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RESEARCH ARTICLE

The Effect of the Anteroposterior Position of Miniscrew Assisted Rapid Palatal Expansion on the Expansion Outcomes in Mature Patients

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ABSTRACT

Objectives: This study aimed to assess how the anteroposterior position of the miniscrew- assisted rapid palatal expansion (MARPE) appliance influences maxillary skeletal expansion and to propose a reference point for optimal placement.

Material and Methods: Thirty- two skeletally mature patients treated with MARPE were retrospectively assigned to an anterior group (anterior miniscrews ≥ 5 mm anterior to the centre of the maxilla (CM)) or a posterior group (≤ 2 mm from or posterior to CM). Pre- and post- expansion cone-beam computed tomography scans were used to measure skeletal, dental, and paramaxillary changes. Independent t- tests following data normality, linear regression with validated model assumptions, and Bayesian mediation analyses evaluated direct and indirect effects of appliance position and bicortical engagement.

Results: The anteroposterior appliance position significantly affected expansion outcomes. Posterior placement yielded greater skeletal expansion and a more parallel pattern ($p = 0.008$), especially in the posterior maxilla ($p = 0.001$). Anterior positioning produced reduced skeletal effects and a V- shaped expansion ($p = 0.001$). Molar tipping increased both directly with anterior positioning ($p = 0.002$) and indirectly through reduced bicortical engagements. Miniscrew movement, indicating activation loss, was likewise indirectly mediated by fewer bicortical engagements (95% highest density interval: [−0.140, −0.009]). The posterior group exhibited significantly greater paramaxillary expansion, especially in the posterior regions of the jugale and zygoma ($p = 0.011$).

Conclusion: Anteroposterior MARPE position significantly impacts skeletal expansion results. Positioning near or posterior to the centre of the maxilla point enhances parallel skeletal expansion and minimizes undesirable dental effects. This reference point can serve as a practical reference to optimize MARPE placement for mature patients.

1 | Introduction

Maxillary transverse deficiency is a prevalent skeletal that can impair occlusal function, compromise periodontal health, and negatively affect facial aesthetics [1]. Miniscrew- assisted rapid palatal expansion (MARPE) has emerged as a promising approach for skeletally mature patients, as it can achieve significant skeletal expansion with fewer undesirable dental side effects than conventional expanders [2, 3]. By anchoring expansion forces to the palatal bone via multiple miniscrews—often with bicortical engagement into the nasal floor—MARPE enhances the orthopaedic component of expansion and reduces the load on the dentition [4, 5].

Despite these advantages, clinical outcomes with MARPE remain variable [3, 6]. Not all patients achieve predictable midpalatal suture separation, parallel expansion, or minimal dental side effects [7]. These differences are likely influenced by multiple biomechanical and anatomical factors, including palatal bone thickness, the number of bicortical engagements, and the three- dimensional position of the appliance relative to the maxillary centre of resistance [3, 6]. Among these factors, the anteroposterior position of the MARPE appliance has drawn particular clinical interest. Many clinicians empirically advocate for a more posterior placement, reasoning that this may enhance engagement of the posterior maxillary buttresses and pterygopalatine region and thereby promote greater posterior skeletal expansion [4, 5]. However, the supporting evidence for this recommendation is largely anecdotal and inconsistent.

To date, only a single study [8] has investigated the impact of anteroposterior placement, and it focused primarily on the type of appliance rather than a clearly defined positional landmark. As a result, it does not provide a robust basis for establishing a standardised guideline on where, anteroposteriorly, MARPE should be positioned. Furthermore, no widely accepted anatomical reference point has been proposed to guide MARPE placement [3]. The palate exhibits marked regional variation in bone thickness, generally being thicker anteriorly and thinner posteriorly [9], which directly affects the feasibility of bicortical engagement and may in turn influence the skeletal versus dental components of expansion. Nonetheless, most previous studies have treated MARPE position implicitly or as a secondary consideration, rather than as a primary independent variable.

This lack of a reproducible, clinically accessible landmark makes it challenging for clinicians to consistently place the appliance in a position that maximises skeletal expansion and minimises unwanted dental movements, while accommodating individual anatomical constraints. Considering these clinical needs, the present study aimed to clarify how the anteroposterior position of the MARPE appliance influences maxillary skeletal expansion, both directly and through its association with bicortical engagement of the miniscrews. Specifically, the objectives were (1) to evaluate the effect of appliance position on the pattern and magnitude of skeletal expansion and (2) to identify a reliable anatomical reference point for optimal placement that promote more uniform skeletal expansion. To comprehensively assess both direct and indirect effects, frequentist linear regression and Bayesian statistical approaches were applied. Establishing such a reference may assist clinicians in achieving predictable and effective expansion outcomes in skeletally mature patients.

