Changes in sagittal and vertical dimensions by non-surgical miniscrew-assisted rapid palatal expansion in adults

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Changes in sagittal and vertical dimensions by non-surgical miniscrew-assisted rapid palatal expansion in adults

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감사의 글

부족한 제자를 이끌어 주시고 논문이 완성되기까지 따뜻한 배려와 함께 세심한 지도와 격려를 아끼지 않으신 이기준 지도교수님께 진심으로 감사 드리며, 바쁘신 와중에도 귀중한 시간을 내주시어 관심과 조언을 보내주신 유형석 교수님, 최윤정 교수님께 깊이 감사 드립니다. 또한 저에게 교정학을 공부할 수 있는 기회를 주시고 많은 가르침을 주신 황충주 교수님, 김경호 교수님, 차정열 교수님, 정주령 교수님, 최성환 교수님께도 감사 드립니다.

논문 집필부터 의국 생활까지 많은 조언과 도움을 주신 천주희 선생님과, 수련 생활 동안 서로에게 큰 힘이 되어주고 함께 동고동락한 의국 동기 강성태, 김다소미, 안윤수, 정희규 선생과 든든한 후배들 강주영, 이채경, 전지윤, 최은학, 한우진 선생에게도 이 자리를 빌려 감사의 마음을 전합니다.

마지막으로 지금의 저를 있게 해주시고 아낌없는 지원과 응원을 보내주시는 사랑하는 부모님께 깊이 감사 드리며, 부족한 형을 잘 따라주고 도움을 아끼지 않는 하나뿐인 동생 문기에게도 고마움을 전합니다.

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저자 씀

TABLE OF CONTENTS

LEGEND OF FIGURES

LEGEND OF TABLES

Abstract

Changes in sagittal and vertical dimensions by non-surgical miniscrew-assisted rapid palatal expansion in adults

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The objective of this study was to evaluate the sagittal and vertical changes in the maxilla, mandible, and maxillary incisors in adults who underwent miniscrew-assisted rapid palatal expansion (MARPE) procedure, and investigate whether the amount of sagittal and vertical cephalometric change was correlated with the amount of maxillary expansion, maxillary first molar axial angulation change, and one's vertical skeletal pattern.

From a total of 129 patients who underwent MARPE procedure since 2004 and whose treatment ended until 2018, 20 patients (mean age, 20.57 ± 2.38 years) who were over 18 years old and underwent non-extraction, non-surgical, non-intrusive orthodontic treatment were selected for this restrospective cohort study. Lateral cephalometric records and dental casts of these subjects obtained before treatment (T0), after MARPE consolidation period (T1), immediately after debonding (T2) were used in measurements.

As a result, orthopedic maxillary expansion induced forward and downward movement of the maxilla without rotational movement. Also, it resulted in downward and backward movement of the mandible which leads to clockwise rotation, but eventually the mandible was relocated counterclockwise at the end of the subsequent orthodontic treatment. The maxillary incisor showed a retrusion and retroclination after the MARPE procedure. However, there was no significant correlation between the amount of maxillary expansion and sagittal and vertical displacement of the maxilla, mandible, and maxillary incisors. Likewise, variation of the maxillary first molar inclination and vertical skeletal pattern of the patients had no significant correlation with the displacement patterns of the structures.

In spite of downward and forward displacement of the maxilla after maxillary expansion, there was no significant vertical dimension change at the end of entire treatment as relocation of the mandible occurred in the process of comprehensive orthodontic treatment. However, displacement patterns of the structures did not show any correlation with other factors such as transverse changes and one’s vertical skeletal pattern. This study would be a help for clinicians to comprehend displacement patterns of the maxilla and mandible after the non-surgical rapid palatal expansion when treating patients who have maxillary transverse deficiency.

Key words: Miniscrew-assisted rapid palatal expansion (MARPE), non-surgical rapid palatal expansion, sagittal and vertical change, adults

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I. Introduction

The maxillary transverse discrepancy which is one of the challenging problems for orthodontists causes an unilateral or bilateral crossbite, crowding, impaction of the maxillary canines. To resolve the maxillary transverse deficiency, many orthodontists have been used a rapid palatal expansion (RPE) in young patients who have narrow maxilla.[1-3] However, several previous studies have claimed that conventional RPE has some limitations and side effects in adults, such as failure of suture separation, limited skeletal expansion, buccal crown tipping, and gingival recession.[4] Surgically assisted RPE (SARPE) which releases fused circummaxillary articulations through surgical osteotomy was introduced to overcome these limitations, but most of the patients tend to prefer non-surgical method because surgery requires great expense, high-risk and hospitalization.[5]

For successful non-surgical skeletal expansion in adults, it is crucial to deliver the expansion force directly to the basal bone. Based on this concept, a miniscrew-assisted RPE (MARPE) which is a tooth-bone-borne appliance was designed to maximize orthopedic maxillary expansion rather than dentoalveolar effect.[6,7] Lin et al[8] reported that bone-borne rapid maxillary expanders (RME) provides larger orthopedic force and less dentoalveolar side effect compared with tooth-borne RME in young adults. Taken together, MARPE is one of the effective devices to deliver orthopedic expansion force non-surgically minimizing dentoalveolar side effects in adult patients.

