging sutural separation rates in young adults[17-20], consensus remains incomplete regarding the true skeletal-to-dentoalveolar expansion ratio, anteroposterior sutural parallelism, and buccal alveolar bone remodeling after standardized retention[21-23]. Therefore, this prospective CBCT study aimed to evaluate three-dimensional skeletal, dentoalveolar, dental inclination, and buccal periodontal changes following MARPE in young adults with MTD.

Materials and Methods

Study Design and Eligibility Criteria

This prospective clinical study was approved by the Institutional Ethics Committee (Protocol No.: [IEC/XXXX/202X]) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants. Sample size calculation using G*Power (v3.1.9.7) based on prior maxillary basal width data [16] (effect size $d = 0.75$, $\alpha = 0.05$, power = 90%) indicated a minimum of 21 subjects; 32 consecutive young adults were enrolled to account for potential attrition.

Inclusion criteria comprised: (1) age 18–28 years with skeletal maturity (Cervical Vertebral Maturation Stage V–VI); (2) MTD >4.0 mm (Yonsei Transverse Index) with unilateral/bilateral posterior crossbite or arch constriction; and (3) healthy periodontium (probing depths <3 mm) with intact maxillary first molars. Exclusion criteria included prior orthodontic/orthognathic treatment, craniofacial syndromes, systemic bone disorders, chin asymmetry >4 mm, or palatal bone thickness <2.0 mm at intended miniscrew sites.

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Appliance Design and Expansion Protocol

Pre-treatment CBCT scans (T0) and intraoral scans (iTero Element 5D; Align Technology, San Jose, CA, USA) were superimposed to fabricate a custom hybrid tooth-and-bone-borne MARPE appliance (MSE-type design; Biomaterials Korea, Seoul, South Korea) featuring bands on the maxillary first molars and a central jackscrew positioned parallel to the midpalatal suture between the second premolars and first molars. Under local anesthesia (2% lidocaine with 1:80,000 epinephrine), four titanium miniscrews (1.8 mm diameter; 11 mm anterior, 13 mm posterior) were inserted perpendicular to the palatal vault to achieve bicortical engagement of the palatal and nasal cortical plates.

After a 7-day healing period, patients activated the screw twice daily (0.26 mm/turn; 0.52 mm/day) until the maxillary molar palatal cusps contacted the mandibular molar buccal cusps (~2 mm overcorrection). The jackscrew was then locked with composite resin for a 6-month retention phase without concurrent fixed orthodontic appliances to isolate pure MARPE effects.

CBCT Acquisition, 3D Measurements, and Statistical Analysis

CBCT scans were acquired pre-expansion (T0) and immediately after expander removal following 6 months of retention (T1) using standardized settings ([Scanner Model]; 90 kVp, 8 mA, 0.20 mm voxel size, 16 × 13 cm FOV) with the Frankfort horizontal plane parallel to the floor. Using Dolphin Imaging software (v11.95; Chatsworth, CA, USA), scans were oriented along the Frankfort horizontal, transporionic coronal, and midsagittal (Nasion–Sella–Basion) planes. The following parameters were measured:

Skeletal Transverse: Anterior and posterior midpalatal suture opening on axial slices at the anterior (MPS-ANS) and posterior (MPS-PNS) nasal spines; nasal cavity width (NCW: maximum transverse distance between lateral nasal walls at the first molar furcation coronal slice); maxillary basal width (MBW: inter-jugal point distance); and palatal alveolar width (PAW: inter-palatal alveolar crest distance at first molars).

Dentoalveolar Transverse: Intercanine cusp width (ICW), interpremolar buccal cusp width (IPW), intermolar mesiobuccal cusp width (IMW), and intermolar palatal root apex width (IMAW).

• Dental Inclination & Periodontal Bone: Maxillary first molar buccal inclination (M1-Inc: acute angle between molar long axis and true vertical perpendicular to palatal plane); buccal alveolar bone thickness (BABT: outer cortical plate to mesiobuccal root surface, 4 mm apical to CEJ); and buccal alveolar bone height (BABH: vertical distance from mesiobuccal cusp tip to buccal alveolar crest).

Ten randomly selected scans were re-measured after 3 weeks, yielding intraclass correlation coefficients (ICC) >0.94. Data normality was confirmed via the Shapiro–Wilk test, and T0–T1 differences were analyzed using paired t-tests in SPSS (v28.0; IBM Corp., Armonk, NY, USA) at $p < 0.05$.

Results

Among the 32 enrolled patients (13 males, 19 females; mean age: 21.4 ± 2.6 years; range: 18.2–27.5 years), midpalatal suture separation—verified by midline diastema formation and a radiolucent sutural gap on CBCT—was achieved in 29 subjects (90.6% success rate). Three patients (2 males aged 25.8 and 27.1 years; 1 female aged 26.4 years) exhibited sutural opening failure with miniscrew tipping and were excluded from post-

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expansion morphometric analysis. In successfully expanded subjects, mean active expansion lasted 16.5 ± 3.2 days (mean jackscrew activation: 8.4 ± 1.3 mm) without soft-tissue necrosis or miniscrew fracture.