2 | Material and Methods

2.1 | Subjects

This retrospective study was approved by the Institutional Review Board of Dankook University Dental hospital (DKUDH IRB 2022–10- 012). A total of 100 patients diagnosed with transverse maxillary discrepancy and treated with MARPE at the Department of Orthodontics, Dankook University Dental Hospital, were initially considered for inclusion.

Inclusion criteria were as follows: (1) Age over 17 years; cervical vertebral stage over 5 (2) maxillary transverse discrepancy (presence of posterior cross bite or severely compensated molar torques) (3) availability of serial CBCT images taken before (T_0) and after (T_1) maxillary expansion; (3) achieving midpalatal suture separation in T_1 images; (3) T_1 CBCT images acquired within 120 days after completion of the expansion; (4) high quality CBCT scans; (5) anterior miniscrews positioned within a defined anatomical range (detailed below) on the CBCT image. Exclusion criteria included: (1) Failure of midpalatal suture separation; (2) use of alternative maxillary expansion devices of different type or design; (3) excessively long time interval between T_0 and T_1; (4) severe maxillary skeletal asymmetry evident on CBCT (Maxillary canting ≥ 5 mm or any yawing), potentially compromising measurement accuracy; (5) history of previous orthodontic treatment or maxillofacial trauma; (6) presence of systemic conditions or craniofacial anomalies such as cleft lip and palate or craniosynostosis.

After applying these criteria, 32 patients with suitable CBCT records were included in the final analysis. Based on the anteroposterior position of their appliances, patients were assigned to two groups:

- Group A: Appliance located anteriorly relative to the centre of the maxilla (CM_AS ≥ 5 mm; group mean 7.99 mm)
- Group P: Appliance positioned posteriorly relative to the centre of the maxilla (CM_AS ≤ 2 mm, group mean −1.67 mm)

The age, sex, and CM_AS distribution were comparable between the two groups (Table 1).

Midpalatal suture (MPS) separation was not achieved in three of 19 patients of potential Group A and in three of 19 patients

TABLE 1 | Baseline characteristics of the groups.

	Group I (Anterior)	Group II (Posterior)
N	**16**	**16**
Age (years)	21.6341 (3.8617) [17.62–32.73]	21.0969 (3.5762) [17.13–30.96]
Sex (M/F)		
Male	7	7
Female	9	9
CM_AS (mm)	7.9875 (3.3734)	−1.6725 (2.4570)
Number of Bicortical Engagement		
0	3	0
2	4	2
4	9	14

of potential Group P. These cases were excluded from the final analysis to ensure that only subjects with confirmed MPS separation were evaluated.

2.2 | Intervention

The expansion device used in this study was the MSE- 1 (Biomaterials, Seoul, South Korea). It consists of a central jackscrew with four integrated sheaths for miniscrew placement and four extension arms soldered to orthodontic bands attached to the maxillary first molars. The anteroposterior position of the appliance was determined according to two criteria: placement posteriorly, near the posterior resistance structures (Group P), or anteriorly, to ensure sufficient bone support (Group A). The positions were randomly allocated to the patients. The base of the appliance passively contacts the palatal soft tissue. After band adjustment and cementation, four miniscrews were placed through the sheaths of the appliance. One full turn of the jackscrew equalled 0.2 mm of expansion. Activation began 1 week after miniscrew placement with a protocol of two turns per day (0.4 mm/day) and continued until the predetermined expansion target was reached. This target was defined using the Yonsei Transverse Index (YTI), calculated as the transverse distance difference between the furcation points of the maxillary and mandibular first molars [10]. Expansion was stopped when the palatal cusp of the maxillary molar contacted the buccal cusp tip of the opposing mandibular molar, even if the prescribed YTI was not fully reached. All patients were treated using a standardised MARPE protocol by multiple orthodontists under the supervision of senior faculty. The appliance design, activation schedule, and expansion rate were kept consistent across all cases to minimise operator- related variability.

