

Maxillary and Mandibular Changes with 3D-Guided Midpalatal Piezocorticotomy - Assisted MARPE in Adults: A Retrospective Longitudinal Study

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Abstract

Introduction. Despite the increasing success rate of MARPE in different age groups, the concern still exists regarding potential downward rotation of the maxillary complex and increase in the middle and lower anterior facial heights due to midfacial expansion. 3D-guided midpalatal piezocorticotomy (3D-GMP) assisted MARPE is intended to increase the success rate of MARPE in adults and eliminate the age and sex parameters as limitations along with improving outcomes of MARPE alone.

Methods. This retrospective longitudinal study evaluated pre- and post-expansion lateral cephalometric radiographs following midfacial expansion with 3D- GMP MARPE. Images were rendered from the CBCTs of 80 adult patients with mean age 35.23 ± 8.76 years (male $n = 28$, female $n = 52$). Fifteen lateral cephalometric measurements were compared. Measurements included maxillary forward displacement, mandibular rotation, inclination of the maxillary plane, occlusal plane rotation, and linear measurements of the facial heights. Maxillary incisor position was measured relative to the maxillary plane.

Results. The angles SNA, ANB, and the linear measurement A-Nperp(FH) differed significantly between stages T0 and T1 indicating forward maxillary base movement following intervention. Multivariate linear regression analysis of the PPA value showed that the only predictor of the post-expansion PPA is the pre-expansion value of the same parameter, while sex, age, ANB, and the amount of midpalatal separation were not significantly associated with post-expansion inclination of the maxillary plane. Risk analysis demonstrated risk reduction of the downward maxillary rotation following the 3D- GMP MARPE.

Conclusions. 3D- guided midpalatal piezocorticotomy assisted MARPE may offer advantages in decreasing the risk of downward maxillary rotation along with maxillary protraction in adults. Forward maxillary movement was shown to be one of the consistent outcomes of 3D- GMP MARPE which is augmented with increased amount of midpalatal separation in adult patients.

Introduction

Various Mini screw Assisted Rapid Palatal Expansion (MARPE) designs have shown high success rates in both adolescents (1) and adult patients. (2, 3). Both direct and indirect positioning of the tooth-bone-borne midpalatal expansion appliances showed predictable midpalatal suture separation. Classifications were suggested based on the expansion efficiency and separation patterns (parallel/V-shaped) with non-piezocorticotomy MARPE showing that age is a reliable predictor for both efficiency and pattern of expansion. (4) Historically, surgically assisted rapid palatal expansion (SARPE) has been considered a golden standard of skeletally achieved midpalatal separation in adults. Advanced expansion devices were described in conjunction with SARPE (5) showing higher levels of success and stability compared to conventional bonded hyrax expanders. Lately, several studies compared MARPE to SARPE in adult patients showing more parallel expansion patterns, higher levels of expansion in posterior palatal regions in MARPE patients (6).

The superiority of combining hybrid hyrax with Herbst appliance over the use of combination of conventional hyrax with Herbst appliance was shown by Manni and coauthors (7) supported by Radescu (8) who showed that pharyngeal airway space was significantly increased with combination of maxillary expansion and mandibular advancement rather than mandibular advancement alone. These findings add evidence of the effects of maxillary expansion as an adjunct in comprehensive orthodontic treatment.

Study by Ngan and Wilmes concluded less dento-alveolar effects of tooth-borne maxillary expander combined with the facemask over hybrid-hyrax combined with the facemask in growing subjects. (9) This study is supported by findings reported by Demirsoy and colleagues (10) who reported equally effective hybrid-MSE and bone-borne expanders in young adults for correcting skeletal crossbites.

Sharma reported significantly greater increase in width measurements when comparing custom MARPE to conventional MARPE in young adult patients. (11) Several minimal surgically-assisted techniques were described over the past five years including midpalatal corticotomies (12) and the MISMARPE approach (13) as auxiliaries to conventional MARPE approach. The corticotomy has elevated the success rate of the assisted MARPE procedure in adults to 95%. The corticotomy-assisted MARPE expansion was shown to reduce intra-expansion pain levels compared to non-assisted MARPE. (12)

3D guided midpalatal piezocorticotomy (3D-GMP) assisted MARPE was introduced in 2025 after two years of clinical observations (14). The method is intended to increase the success rate of MARPE in adults and eliminate the age and sex parameters as limitations. Secondary outcomes of the 3D-GMP include achieving parallel and symmetrical separation of the midpalatal suture, preventing nasal septum from displacement in either direction while allowing for more predictable pterygomaxillary suture separation.

Despite the increasing success rate of MARPE in different age groups, the concern still exists regarding potential downward rotation of the maxillary complex and increase in the middle and lower anterior facial heights due to midfacial expansion. While Rapid Palatal Expansion effects in growing individuals are well documented (15, 16), there is still conflicting evidence regarding the effects of Midfacial expansion in non-growing patients. This study is aimed to evaluate the maxillary and mandibular positional changes following 3D-GMP assisted MARPE in

adult patients on lateral cephalometric radiographs derived from the CBCT volumes collected before the intervention and immediately following the completion of midfacial expansion. The study is additionally intended to define if Skeletal Classification or pre-existing downward rotation are associated with maxillary downward rotation, increase in Total Anterior Facial Height (TAFH), Lower Anterior Facial Height (LAFH) and other vertical measurements.

Materials and Methods

Study design. Approval was obtained from the Solutions IRB, protocol 0846. This retrospective study included patients with nasal base and maxillary base transverse deficiency with or without the presence of crossbite who underwent 3D- guided midpalatal piezocorticotomy-assisted MARPE expansion using custom designed and printed 3D piezocorticotomy guide and custom MARPE appliance at the private practice in Boca Raton, Florida, USA.

Inclusion and exclusion Criteria. Initially 89 patients were considered for the study, 9 patients were later excluded due to incomplete records. The inclusion criteria were adults 19 years old and older with no previous history of midpalatal expansion and orthognathic surgery, no systemic diseases, no craniofacial deformities, with high quality CBCT images taken in full intercuspation before treatment (T0) and immediately after completion of midfacial expansion stage (T1). The mean duration of T0-T1 period was 8 ± 1.4 weeks.