All skeletal transverse dimensions increased significantly from T0 to T1 ($p < 0.001$; Table 1). Midpalatal suture opening averaged 3.42 ± 0.78 mm at ANS and 2.89 ± 0.71 mm at PNS, representing an 84.5% posterior-to-anterior opening ratio. Significant increases were also recorded in NCW (+2.38 ± 0.64 mm), MBW (+3.12 ± 0.81 mm), and PAW (+3.86 ± 0.89 mm) (all $p < 0.001$).

Dentoalveolar arch widths expanded significantly across all segments ($p < 0.001$; Table 2), with gains of 3.68 ± 0.94 mm in ICW, 4.74 ± 1.05 mm in IPW, 5.46 ± 1.12 mm in IMW, and 3.54 ± 0.88 mm in IMAW. Comparing ΔMBW (3.12 mm) to ΔIMW (5.46 mm), pure skeletal expansion contributed 57.1% of total intermolar transverse gain, while alveolar bending and dental tipping accounted for 42.9%.

Maxillary first molars showed mild buccal tipping of 3.64° ± 1.45° on the right and 3.81° ± 1.52° on the left ($p < 0.001$; Table 3). Buccal alveolar bone thickness at the first molar mesiobuccal root decreased modestly by -0.42 ± 0.21 mm (right) and -0.45 ± 0.23 mm (left) ($p < 0.001$), while vertical crestal distance (BABH) increased by 0.51 ± 0.28 mm (right) and 0.54 ± 0.30 mm (left) ($p < 0.001$).

Table 1: Pre-Expansion (T0) and Post-Retention (T1) Skeletal Transverse Measurements (n = 29)

Parameter	T0 (Mean ± SD)	T1 (Mean ± SD)	ΔT1–T0	95% CI	t-value	p-value
MPS-ANS (mm)	0.00 ± 0.00	3.42 ± 0.78	+3.42 ± 0.78	3.12, 3.72	23.61	<0.001*
MPS-PNS (mm)	0.00 ± 0.00	2.89 ± 0.71	+2.89 ± 0.71	2.62, 3.16	21.92	<0.001*
Nasal Cavity Width (NCW, mm)	28.45 ± 2.14	30.83 ± 2.21	+2.38 ± 0.64	2.14, 2.62	20.03	<0.001*
Maxillary Basal Width (MBW, mm)	61.20 ± 3.18	64.32 ± 3.25	+3.12 ± 0.81	2.81, 3.43	20.74	<0.001*
Palatal Alveolar Width (PAW, mm)	27.90 ± 2.45	31.76 ± 2.52	+3.86 ± 0.89	3.52, 4.20	23.35	<0.001*

MPS-ANS/PNS: Midpalatal suture opening at anterior/posterior nasal spine; CI: Confidence interval. *Statistically significant ($p < 0.001$, paired t-test).

Table 2: Pre-Expansion (T0) and Post-Retention (T1) Dentoalveolar Transverse Measurements (n = 29)

Parameter	T0 (Mean ± SD)	T1 (Mean ± SD)	ΔT1–T0	95% CI	t-value	p-value
Intercanine Width (ICW, mm)	32.15 ± 2.30	35.83 ± 2.38	+3.68 ± 0.94	3.32, 4.04	21.08	<0.001*
Interpremolar Width (IPW, mm)	38.40 ± 2.62	43.14 ± 2.70	+4.74 ± 1.05	4.34, 5.14	24.31	<0.001*
Intermolar Width (IMW, mm)	48.65 ± 2.95	54.11 ± 3.04	+5.46 ± 1.12	5.03, 5.89	26.25	<0.001*
Intermolar Apex Width (IMAW, mm)	30.80 ± 2.41	34.34 ± 2.48	+3.54 ± 0.88	3.21, 3.87	21.66	<0.001*

*Statistically significant ($p < 0.001$, paired t-test).