2.3 | Measurement

All measurements and data analyses were performed by a single calibrated examiner (SGH). To ensure blinding, all patient data were anonymized using randomised identifiers. CBCT scans were obtained using the Alphard VEGA system (ASAHI Roentgen IND, Kyoto, Japan) in P- mode (field of view: 15.4 × 15.4 cm; 5.0 mA; 80 kV; exposure time: 17 s; voxel size: 0.30 mm). Radiation exposure was minimised according to the ALADA (as low as diagnostically acceptable) principle, while maintaining diagnostic image quality. DICOM files were processed using InVivo Dental version 5.0 software (Anatomage Inc., San Jose, CA, USA) for image orientation, landmark identification, and dimensional measurements.

The key anatomical landmark in this study was the center of the maxilla (CM), which served as the reference point for classifying appliance positioning (Figure 1). The CM point was defined as the intersection of three planes: (1) the midsagittal plane (MSP), which passes through the posterior segment of the midpalatal suture and the most posterior point of the vomer; (2) the palatal plane (PP), which is perpendicular to the MSP and also aligned with the posterior midpalatal suture; (3) the bi- zygomatic plane (BZP), which is orthogonal to the PP and extends through the outermost points of the left and right zygomatic processes of the maxilla. This landmark was chosen as a key landmark because it is both highly accessible and reproducible due to being a distinct anatomical feature. Furthermore, its position close to the maxillary centre of resistance on the palatal plane indicates it is the primary area of resistance to expansion.

The anteroposterior position of the appliance (CM_AS) was determined by measuring the distance on the MSP from the CM point to the midpoint between the projections of the left and right AS points (where the anterior miniscrews first contact the palatal bone) on the MSP. This study categorised patients into two groups. Group A (anterior) was defined by an appliance position of CM_AS ≥ 5 mm, reflecting the clinician's intent for anterior placement. Conversely, Group P (posterior) was defined by CM_AS ≤ 2 mm, indicating an intended posterior placement.

Several anatomical and dental parameters were assessed to quantify the transverse changes resulting from MARPE (Table 2). The differences between T_1 and T_0 measurements were calculated and then normalised by the total activation amount (in mm) to obtain the change per unit expansion. In addition, the anteroposterior ratio of skeletal expansion (AP_ratio) was calculated as the ratio of posterior to anterior skeletal expansion in the midpalatal region.

2.4 | Statistical Analysis

Statistical analyses were performed using the Python StatsModels and PyMC libraries. To evaluate measurement reliability, six CBCT images were randomly selected and remeasured by the same examiner (SGH) after a 2- week interval. Intraclass correlation coefficients (ICCs) and Dahlberg's error (DE) were computed, indicating excellent reliability with ICC values greater than 0.92. The sample size calculation was performed using G*Power software (version 3.1.9.7; Franz Faul, Christian- Albrechts-Universität, Kiel, Germany) to determine the required sample size. The effect size was derived from pilot data, and the analysis indicated that a minimum total of 24 subjects (12 per group) would provide a statistical power of 0.81 at a two- tailed α level of 0.05.

The Shapiro–Wilk test was used to assess the normality of the data distributions within each group based on appliance position. Independent *t*- tests were performed to compare all trans verse change variables between the two groups. To further investigate associations, linear regression was used to evaluate the relationship between appliance position and variables with statistically significant intergroup differences. Additionally, simple linear regression was used to examine the direct effect of the anteroposterior position of the appliance (CM_AS) on each dependent variable, independent of bicortical engagement, based on subsequent mediation analysis.

A significant difference in the frequency of bicortical engagement between the two groups was observed (Table 1), highlighting the potential mediating role of bicortical engagement in influencing the outcome variables. Due to the limited number of samples with no or minimal bicortical engagement, Bayesian statistical methods were employed to evaluate the indirect effects. Bayesian mediation analysis was used to assess whether bicortical engagement of miniscrews (denoted as *B*) mediated the relationship between

FIGURE 1 | Representation of landmarks and measurements used in the study. (A) Centre of maxilla (CM) reference point. (B) Anteroposterior appliance position relative to the CM point (CM_AS). (C) paramaxillary points: Zygoma (Z), Jugale (J) and Nasal Cavity (NC). (D) Incisive canal reference point (IC) and its measurement (D_IC). (E) Anterior miniscrew position (AS) and its measurement (D_AS). (F) Pterygomaxillary figure reference point (PM) and its measurement (D_PM). (G) Distance between the centre of resistance of left and right upper first molars (D_CreU6).

appliance position (P) and the outcome variables (O). The hypothesized causal model was $P \rightarrow \mathrm{B} \rightarrow \mathrm{O}$, allowing for the possibility of both indirect ($P \rightarrow \mathrm{B} \rightarrow \mathrm{O}$) and direct effects ($P \rightarrow \mathrm{O}$, $B \rightarrow \mathrm{O}$). Two Bayesian regression models were specified:

Mediator model: $\mathrm{B}_i \sim \mathcal{N}\left(\alpha_B + \beta_B \cdot P_i, \sigma_B^2\right)$.