All patients exhibited successful separation of the midpalatal suture, reaching the success rate of the expansion procedure of 100%. None of the patients was excluded due to unsuccessful separation. The final sample included 80 patients (mean age 35.23 ± 8.76 years; male $n = 28$, female $n = 52$). (Table 1).

Intervention. The 3D midpalatal piezocorticotomy guide was designed using CBCT volumes obtained with Planmeca G7 Viso (FOV 16x16 cm, Planmeca, Helsinki, Finland) and intraoral scans (iTero, Align Technology, San Jose, California, USA) of the patients, superimposed, and digitally analyzed in NemoCast (Nemotec, Madrid, Spain). The 3D guides were digitally constructed of three parts: occlusal coverage of the maxillary digital model, palatal coverage of the maxillary digital casts, and connectors. (Fig. 1) The location of the notches used for further 3D-guided midpalatal piezocorticotomy was determined by viewing the digital guided in axial plane. The landmarks for determining the location of the notches were the position of the maxillary crests, location of the nasal septum, position of the PNS point. The depth of the cuts was measured and marked on the surface of the guided at the level of each incision. The location of the incisive foramen was marked and bypassed. The position of the notches was always planned distal to the incisive foramen to avoid injury to the incisive nerve and concomitant blood vessels. (Fig. 2)

The custom MARPE appliance contained 6 miniscrews (Biomaterials Korea, Seoul, South Korea) with the length ranging from 9 to 15 mm and diameter 1.8 mm (Fig. 3). The Powerscrew (TigerDental, Hörbranz, Austria.) was used for the expansion with the activation of 0.11 mm per turn. The activation protocol included a period of 7 days with 2 turns/day after the initial installation and piezocorticotomy to allow for sufficient soft tissue healing. Further activation were kept at 1 turn a day (0.11 mm) for both males and females after the midpalatal split was confirmed. Patients were seen every week for the duration of the expansion stage. The expansion was considered completed when the palatal cusps of the maxillary first molars contacted the buccal cusps of the mandibular first molars. The framework arms of the appliance were removed at the expansion completion appointment, the CBCT (FOV 16x16 cm, Planmeca, Helsinki, Finland) with Ultra Low Dose protocol (ULD), 100 kV, 6.3 msA, 30 mkmSv, 600 voxel size was taken to confirm the amount of expansion.

Data analysis. The exported lateral cephalometric radiographs processed in Romexis (Planmeca, Helsinki, Finland) were further traced manually in WebCeph (Seongnam-si, South Korea) by the Principal Investigator (SK). The lateral cephalometric radiographs were retraced again in 2 weeks for the increase intra-examiner reliability. Fifteen measurements were identified for the purpose of this study. (Table 2).

Primary outcomes. The primary outcomes included identification of the measurements that significantly changed following intervention. The main parameters of interest included maxillary forward position defined by SNA, A-Nperp(FH), and maxillary downward rotation (SN-MP, PPA).

Secondary Outcomes. Secondary outcomes included identifying any changes to the mandibular rotation (SNGoMe), changes in facial height (TAFH, LAFH, UAFH, PFH), changes in occlusal plane rotation (OcPSN, OcPFH, OcPGoMe), and maxillary incisor length (U1LENGTH), and inclination (U1MP). Additionally, multivariate regression analysis was run to determine if any factors are associated with the downward rotation of the maxillary plane following intervention.

Sample size.

$$n = \left(\frac{Z_{1-\alpha/2} + Z_{1-\beta}}{ES} \right)^2$$

$$C = (Z_{1-\alpha/2} + Z_{1-\beta})^2$$

$$\alpha = 0.05$$

$$\beta = 0.2$$

$$C = .058, \text{ where}$$

n: The number of participants calculated for the study (sample size)

C: Cohen` coefficient,

α: Level of significance

β: Probability of a type II error.

The optimal number of participants for the study was calculated as 80 subjects.

Statistical Methods

All statistical analyses were conducted in StataNow/SE 19.5 (Stata Corp, College Station, TX, USA). Descriptive statistics were used to summarize studied population. To test the data normality, Shapiro-Wilk test and Quantile-Quantile plots were used for every measured variable. Paired t-tests and two-sample t-test was used to identify differences between groups for all measured variables. To demonstrate statistical significance and P-value of < .05 was used.

Table 1
Characteristics of the study participants.

	Gender		
	Female	Male	Total
N	52 (65.0%)	28 (35.0%)	80 (100.0%)
Age	37.942 (7.714)	30.179 (8.446)	35.225 (8.757)
ANTSEP	5.554 (1.338)	6.646 (1.953)	5.936 (1.654)
MEDSEP	5.745 (1.377)	6.802 (1.825)	6.115 (1.619)
POSTSEP	5.210 (1.338)	6.390 (1.857)	5.623 (1.629)
MEANSEP	5.503 (1.276)	6.612 (1.833)	5.891 (1.575)
ANB	4.071 (2.336)	3.121 (2.992)	3.739 (2.606)

Table 2
Descriptions of the parameters measured in the study

ANTERSEP	Separation of the midpalatal suture at the level of ANS, mm
MEDSEP	Separation of the midpalatal suture at the middle third, mm
POSTSEP	Separation of the midpalatal suture at the level of PNS, mm
FRNASSEP	Fronto-nasal separation, mm
SKCLASS	Skeletal Class
DOWNWROT	Downward rotation of the maxillary plane before treatment, 0 = < 11 degrees, 1 = > 11 degrees
SNA	SNA before treatment, degrees
ANB	ANB angle degrees
A-Nperp(FH)	Distance between point A to the perpendicular to FH constructed through point N, mm
SN-MP	SN-ANS-PNS angle before treatment, degrees
FH- MP (PPA)	Palatal Plane angle to FH, degrees
SN-GoMe	Angle between the SN and GoMe, degrees
OcP-SN	Angle between the SN plane and the Occlusal plane, degrees
OcP-GoMe	Angle between the GoMe plane and the Occlusal plane, degrees
OcP-FH	Angle between the FH plane and the Occlusal plane, degrees
TAFH	Total anterior facial height, mm
PFH	Posterior Facial Height mm
LAFH	Lower anterior facial height, mm
UAFH	Upper anterior facial height, mm
U1MP	Angle between the axis of the maxillary central incisor and ANS-PNS plane, degrees
U1LENGTH	Length of the maxillary central incisor to the ANS-PNS plane mm