Table 3. Pre-Expansion (T0) and Post-Retention (T1) Molar Inclination and Buccal Alveolar Bone Measurements (n = 29)

Parameter	T0 (Mean ± SD)	T1 (Mean ± SD)	ΔT1–T0	95% CI	t-value	p-value
Right First Molar Inclination (°)	96.40 ± 4.12	100.04 ± 4.25	+3.64 ± 1.45	3.09, 4.19	13.52	<0.001*
Left First Molar Inclination (°)	97.10 ± 4.05	100.91 ± 4.18	+3.81 ± 1.52	3.23, 4.39	13.50	<0.001*
Right M1 Buccal Bone Thickness (mm)	1.68 ± 0.42	1.26 ± 0.39	-0.42 ± 0.21	-0.50, -0.34	-10.77	<0.001*
Left M1 Buccal Bone Thickness (mm)	1.65 ± 0.40	1.20 ± 0.38	-0.45 ± 0.23	-0.54, -0.36	-10.54	<0.001*

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Parameter	T0 (Mean ± SD)	T1 (Mean ± SD)	ΔT1–T0	95% CI	t-value	p-value
Right M1 Buccal Bone Height (mm)	12.10 ± 1.15	12.61 ± 1.18	+0.51 ± 0.28	0.40, 0.62	9.81	<0.001*
Left M1 Buccal Bone Height (mm)	12.18 ± 1.12	12.72 ± 1.16	+0.54 ± 0.30	0.43, 0.65	9.69	<0.001*

M1: Maxillary first molar; Buccal bone height measured vertically from mesiobuccal cusp tip to buccal alveolar crest. *Statistically significant ($p < 0.001$, paired t-test).

Discussion

Non-surgical maxillary expansion in skeletally mature young adults requires overcoming substantial resistance from an interdigitated midpalatal suture and rigid zygomaticomaxillary and pterygomaxillary buttresses[6,7]. In this prospective CBCT investigation, hybrid tooth-and-bone-borne MARPE achieved a 90.6% sutural separation rate with substantial basal skeletal widening and controlled dentoalveolar side effects, supporting its role as a viable alternative to SARPE.

Our 90.6% orthopedic success rate (mean age: 21.4 years) aligns with recent systematic reviews and clinical studies reporting success rates of 86.9% to 94.2% in young adults[17-21]. Notably, all three expansion failures occurred in patients older than 25 years, corroborating micro-CT and clinical findings that sutural obliteration density and circummaxillary rigidity escalate markedly after the mid-twenties[6,22]. Bicortical engagement of the four miniscrews through both palatal and nasal cortical plates likely contributed to this high success rate, as finite element and clinical studies demonstrate that bicortical anchorage doubles resistance against pterygomaxillary stress and prevents miniscrew deformation compared to monocortical placement[15,22].

Unlike conventional tooth-borne RPE, which produces a V-shaped anterior-widening pattern due to resistance from the posterior pterygoid plates[5,9] MARPE generated a nearly parallel anteroposterior sutural split (84.5% PNS/ANS ratio; 2.89 mm vs. 3.42 mm). Positioning the jackscrew posteriorly between the second premolars and first molars directs the force vector closer to the maxillary center of resistance, yielding parallelism comparable to recent 3D prospective evaluations (80%–90%)[16,20]. Coronal basal maxillary expansion (3.12 mm) accounted for 57.1% of total intermolar widening (5.46 mm), aligning with recent meta-analytic benchmarks (55%–68%)[17,20,24] and markedly outperforming conventional RPE in late adolescents (35%–42%)[8,25]. Furthermore, the 2.38 mm gain in nasal cavity width reflects outward rotation of the nasomaxillary complex, which recent randomized trials and airway meta-analyses link to reduced nasal airway resistance and enhanced upper airway volume[25,26].

Because hybrid MARPE appliances remain banded to the maxillary first molars for intraoperative stability, minor dentoalveolar side effects persist[27]. Nevertheless, the observed buccal molar tipping (3.64°–3.81°) was less than half the 6°–11° flaring typically reported after tooth-borne RPE in young adults[8,25] and matches recent prospective CBCT findings[20,25]. Periodontally, buccal alveolar bone thickness decreased by only 0.42–0.45 mm and marginal crest height by 0.51–0.54 mm—well below the 0.8–1.5 mm cortical bone loss and dehiscence risk documented with tooth-borne expanders[8,28,29]. Because T1 scans were acquired after 6 months of retention rather than immediately post-activation, partial buccal cortical remodeling and sutural ossification had likely already transpired[3].

Clinically, pre-treatment CBCT assessment of palatal bone thickness and buccal cortical housing remains essential; patients with severely thin buccal plates (<1.0 mm) or advanced age (>25 years) may benefit from

purely bone-borne MARPE designs[24] or corticopuncture-assisted protocols[31]. Limitations of this study include the absence of a parallel surgical or untreated control group due to ethical constraints, lack of objective rhinomanometric airflow measurements, and follow-up restricted to the 6-month retention period. Long-term post-debonding CBCT studies are warranted to verify multi-year skeletal stability.

Conclusion

MARPE achieved a 90.6% midpalatal suture separation rate in skeletally mature young adults, producing substantial, nearly parallel anteroposterior skeletal expansion that accounted for 57.1% of total transverse dental gain while restricting buccal molar tipping and buccal alveolar bone remodeling to mild, clinically acceptable limits.

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