Outcome model: $O_i \sim \mathcal{N}\left(\alpha_O + \beta_{O,P} \cdot P_i + \beta_{O,B} \cdot B_i, \sigma_O^2\right)$.

The indirect effect of B was calculated as $\beta_B \cdot \beta_{O,B}$, the direct effect of P as $\beta_{O,P}$, the total effect as their sum, and the direct effect of B as $\beta_{O,B}$. These Bayesian models were implemented using PyMC, with weakly informative priors specified for all parameters. Posterior distributions were estimated using the No-U- Turn Sampler (NUTS), with 2000 posterior draws following 1000 tuning steps. For each effect, the posterior mean and 95% highest density intervals (HDIs) were reported.

3 | Results

Figure 2 and Table S1 demonstrate the result of Bayesian mediation analysis. Table 3 summarises the intergroup differences of variables between two groups. Table S2 displays the estimated effect of the anteroposterior position of the appliance (CM_AS) on variables.

3.1 | Palatal Movement: IC_u, PM_u, AP_ratio and Exp_ratio

Based on the Bayesian mediation analysis (Figure 2; Table S1), bicortical engagement did not have a significant indirect effect on IC_u (95% HDI: [−0.050, 0.075]), PM_u (95% HDI: [−0.043, 0.069]), or AP_ratio (95% HDI: [−0.042, 0.060]). However, it had a significant indirect effect on Exp_ratio (95% HDI: [−0.001,

TABLE 2 | Variables and their definition used in the current study.

	Variable	Definition of measurements
Appliance position		
Midsagittal plane	CM_AS	Anteroposterior distance between the centre of maxilla (CM) point and the mean of projection of anterior miniscrew (AS) point on the midsagittal plane
Palatal movement		
Palatal plane	IC_u	ΔIC/Activation; ΔIC is the distance between the right and left midpalatal points on the most posteroinferior side of the incisive foramen
	PM_u	ΔPM/Activation; ΔPM is the distance between the most posterolateral points of the left and right pterygomaxillary fissures
Calculated variable	AP_ratio	ΔPM/ΔIC; The antero- posterior ratio of the transverse change of the midpalatal region
	Exp_ratio	ΔU6/ΔIMW; The ratio of the skeletal expansion amount to the dental expansion amount in U6 level
Dental movement		
3D Coordinate system	IMW_u	ΔIMW/Activation; ΔIMW is the distance between the right and left meisobuccal cusp tips of upper first molars
Coronal plane accross U6 axis lines	CreU6_u	ΔCreU6/Activation; ΔCreU6 is the distance between the points of the center of the resistance of the right and left upper first molars
Calculated variable	U6Tip_u	CreU6_u—U6_u; The amount of the buccal tipping of right and left upper first molars per activation amount
Miniscrew movement		
Miniscrew plane[a]	AS_u	ΔAS/Activation; ΔAS is the distance between the center points of right and left anterior microimplants in axial slice
	ASMove_u	AS_u—U6_u; The amount of the buccal movement of right and left microimplants per activation amount
Paramaxillary movement		
3D coordinate system	J_u	ΔJ/Activation; ΔJ is the distance between the left and right J points. J point is the intersection of maxillary tuberosity and zygomatic buttress
	Z_u	ΔZ/Activation; ΔZ is the distance between the left and right Z points. Z is the most lateral point of zygomaticomaxillary suture
	NC_u	ΔNC/Activation; ΔNC is the distance between the left and right NC points. NC point is the most lateral point of nasal cavity on frontal view
Others		
Chronologic age		Chronologic age
Sex		Male or female
BE		The number of miniscrews accomplishing bicortical engagment
Activation		The amount (mm) of the hyrax activation

[a]Miniscrew plane, an axial slice on the oriented position where the long axis of an anterior microimplant was parallel to the coronal plane in a lateral view.

0.121]). In addition, Exp_ratio showed a significant direct effect of CM_AS (95% HDI: [0.029, 0.266]).