Results

Participant characteristics. The total number of participants (80) comprised of 52 females (65%) and 28 males (35%) with the mean age of 37.94 ± 7.71 years and 30.18 ± 8.45 years, respectively. The average ANB angle before treatment in females was 4.07 ± 2.34 degrees in females and 3.12 ± 3.0 degrees in males. The average midpalatal separation measured as a mean of anterior, medial, and posterior separation, was 5.5 ± 1.28 mm in females and 6.61 ± 1.83 mm in males. (Fig. 4)

Figure 4. Lateral cephalometric tracing and measurements used for pre- and posttreatment analysis

1- ANB, 2 -PPA, 3- PFH, 4- SNA, 5 – SNGoMe, 6- SN-ANSPNS, 7 -U1MP, 8 -OcPFH, 9 – OcPSN, 10 – OcPGoMe, 11 – A- Nperp(FH), 12- TAFH, 13- UAFH, 14- U1LENGTH, 15 – LAFH.

Maxillary forward position and base rotation. The angles SNA, ANB, and the linear measurement A-Nperp(FH) differed significantly between stages T0 and T1 indicating forward maxillary base movement following intervention. Subgroup analysis in midpalatal separation (MEANSEP) percentile groups showed significant variation in A-Nperp(FH) parameter. Regression analysis for the A-Nperp(FH) demonstrated a progressive increase in forward movement corresponding to increased midpalatal separation. The coefficients were – 1.74 for the percentile group 1 (0–25%), + 1.46 (for group 2), + 0.22 (group 3), and + 1.97 (group 4). (Table 4,5). No statistically significant difference of the maxillary forward position measurements (SNA, ANB, A-Nperp(FH)) was found between Skeletal Class I and II subgroups. Additionally, maxillary downward rotation (SN-MP, PPA) showed no statistically significant difference at T0 and T1. There were also no significant differences between percentile groups (indicating no association with the amount of midpalatal separation (MEANSEP)), nor Skeletal Class I and II subgroups.

Mandibular rotation. Mandibular rotation was measured with SNGoMe angle. It demonstrated significant increase between T0 and T1, but did not show any significance between percentile groups or between Skeletal Class I and II groups.

Occlusal plane rotation. Occlusal plane rotation was measured with three angles (OcPSN, OcPFH, OcPGoMe). OcPFH showed significant increase between T0 and T1 in Skeletal Class II. No difference between percentile groups was found.

Posterior Facial Height. Posterior Facial Height (PFH) showed significant reduction following intervention (T0-T1). No difference between percentile groups nor Skeletal Class subgroups was found.

Total anterior facial height, upper and lower anterior facial height. All three anterior facial height measurements (TAFH, UAFH, LAFH) did not demonstrate significant difference with intervention (T0-T1). There was no significant difference found between percentile groups and Skeletal Class I and II subgroups.

Maxillary incisor length and inclination. Maxillary incisor length (U1LENGTH) significantly decreased following procedure while inclination (U1MP) showed no significant difference between stages T0 and T1. Additionally, no difference was demonstrated between Skeletal Class I and II groups and percentile groups.

Maxillary downward rotation risk assessment (Table 8). Multivariate linear regression analysis of the PPA value showed that the only predictor of the post-expansion PPA is the pre-expansion value of the same parameter, while sex, age, ANB, and the amount of midpalatal separation were not significantly associated with post-expansion inclination of the maxillary plane. Risk analysis demonstrated risk reduction of the downward maxillary rotation following the 3D GMP MARPE.

Pre- and post-expansion crude analysis is presented in Table 3. Evaluation of the main parameters in subgroups based on the amount of midpalatal expansion is presented in Tables 4,5.

Table 3
Pre- and Post- expansion Comparison

Measurements	T0					T1					P-value	
	Mean	SD	Min	Max	[95% conf.interv]	Mean	SD	Min	Max	[95% conf.interv]		
SNA	80.82	3.94	69.9	88.7	79.94 81.70	81.66	4.08	72.7	90.1	80.75 82.56	0.003*	
ANB	3.74	2.60	-3.9	10	3.16 4.32	5.16	2.67	-1	11.7	4.56 4.56	< 0.000*	
A-N perp(FH)	.03	3.97	-.85	.91	-.85 .91	.84	3.66	.03	1.66	.03 1.66	0.006*	
SN-MP	8.11	3.52	-.9	15.9	7.33 8.89	8.26	3.37	.6	15.3	7.51 9.01	0.64	
FH-MP (PPA)	-1.16	3.40	-9.4	9.2	-1.92 -.41	-.98	3.38	-8.5	6.9	-1.73 -.22	0.60	
SNGoME	35.27	8.22	16.5	51.8	33.44 37.10	36.25	8.61	17.6	52.1	34.33 38.16	0.001*	
OcP-SN	17.89	6.13	.8	41.5	16.52 19.25	18.24	5.70	3.2	31.3	16.97 19.50	0.49	
OcP -GoMe	17.38	6.57	-11.6	31.1	15.91 18.84	18.00	6.11	1.2	32.2	16.65 19.36	0.21	
OcP-FH	8.63	5.38	-3.8	31.6	7.43 9.82	9.0	5.05	-1.5	22.8	7.87 10.12	.46	
TAFH	117.47	9.09	77.5	140.3	115.45 119.49	116.08	11.70	79.8	135.2	113.47 118.68	.13	
PFH	76.65	8.03	52.4	99	74.86 78.44	75.08	9.78	50.7	99.1	72.90 77.26	.014*	
LAFH	68.38	6.29	41.9	83.1	66.98 69.78	67.62	7.73	43.2	81.9	65.90 69.34	.23	
UAFH	50.90	4.17	35.9	63.9	49.97 51.83	50.63	5.09	37.1	58.9	49.49 51.76	.51	
U1MP	108.76	7.71	91.6	124.8	107.04 110.48	107.76	8.40	82.4	127.3	105.89 109.63	0.07	
U1LENGTH	29.70	2.94	20.2	35.3	29.04 30.35	28.99	3.51	17.8	35.1	28.21 29.77	.03*	