As shown in the intergroup comparisons (Table 3), all four variables showed statistically significant differences between Group A and Group P. The skeletal expansion efficiency indicators, IC_u and PM_u, were greater in Group P compared to Group A, which corresponded with variations in CM_AS. In particular, PM_u (MD = 0.190, $p = 0.001$) showed a stronger significance than IC_u (MD = 0.154, $p = 0.016$). Group P also demonstrated a more parallel expansion pattern, as reflected by a significantly higher AP_ratio (MD = 0.143, $p = 0.008$), attributable to CM_AS. In addition, the skeletal- to-dental ex pansion ratio (Exp_ratio) was significantly higher in Group P than in Group A (MD = 0.191, $p = 0.002$), and this variable showed both significant direct and indirect effects. Linear

FIGURE 2 | Schematic diagram summarising the Bayesian mediation analysis, showing the direct and indirect effects of MARPE position (CM_AS) and bicortical engagement (BEs). More posterior MARPE placement, or smaller CM_AS value, had a stronger direct effect on skeletal and paramaxillary expansion, whereas a greater number of miniscrews with bicortical engagement mainly influenced molar tipping and miniscrew movement. Solid arrows indicate statistically significant effects, and dashed arrows indicate weaker effects; plus (+) and minus (−) symbols denote positive and negative directions of effect. BEs, number of miniscrews achieving bicortical engagement; Posterior, more posterior MARPE placement indicating a smaller CM_AS value. Definitions of the other abbreviations are provided in Table 2.

regression analysis (Table S2) indicated that the anteroposterior position of the appliance (CM_AS) significantly affected IC_u ($p = 0.095$, $R^2 = 0.091$), PM_u ($p = 0.004$, $R^2 = 0.241$), and AP_ratio ($p = 0.001$, $R^2 = 0.299$).

3.2 | Dental Movement: IMW_u, CreU6_u and U6Tip_u

Bayesian mediation analysis (Figure 2; Table S1) revealed that bicortical engagement had no significant indirect effect on CreU6_u (95% HDI: [−0.101, 0.031]), but showed a significant indirect effect on IMW_u (95% HDI: [−0.200, 0.000]) and a marginally significant indirect effect on U6Tip_u (95% HDI: [−0.151, 0.010]). The direct effects of CM_AS on IMW_u and U6Tip_u were also weakly significant (95% HDIs: [−0.038, 0.322] and [−0.200, 0.041], respectively).

In the intergroup comparison (Table 3), CreU6_u and U6Tip_u showed significant differences between groups (MD = 0.216 and −0.149, respectively; $p = 0.002$ for both), while IMW_u showed no significant difference (MD = 0.045, $p = 0.617$).

Linear regression (Table S2) showed that CM_AS significantly influenced CreU6_u ($p = 0.035$, $R^2 = 0.140$).

3.3 | Miniscrew Movement: AS_u and ASMove_u

Bayesian mediation analysis (Figure 2; Table S1) indicated a strong significant indirect effect of bicortical engagement on ASMove_u (95% HDI: [−0.140, −0.009]) and a marginally significant indirect effect on AS_u (95% HDI: [−0.138, 0.010]). The direct effects of CM_AS on these two variables were weak (95% HDIs: [−0.155, 0.036] for AS_u and [−0.030, 0.264] for ASMove_u).

When compared between groups (Table 3), there was no significant difference in AS_u (MD = −0.089, $p = 0.215$). Although ASMove_u was greater in Group A than in Group P, this difference did not reach statistical significance (MD = −0.101, $p = 0.082$).

3.4 | Paramaxillary Movement: J_u, Z_u and NC_u

Bayesian mediation analysis (Figure 2; Table S1) showed no significant indirect effects of bicortical engagement on any of

TABLE 3 | Results of independent *t*- test evaluating intergroup difference of all variables.

Category	Variable	Group	Mean	SD	MD (I—II)	*t*-statistics	DoF	95% CI	*p*	Power
Appliance position	CM_AS	Group A	7.9875	3.3373	9.6600	9.2588	30	[7.53, 11.79]	< 0.0001***	1.0000
		Group P	−1.6725	2.4570						
Palatal movment	IC_u	Group A	0.3921	0.1290	−0.1537	−2.5624	30	[−0.28, −0.03]	0.0157*	0.6984
		Group P	0.5458	0.2023						
	PM_u	Group A	0.2680	0.1018	−0.1901	−3.6303	30	[−0.30, −0.08]	0.0010**	0.9396
		Group P	0.4581	0.1830						
	AP_ratio	Group A	0.6931	0.1485	−0.1430	−2.8566	30	[−0.25, −0.04]	0.0077**	0.7894
		Group P	0.8361	0.1344						
	Exp_ratio	Group A	0.4235	0.1491	−0.1910	−3.3700	30	[−0.31, −0.08]	0.0021**	0.9033
		Group P	0.6145	0.1707						
Dental movement	IMW_u	Group A	0.7520	0.2741	−0.0452	−0.5050	30	[−0.23, 0.14]	0.6172	0.0778
		Group P	0.7972	0.2301						
	CreU6_u	Group A	0.4946	0.1773	−0.2160	−3.3667	30	[−0.35, −0.08]	0.0021**	0.9027
		Group P	0.7106	0.1854						
	U6Tip_u	Group A	0.2359	0.2120	0.1493	2.4588	30	[0.03, 0.27]	0.0199*	0.6626
		Group P	0.0866	0.1186						
Miniscrew movement	AS_u	Group A	0.5684	0.1908	−0.0894	−1.2672	30	[−0.23, 0.05]	0.2148	0.2325
		Group P	0.6578	0.2077						
	ASMove_u	Group A	0.3004	0.1794	0.1007	1.8025	30	[−0.01, 0.21]	0.0815	0.4149
		Group P	0.1997	0.1333						
Paramaxillary movement	J_u	Group A	0.2573	0.1303	−0.1961	−3.8372	30	[−0.30, −0.09]	0.0006***	0.9601
		Group P	0.4534	0.1575						
	Z_u	Group A	0.3031	0.1190	−0.1316	−2.7265	30	[−0.23, −0.03]	0.0106*	0.7512
		Group P	0.4347	0.1519						
	NC_u	Group A	0.3458	0.1168	−0.1328	−2.6538	31	[−0.23, −0.03]	0.0126*	0.7285
		Group P	0.4786	0.1625						
Others	Age	Group A	21.6341	3.8617	0.5372	0.4082	30	[−2.15, −3.22]	0.686	0.0681
		Group P	21.0969	3.5762						

Note: The significance of $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

the paramaxillary movement variables: J_u (95% HDI: [−0.019, 0.087]), Z_u (95% HDI: [−0.044, 0.056]), and NC_u (95% HDI: [−0.059, 0.047]).

However, intergroup comparisons (Table 3) showed that all three variables—J_u, Z_u, and NC_u—were significantly greater in Group P than in Group A, mainly due to the influence of CM_AS. The anterior paramaxillary region (NC_u) and the posterior lateral region (Z_u) showed similar magnitudes of difference (MD = 0.133 and 0.132; $p = 0.013$ and 0.011, respectively). Linear regression (Table S2) revealed a significant effect of CM_AS on J_u ($p = 0.002$, $R^2 = 0.272$). Although not statistically significant, the influence of CM_AS appeared to be greater on Z_u ($p = 0.070$, $R^2 = 0.106$) compared to NC_u ($p = 0.190$, $R^2 = 0.057$).

4 | Discussion

The results of this study suggest that the anteroposterior position of the MARPE appliance significantly influences skeletal expansion outcomes in skeletally mature patients. Appliances positioned near or posterior to the CM point exhibited more parallel expansion and a greater magnitude of posterior expansion, resulting in enhanced overall skeletal widening compared with anteriorly positioned appliances. Conversely, anterior positioning yielded reduced skeletal expansion and a characteristic V- shaped pattern, indicating limited posterior widening. Furthermore, anterior placement contributed both directly and indirectly—via reduced bicortical engagement—to increased molar tipping and miniscrew movement. Collectively, these findings support the CM point as a practical anatomical reference for MARPE placement, enabling clinicians to optimise skeletal expansion while minimising undesirable dental effects.

In the current study, the AS point was used to the landmark representing the appliance position and the transverse change of miniscrews. The transverse change of anterior miniscrews can explain the entire transverse change of miniscrews since there is no significant difference in the extent of suture opening between the anterior and posterior miniscrews [11]. Also, the anterior miniscrews are more adequate to represent the anteroposterior position since they are closer to the hemiplate line of the appliance than the posterior's [11]. Additionally, the AS point has a benefit to be observed easily in clinical conditions, which aid clinicians evaluate the appliance position roughly.