* Statistically significant difference

Table 4
Amount of Midpalatal Separation in Percentile Groups

Percentile Groups	Min	Max	Mean	SD	Count
1	3.3	4.8	4.10	.55	20
2	4.81	5.7	5.22	.27	21
3	5.71	6.81	6.26	.32	19
4	6.81	10.17	5.89	1.58	20
Total					80

Table 5
Inter percentile group analysis for different variables

Variable	Group 1		Group 2		Group 3		Group 4		ANOVA	Bartlett's Test	Kruskal-Wallis test
	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
SNA	-1.33	2.05	-1.06	2.17	-.99	1.80	.04	3.48	n/a	.02	.66
ANB	-1.63	1.84	-1.29	1.84	-1.54	1.68	-1.24	1.49	.86	.78	n/a
A-N perp(FH)	-1.74	2.53	-.28	1.83	-1.52	2.97	.23	2.54	n/a	.02	.04*
SN-MP	-1.07	2.17	.32	2.11	.88	2.69	-.72	4.11	n/a	.01	.22
FH-MP (PPA)	-.71	3.53	-.43	2.75	1.35	2.86	-.86	3.12	.10	.70	n/a
SNGoME	-1.21	1.54	-.80	2.10	-.93	1.83	-.98	4.01	n/a	< .000	.73
OcP-SN	.11	4.15	-.38	2.16	-.18	7.28	-.93	3.84	n/a	< .000	.52
OcP-GoMe	-1.32	4.41	-.45	2.68	-.75	6.54	-.02	3.99	n/a	< .002	.69
OcP-FH	.48	4.25	-1.11	2.78	.3	6.85	-1.08	3.36	n/a	< .000	.63
TAFH	.25	3.76	-.82	3.85	1.87	8.92	4.41	12.54	n/a	< .000	.87
PFH	1.21	2.37	.22	3.31	1.76	6.11	3.16	8.55	n/a	< .000	.68
LAFH	.50	3.34	-.71	2.60	.27	6.51	3.04	8.39	n/a	< .000	.41
UAFH	-.48	2.53	-.67	2.68	1.32	3.88	1.03	5.08	n/a	< .006	.43
U1MP	-.35	4.42	2.04	4.66	2.89	3.81	-.54	5.92	.06	.29	n/a
U1LENGTH	.89	1.71	.06	1.67	-.20	3.40	2.05	3.98	n/a	< .000	.09

*Statistically significant difference.

The Regression analysis for four percentile groups for the Difference in A-N distance measured along FH (Fig. 5):

$$\text{DIFFANFH} = -1.74 + 1.46 (\text{Group2}) + 0.22 (\text{Group3}) + 1.97 (\text{Group4})$$

DIFFANFH – change in score (predicted outcome)

-1.74 – the constant defined by the baseline change in Group 1

+ 1.46, + 0.22, + 1.97 – coefficients showing how much higher Groups 2,3, and 4 are compared to Group 1

Subgroup analysis based on skeletal classification is presented in Tables 6 and 7.

Table 6
Skeletal Class I and Class II Subgroups Characteristics before Treatment

	Skeletal Class		
	I	II	Total
N	38 (50.7%)	37 (49.3%)	75 (100.0%)
MEANSEP	5.844 (1.682)	5.875 (1.462)	5.859 (1.567)
ANB	2.284 (1.081)	5.965 (1.428)	4.100 (2.238)
TAFH	118.400 (10.975)	116.892 (6.788)	117.656 (9.122)
PPA	-1.153 (3.655)	-0.997 (3.150)	-1.076 (3.393)
PFH	76.992 (8.728)	75.727 (7.451)	76.368 (8.093)
SNA	79.876 (3.911)	81.722 (3.842)	80.787 (3.961)
SNGoMe	35.253 (8.179)	36.389 (7.848)	35.813 (7.984)
SN-MP	8.366 (3.439)	8.014 (3.735)	8.192 (3.568)
U1-MP	110.011 (6.069)	106.273 (8.397)	108.167 (7.501)
OcP-SN	17.668 (4.638)	19.051 (6.951)	18.351 (5.895)
OcP-GoMe	17.576 (5.889)	17.332 (7.509)	17.456 (6.692)
OcP_FH	8.161 (4.261)	10.043 (5.783)	9.089 (5.123)
ANperpFH	-0.726 (3.652)	0.749 (3.908)	0.001 (3.827)
LAFH	68.424 (7.594)	68.630 (4.652)	68.525 (6.275)
UAFH	51.318 (4.545)	50.722 (3.957)	51.024 (4.247)
U1-length	29.521 (3.128)	30.127 (2.638)	29.820 (2.893)

Table 7
Skeletal Class I and II Subgroup Comparative Analysis

Variable	I				II						Intergroup P value
	T0		T1		P value	T0		T1		P value	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		
SNA	79.88	3.91	81.00	4.03	.004	81.72	3.84	81.98	4.00	.16	.13
ANB	2.28	1.08	3.93	2.01	.0052*	5.96	1.43	6.95	1.99	.16	.08
A-N perp(FH)	− .73	3.65	− .084	3.39	.15	.75	3.91	1.62	3.21	.027*	.07
SN-MP	8.37	3.44	8.33	2.87	.92	8.01	3.73	8.77	3.59	.12	.22
FH-MP (PPA)	-1.15	3.66	− .70	3.48	.36	− .10	3.15	− .83	3.20	.74	.687
SNGoME	35.25	8.18	36.03	8.28	.01*	36.39	7.85	37.68	8.49	.004*	.69
OcP-SN	17.67	4.64	18.53	4.98	.025*	19.05	6.95	18.78	6.00	.45	.29
OcP -GoMe	17.58	5.89	17.49	5.62	.50	17.33	7.51	18.89	6.55	.19	.12
OcP-FH	8.16	4.26	9.49	4.96	.016*	10.04	5.78	9.19	4.95	.98	.04*
TAFH	118.4	10.97	118.23	11.44	.096	116.89	6.79	114.53	10.91	.35	.23
PFH	76.99	8.73	76.64	9.29	.36	75.73	7.45	72.98	9.77	.001*	.052
LAFH	68.42	7.59	68.67	7.94	.10	68.63	4.65	66.97	6.65	.32	.13
UAFH	51.32	4.54	51.37	4.56	.319	50.72	3.96	50.25	5.48	.86	.53
U1MP	110.01	6.07	109.62	7.79	.616	106.27	8.40	105.19	8.55	.17	.53
U1LENGTH	29.52	3.13	29.04	3.36	.50	30.13	2.64	29.16	3.22	.18	.47
*Statistically significant difference											

Table 8
Risk Assessment for the Downward Maxillary Plane Rotation in Subjects with and without downward rotation before treatment

Risk in Group with Initial Rotation	Risk in Group without Initial Rotation	Total
0.53	0.11	0.19
95% CI		
Risk Difference	.43	.16 .69
Risk Ratio	5.0	2.18 11.53
		P<.001

Multivariable linear regression analysis for the downward maxillary plane analysis:

$PPAA = -1.91 + 0.576(PPAB) - 1.64(SEX) - 0.05(AGE) - 0.08(MEANSEP) + 0.05(SNAB) - 0.004(ANBB)$, where

SEX, AGE, MEANSEP, SNA, ANB were not statistically significant, PPAA – is PPA after intervention, PPAB – is PPA before intervention, $-1.91 = \beta_0$, $-1.64 = \beta_1$, $-0.05 = \beta_2$, $-0.08 = \beta_3$, $+0.05 = \beta_4$, $-0.004 = \beta_5$.

Thus, simplified, the regression analysis of the predicted PPA after intervention is dependent on the value of PPA before the intervention and not significantly associated with sex, age, amount of midpalatal septation, amount of posterior midpalatal separation, pre-treatment SNA and ANB:

$PPAA = -1.91 + 0.576(PPAB) - 1.64 (SEX)$

If SEX equals 1 (male), the outcome is decreased by the β of SEX.

For example: $PPAA = -1.91 + 0.576 (0.6) - 1.64 (0) = -1.91 + 0.346 - 0 = -1.56$: In a female with the pre-treatment PPA = 0.6 degrees the post-treatment PPA is predicted to be -1.56 which indicated counter-clockwise rotation.

This model describes 37.7% variation in PPA after the procedure.

Discussion

The objective of this study was to evaluate the effects of 3D guided midpalatal piezocorticotomy-assisted MARPE in adults. The mechanisms of maxillary, mandibular base, and occlusal plane responses differ between various maxillary expansion techniques. The latter are widely described in the literature and include Rapid Palatal Expansion (RPE), Surgically-Assisted Rapid Palatal Expansion (SARPE), and Miniscrew-Assisted Rapid Palatal Expansion (MARPE).

Some studies involving RPE in mixed dentition reported both forward maxillary displacement and downward maxillary base rotation (17, 18), others report significant anterior facial height increase along with maxillary downward rotation (19, 20). Similarly, Chung (16) described significant downward maxillary rotation with the increase in the anterior face height following RPE in adolescents.

Mandibular backward rotation along with occlusal plane rotation was described by Da Costa Silva in mixed dentition patients treated with RPE. (21)

SARPE treatment routinely involved the use of fixed hyrax-type expanders. Studies analyzed in a systematic review and meta-analysis published by Lin and coauthors (22) demonstrated similar forward maxillary translation and downward maxillary plane rotation when measured with SN-MP angle. Study by Oliveira (23) supported backward mandibular rotation and transient lateral mandibular displacement following maxillary expansion with SARPE. On the opposite side, maxillary rotation following SARPE was described by Farfel (24) who did not report any rotation of the ANS-PNS plane.

Parhiz (5) suggested predictive parameters that were associated with the downward rotation of the maxillary plane following SARPE. Those parameters included pre-existing downward rotation of the maxillary plane (measured as SN-ANS-PNS angle), gender, and age. These were shown to define 75% of the post-treatment downward rotation of the maxillary plane.

Most studies on SARPE report downward rotation of the maxillary plane similar to studies on RPE. RPE was also reported to produce more dento-alveolar effects associated with molar mesial movement, molar extrusion, maxillary incisor proclination and others (9). These effects could be contributing to the maxillary downward rotation with both treatment modalities.

Our study of 3D-GMP MARPE supports earlier studies on MARPE in adolescents and young adults which showed no downward rotation of the maxillary plane (25, 26). In the current study, when measured with SN-MP and PPA angles, no statistically significant difference was found between pre- and post-treatment measurements. Moreover, no difference was found between Skeletal Classes I and II, which was not evaluated earlier. In our study, patients with downward rotation before treatment were evaluated to determine the risk of development downward rotation following intervention. Our results indicate that even though there is a low risk to develop downward rotation in subjects who did not exhibit this characteristic before treatment, there is only 53% risk of maintaining downward rotation after intervention in those who entered the treatment with pre-existing downward rotation. This data indicates a possibility of counterclockwise rotation of the maxillary plane. This tendency was described using 3D cephalometric evaluation by Koval and co-authors (27) in a case report showing uneven rotation of the maxillary plane around the center of resistance with relatively equal upward displacement of ANS and downward displacement of PNS.

Empson and colleagues (28) compared MARPE and RPE treatment. MARPE intervention led to backward mandibular rotation, while RPE intervention was associated with the significant downward displacement of point A, which was not observed with MARPE. Our data supports backward mandibular rotation measured with SNGoMe angle. Mandibular backward rotation following intervention was supported by the significant increase in occlusal plane rotation measured with OcPGoMe angle but not with OcPFH nor OcPSN angles. Occlusal plane inclination shows similar pattern with all expansion techniques (RPE, SARPE, MARPE) and are possibly linked to maxillary molar tipping and cusp inclination.