A previous study [8] reported the effect of anteroposterior appliance position on skeletal expansion outcomes. The authors reported that an anterior appliance position could lead to V-shaped expansion due to a reduced number of bicortical engagements, although the intergroup difference was not statistically significant. The V- shaped expansion pattern observed in the anterior- positioned group in that study aligns with the present findings. However, the current results indicate that the number of bicortical engagements exerts only a weak indirect effect on V- shaped expansion in the anterior group, whereas the direct effect of appliance position is the primary factor. The indirect effect of bicortical engagement is predominantly manifested in molar tipping and miniscrew movement, which suggest that the bicortical engagement may play a larger role in producing a parallel expansion in a coronal section. The limitations of the previous study lay in its design: the groups were based on anchor type rather than appliance position, and bicortical engagement was not considered a mediator due to normality constraints of its sample. Another study performed a finite element analysis of the tissue- borne type of MARPE and reported that posterior positioning maximised posterior skeletal expansion in relation to anterior expansion [4, 5, 12]. This finding aligns with the current study's results.

Bicortical engagement of miniscrews is a pivotal element in achieving both successful skeletal maxillary expansion [13] and the stability of the miniscrews [14]. Given the anatomical characteristics of the palate which tends to be thicker in the anterior region [11, 15], placing the appliance more anteriorly often reduces the likelihood of achieving bicortical engagement. Consequently, anterior positioning may influence expansion outcomes by diminishing bicortical engagement. Indeed, a significant difference in the frequency of bicortical engagements was reported in a study comparing different appliance types [8]. Therefore, accounting for the indirect effects of bicortical engagement on expansion results is crucial. In this investigation, Bayesian mediation analysis was employed to estimate both direct and indirect effects, while accommodating the relatively small sample of patients with limited bicortical engagement. The findings suggest that bicortical engagement primarily affects miniscrews' slippering on the palatal bone—reflected as appliance- level loss of activation—and contributes to molar tipping, indicating tooth- level loss of activation, which is known as the negligible side effect. It is noteworthy that anterior- group samples achieving full bicortical engagement exhibited less activation loss at both the appliance and tooth levels, resulting in a more favourable skeletal- to-dental expansion ratio, the patterns of which are observed in the conventional rapid palatal expansion [16].

In this study, the V- shaped expansion observed in the anterior group appears to be primarily attributed to the smaller amount of skeletal posterior expansion in the palate. This outcome is consistent with other reports on MARPE [7, 17, 18]. Posterior expansion is more important than anterior expansion in aspect of the long- term relapse of MARPE considering its inverted V-shaped relapse pattern, which is more posterior relapse than the anterior [19]. The variation in expansion patterns is likely attributable to differences in force orientation and direction relative to the maxilla's center of resistance [20]. Of particular note is the location of the CM point utilised for the posterior group, which is in close proximity to the maxilla's center of resistance when projected onto the palatal plane. The strategic placement of the appliance close to the CM point offers two primary advantages: enhanced force transmission to posterior skeletal structures; for example, the zygomatic buttress [20, 21] and pterygopalatine suture [17, 22], and reduced force moments that might result from unfavourable vectors. The substantial discrepancy in posterior expansion between anterior and posterior groups is thus linked to insufficient force transmission to distal resistance areas, rather than an overly large force moment. Furthermore, the weak indirect effect of bicortical engagement on skeletal expansion highlights the importance of optimising force transmission itself.

The success rates of MPS separation were 84.21% for both anterior and posterior group, which are comparable to values reported in previous studies [2]. Interestingly, among Group P patients in whom MPS separation failed, posterior palatal thickness was significantly lower, whereas Group A patients with failed MPS separation showed no or only single bicortical engagement of the miniscrews. Previous studies have reported that both palatal bone thickness near miniscrews and bicortical engagement affect the success of MPS separation [6, 23]. Consistent with these findings, our data imply that both factors contribute to successful MPS separation, but the predominant factor differs between groups: for posterior MARPE placement, success appears to be influenced mainly by palatal bone thickness near the anchor miniscrews, whereas for anterior MARPE placement, it is influenced primarily by the number of bicortical engagements. Clinically, posterior position may therefore be recommended for patients with anterior palatal thickness that is too thick to allow bicortical engagements, while an anterior position may be preferable for patients with posterior palatal bone that is too thin to withstand the expansion forces generated during activation.

In the posterior group, paramaxillary movement involving the anterosuperior maxilla and nasal alae was more pronounced, occasionally leading to an increase in the width of the nose and zygomatic area in some patients [24–26]. While these soft tissue alterations are often transient [26, 27], certain individuals—such as patients with lower nasal height, young patients, or East Asian patinets—may be more vulnerable to prolonged cosmetic concerns. However, most existing studies on facial changes associated with MARPE have not specified the appliance position and have implicitly assumed that all MARPE appliances would have the similar results. Given that the previous research has reported that short- term soft tissue movements following MARPE are correlated with the amount of suture opening [25], it may be preferable to position the MARPE anteriorly in such patients.