When MARPE was combined with the facemask or similar protraction device and compared with combination of RPE and facemask (FM) (29), significant maxillary incisor inclination with mandibular plane rotation was demonstrated in RPE + FM group. Both groups equally significantly showed forward maxillary displacement with increase in SNA. Skeletal Class III patients treatment with combination of MARPE and FM was reported by Cho and coauthors (30) who concluded significant increase in SNA and ANB, no changes in mandibular plane angle, no changes in SNB. Authors did not evaluate the maxillary plane and occlusal plane inclinations. Qi and colleagues (31) evaluated the internal Temporomandibular Joint (TMJ) spaces in comparison with the maxillary base and upper molar height changes. Their results indicated that immediately after MARPE-induced expansion, superior and posterior condylar spaces increased. Both changes weakly correlated with the increase in the maxillary molar palatal cusp height and maxillary base increase. Our data of 80 patients treated with 3D-GMP MARPE provides

evidence of significant forward movement of maxillary base when measured with SNA, ANB, and A-Nperp(FH). The latter was shown to progress with the increase in the amount of midpalatal separation. Possible explanation of these findings is that the amount of midfacial expansion with 3D- GMP MARPE releases pterygomaxillary sutures allowing for the forward maxillary movement. Pterygomaxillary suture separation with MARPE expansion was earlier reported by Colak and Cantarella (32, 33).

3D-GMP as an auxiliary procedure combined with MARPE increased success rate of MARPE expansion to 100% compared to 84% reported by Shin and colleagues (34) who studied the predictability of midpalatal suture separation was evaluated with regression analysis. Authors showed that age, palate length, and midpalatal suture maturation stage were predictors for successful midpalatal separation in young adult patients. The 3D-GMP -Assisted MARPE is reported to eliminate remaining limitations to predictable midfacial separation in adult patients.

Our data did not report any significant maxillary plane changes. This can be explained in several ways. First of all, all studies involving custom MARPE appliances featured hybrid design with different framework design but mutual feature of bone-borne middle part. The existing framework design attached to the rigidly anchored middle part resulted in no-to-minimal mesial dental migration while allowing for some lateral tipping. SARPE involves some variation of hyrax-type fixed expander with or without pre-surgical activation, which guides further maxillary plane to follow dento-alveolar relationship while in active expansion process. All three treatment modalities involve significant backward mandibular rotation that was shown to be transient when compared to post-expansion orthodontic finishing. This is possibly explained by dento-alveolar and dental movements that guide forward mandibular displacement after expansion.

The limitations of the current study include lack of the comparison group with no auxiliary procedure when combined with MARPE and the lack of long-term data reported. Further studies are needed to compare long-term stability of the 3D- GMP MARPE.

Conclusions

3D- guided midpalatal piezocorticotomy assisted MARPE may offer advantages in decreasing the risk of downward maxillary rotation along with maxillary protraction in adults. Forward maxillary movement was shown to be one of the consistent outcomes of 3D- GMP MARPE which is augmented with increased amount of midpalatal separation in adult patients. Long-term research is needed to evaluate the effects of different designs of MARPE appliances in conjunction with 3D GMP MARPE along with the stability of the outcomes.

Abbreviations

MARPE	Miniscrew-Assisted Rapid Palatal Expansion
SARPE	Surgically Assisted Rapid Palatal Expansion
RPE	Rapid Palatal Expander
3D-GMP	3-Dimensional Guided Midpalatal Piezocorticotomy

Declarations

Author contributions

SK contributed to conceptualization, manuscript text, editing, supervision of the project; DC contributed to preparing Fig.1-4, Tables 1-8, editing and reviewing; NS contributed to manuscript writing and editing; AB contributed to data analysis, editing, and writing.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study protocol was reviewed and approved by Solutions Institutional Review Board (Solutions IRB) (Approval No. 0846). Written informed consent was obtained from all participants.

Consent for publication

Written informed consent for publication of anonymized data was obtained from all participants prior to enrollment.

Declaration of competing interest

One author (SK) declares a pending patent: US and Canada Patent Pending: Piezocorticotomy guide for midpalatal skeletal expansion (Application # 18/919,416).

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Figures

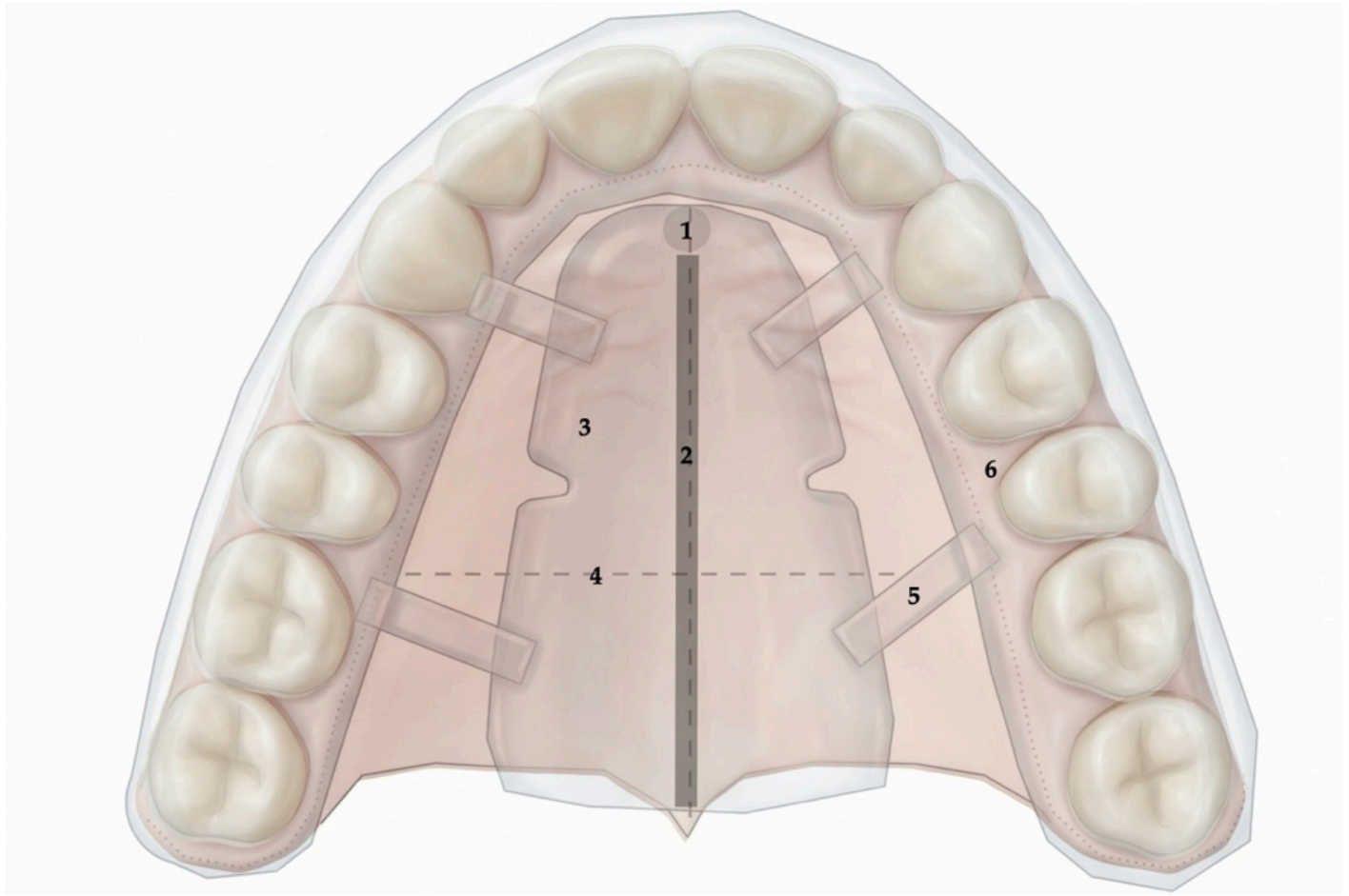


Figure 1

Schematic image of the 3D- printed midpalatal piezocorticotomy guide: 1- incisive foramen, 2 – incision notch for the midpalatal piezocorticotomy, 3 – guide base covering the hard palate, 4 – location of the transverse palatal suture, 5 – 3D printed guide connector, 6 – 3D printed guide occlusal splint covering occlusal surfaces of the maxillary teeth.

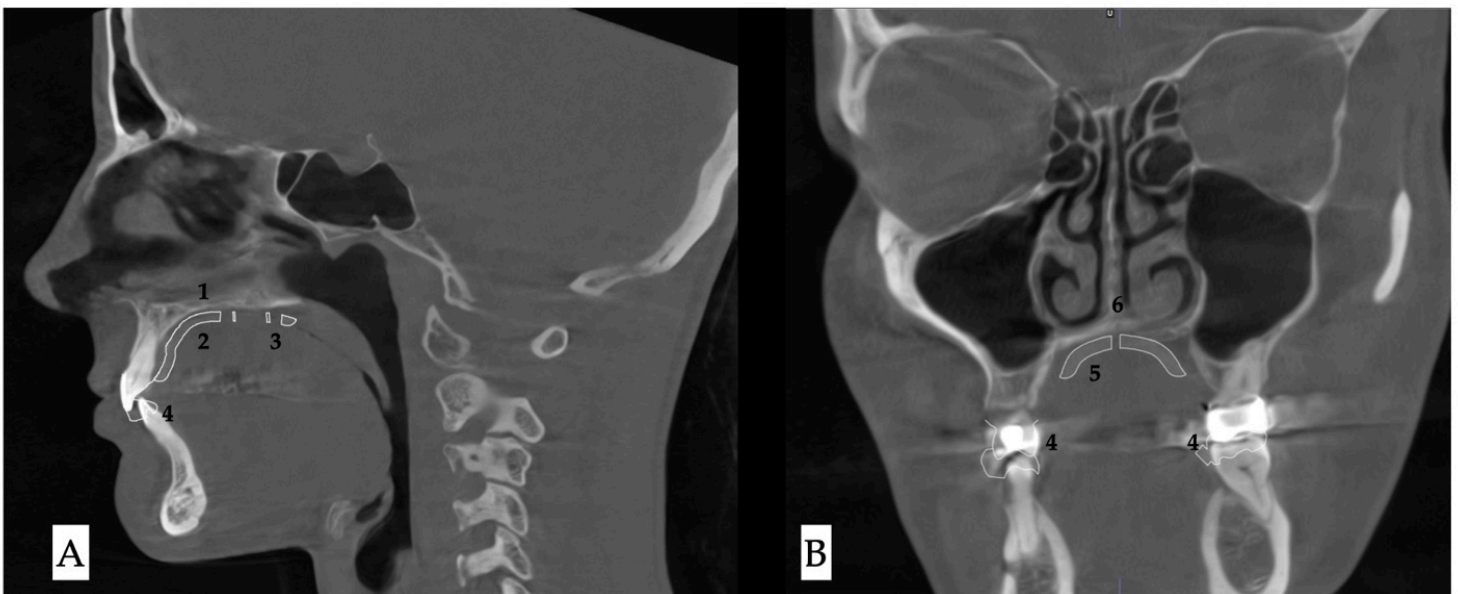


Figure 2

CBCT slices (A- sagittal, B- coronal) with the 3D designed midpalatal piezocorticotomy guide: 1 – location of the hard palate, 2 – cross-sectional view of the guide base covering the hard palate, 3 – location of the incision notches within the base of the 3D designed guide, 4 – designed occlusal coverage of the guide, 5 – coronal view of the guide base, 6 – nasal septum.



Figure 3

Occlusal view of the custom designed MARPE following 3D guided midpalatal piezocorticotomy: 1 – diastema following expansion, 2 – flowable composite covered miniscrew heads, 3 – expansion screw, 4 – healing piezocorticotomy incision, 5 – custom designed and milled MARPE framework.