Nonetheless, the anterior MARPE position is not invariably unfavourable. The appropriateness of this position is contingent upon the patient's baseline characteristics. Posterior palate is often thin and may not offer adequate bone anchor. The anterior MARPE position may be favoured by some clinicians, with understanding that the expansion pattern will be a V- shaped with a limited posterior expansion. Younger patients with substantial skeletal transverse discrepancies may still benefit from an anterior position because they could achieve favourable expansion outcomes easier [28], Cantarella et al. proposed keeping the posterior position and adding two more mini- screws laterally near the CM point instead of changing the appliance position [29]. Table 4 provides a summary of the clinical recommendations for MARPE positioning based on the results of the present study.

This study has a limitation. The study exclusively included patients who had undergone midpalatal suture separation. Patients who did not achieve separation were excluded due to both a small sample size and a lack of T2 CBCT scans. Consequently, the larger sample is needed to rigorously assess how MARPE positioning impacts the likelihood of successful suture separation. Additionally, the findings of this retrospective study are based on a comparison between two distinct groups. Consequently, their generalizability to the patient population within the intermediate range (2 mm < CM_AS < 5 mm) is limited. Finally, minor variations in appliance placement may have occurred since treatments were performed by multiple orthodontists. However, a standardised treatment protocol was implemented to minimise such variability, and all procedures were performed under faculty supervision to ensure consistency.

TABLE 4 | Clinical recommendations of MARPE positioning in skeletally mature patients.

Consider posterior MARPE position
Thick anterior palatal bone, making bicortical engagement difficult at the anterior site
Moderate- to-severe skeletal transverse discrepancy, requiring greater posterior skeletal expansion
Strong skeletal resistance (advanced suture maturation, high posterior resistance) where maximal skeletal widening is desired
Desired parallel or near- parallel skeletal expansion, especially in the posterior maxilla (higher AP_ratio)
When minimising molar tipping and miniscrew sliding (loss of activation) is a high priority
Need or tolerance for greater paramaxillary expansion, and possible increase in nasal and midfacial width
Patients with low concern about transient or mild increases in nasal and midfacial width
Consider anterior MARPE position
Thin posterior palatal bone, insufficient to provide stable miniscrew anchorage or to withstand expansion forces
Mild skeletal transverse discrepancy, requiring only mild- to-moderate posterior skeletal expansion
Lower skeletal resistance where full posterior expansion is not essential or is expected to be easier to obtain
Acceptance of a V- shaped expansion pattern with relatively limited posterior skeletal widening and greater dental contribution
When some degree of molar tipping and greater dental expansion is desirable
Desire to limit posterior paramaxillary expansion and to reduce the risk of nasal and zygomatic widening
Patients susceptible to unfavourable transverse soft- tissue changes where facial widening should be minimised

5 | Conclusions

1. Anterior positioning of the MARPE, relative to the point of the center of the maxilla (CM), directly results in reduced skeletal expansion and a V- shaped expansion pattern primarily due to insufficient posterior skeletal expansion.
2. Anterior MARPE placement increases molar tipping, both directly and indirectly through a reduced number of bicortical engagements.
3. Anterior MARPE placement also indirectly increases miniscrew sliding on the palatal bone and associated loss of activation, again mediated by fewer bicortical engagements.
4. Posterior MARPE placement is associated with greater paramaxillary expansion, particularly in the posterior maxilla and zygomatic regions.
5. The CM can serve as a practical anatomical landmark for MARPE positioning, supporting a preliminary guideline that favors posterior placement when greater posterior skeletal expansion is required and anterior placement when posterior palatal bone is thin or facial widening should be minimized.

Author Contributions

Gwan- Hyeong Song: methodology, investigation, formal analysis, visualisation, writing – original draft. Jae Hyun Park: writing – review and editing. Sang- Min Lee: project administration, resources, writing – review and editing. Dong- Hwa Chung: supervision, conceptualization, resources, writing – review and editing. Won Moon: conceptualization, writing – review and editing.

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Ethics Statement

This study was conducted in compliance with ethical standards and guidelines. Ethical approval was obtained from the Institutional Review Board of Dankook University Dental hospital with approval number DKUDH IRB 2022-10-012.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Results of Bayesian mediation analysis. **Table S2:** Linear regression analysis of the effect of appliance position on dependent variables.