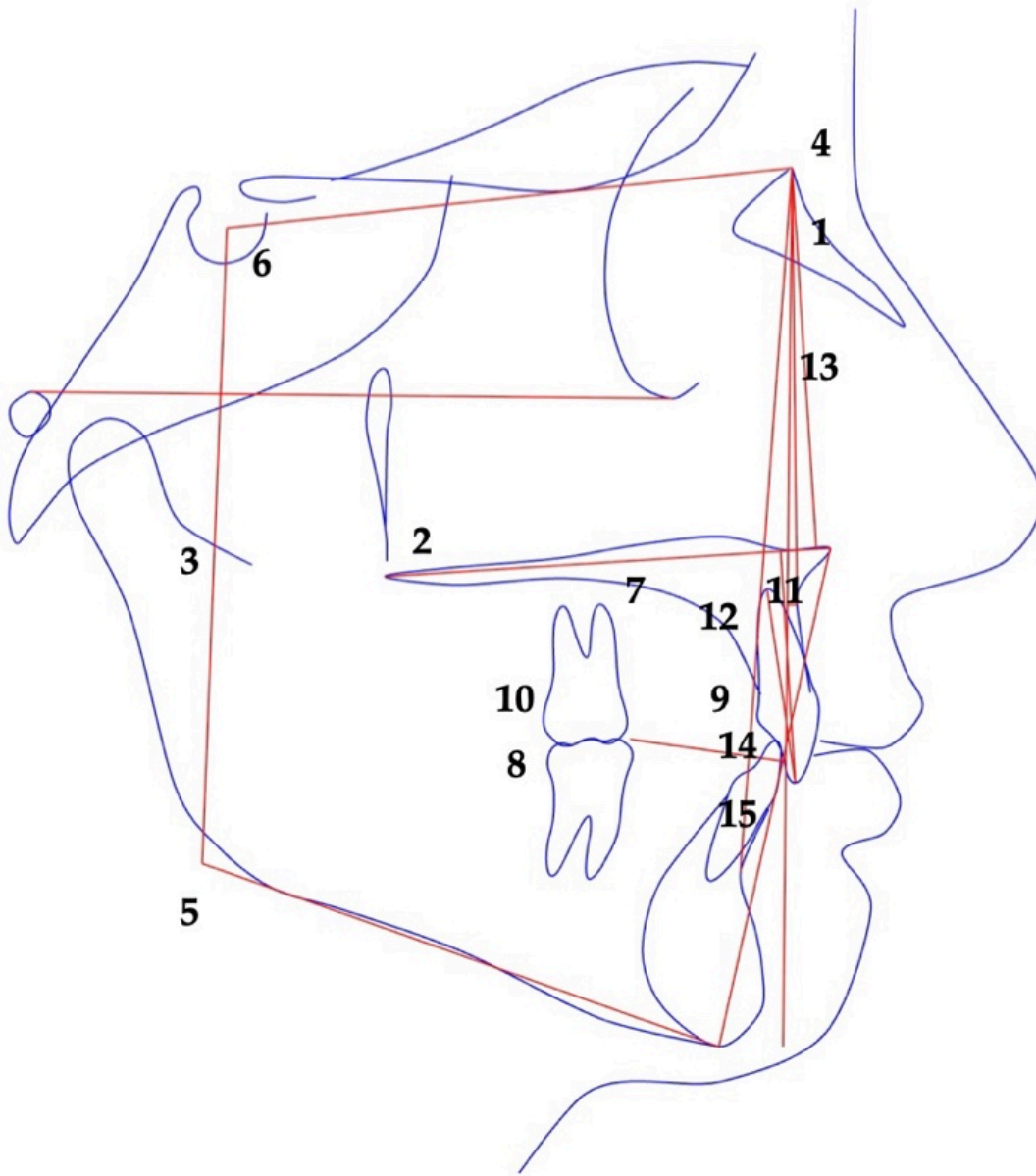


Figure 4

Lateral cephalometric tracing and measurements used for pre- and posttreatment analysis: 1- ANB, 2 -PPA, 3- PFH, 4- SNA, 5 – SNGoMe, 6- SN-ANSPNS, 7 -U1MP, 8 -OcPFH, 9 – OcPSN, 10 – OcPGoMe, 11 – A- Nperp(FH), 12- TAFH, 13- UAFH, 14- U1LENGTH, 15 – LAFH.

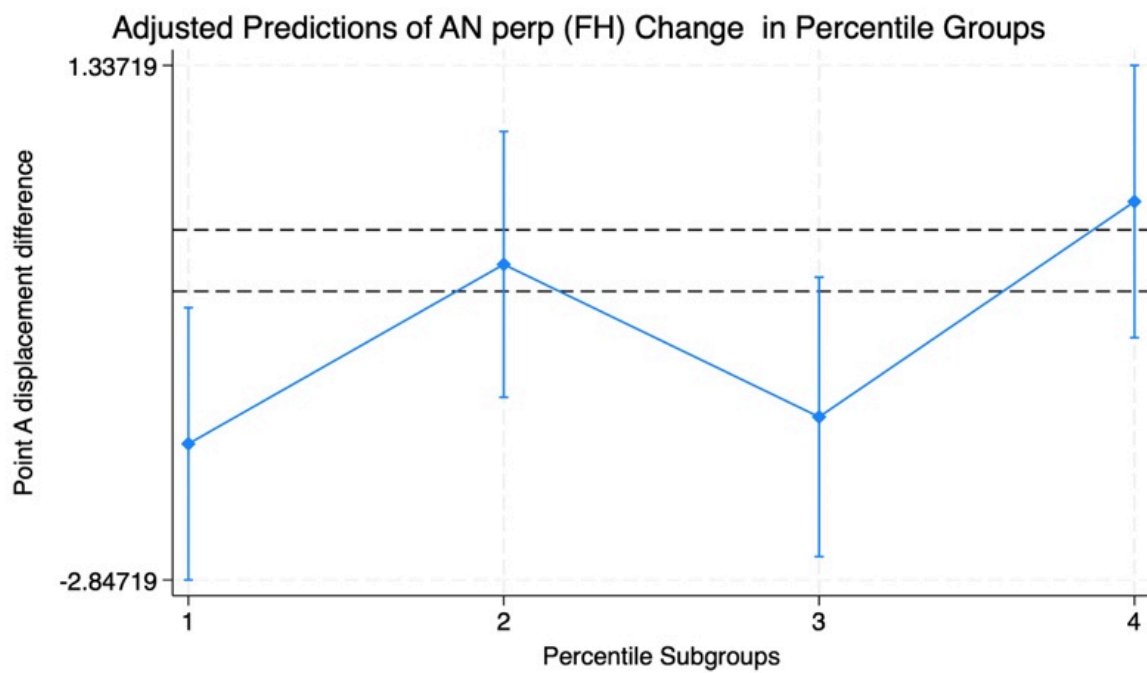


Figure 5

Adjusted predictions of A-Nperp(FH) change in Percentile Groups.