Several investigators had a curiosity about the pure skeletal and dental effect of the rapid palatal expansion. Representatively, Handelman[9,10] reported the effect of RPE in adult patients demonstrating the dental cast measurement, though it didn’t show any specific radiographic evaluation. Furthermore, since RPE is an orthopedic appliance, some researchers have speculated that the orthopedic maxillary expansion results in not only transverse change of maxilla but also sagittal and vertical displacement of maxilla and mandible.[3,11,12] This question has a significant implication clinically because the sagittal and vertical displacement patterns of the skeletal structure could affect patient's facial profile. Based on this concept, various studies have been done to find out the sagittal and vertical effect of non-surgical orthopedic palatal expansion.

However, previous researches have not reached a consensus on the sagittal and vertical displacement pattern of maxilla, mandible and the dental effect when midpalatal suture is expanded. For example, Haas,[1] Davis and Kronman,[13] and Wertz[14] reported that the maxilla was displaced downward and forward in young patients who underwent orthopedic maxillary expansion using Haas-type RPE. Habeeb et al[12] also reported similar conclusion when a bonded Haas-type expander was applied to young patients. However, Silva Filho et al[15] reported that there was only downward movement of maxilla displaying clockwise rotation in palatal plane with no antero-posterior movement after RPE. They also found some downward and backward movement of mandible. Akkaya et al[16] reported that the maxilla moved forward, and the mandible moved backward. In regard to SARPE, Chung et al[17] reported that SARPE induced a slight forward movement of maxilla with no significant vertical movement and a retroclination of the maxillary incisors in adults.

In addition, previous studies above mentioned have several limitations. First, only pre-treatment and postexpansion data were taken to evaluate the movement of maxilla, mandible, and denture. However, post-treatment records were included in this study because we wanted to observe how the skeletal and dental structure would be changed sagittally and vertically after the orthopedic palatal expansion throughout the entire treatment which can affect the final facial profile of the patients. Secondly, the samples of previous RPE studies were young patients whose growth was ongoing. Although the interval between pre-treatment and postexpansion was approximately 6 to 12 months, the growth could compromise the pure displacement of maxilla-mandibular complex in young patients who is in growth spurt. Chung et al[17] reported the sagittal and vertical movement of maxilla-mandibular complex in adult patients who underwent SARPE. However, the skeletal and dental displacement modality of the non-surgical maxillary expansion in adult patients would show the difference with that of SARPE since it resolves the high resistance from the circum-maxillary sutures and structure through LeFort I osteotomy with a midpalatal cut.[18] In other words, it is rare to find a clear-cut report about the sagittal and vertical effects of the non-surgical maxillary expansion in adults including post-treatment evaluation up to date.

The purpose of this study was to evaluate the sagittal and vertical changes of the maxilla, mandible, and upper incisor in adult patients who underwent MARPE procedure, and investigate whether the amount of sagittal and vertical displacement of them was correlated with other factors such as the amount of maxillary expansion, maxillary first molar angulation, and vertical skeletal pattern.

II. Materials and methods

1. Subjects

This retrospective cohort study included 129 patients with a transverse maxillary deficiency who underwent MARPE procedure since 2004 and whose treatment ended until 2018 at the Department of Orthodontics, Yonsei University Dental Hospital, Seoul, Korea. The inclusion criteria for this study were as follows: (1) patients over 18 years old (2) patients who did not undergo orthognathic surgery (3) non-extraction case (4) lateral cephalogram taken before treatment (T0), after MARPE consolidation period (T1), and immediately after debond (T2) and dental cast records taken at T0, T2 were present (5) success of suture separation (6) patients who did not undergo active intrusion of the posterior dentition during subsequent orthodontic treatment(e.g. openbite) (7) no dentofacial deformity (8) good oral hygiene and healthy periodontal tissues.

Eventually, 20 patients (7 men and 13 women) who satisfied the inclusion criteria were selected for the study (Figure 1). The mean age at start of the treatment was 20.57 ± 2.38 years (range, 18-26 years). The average treatment duration was 25.55 ± 7.85 months (Table 1).

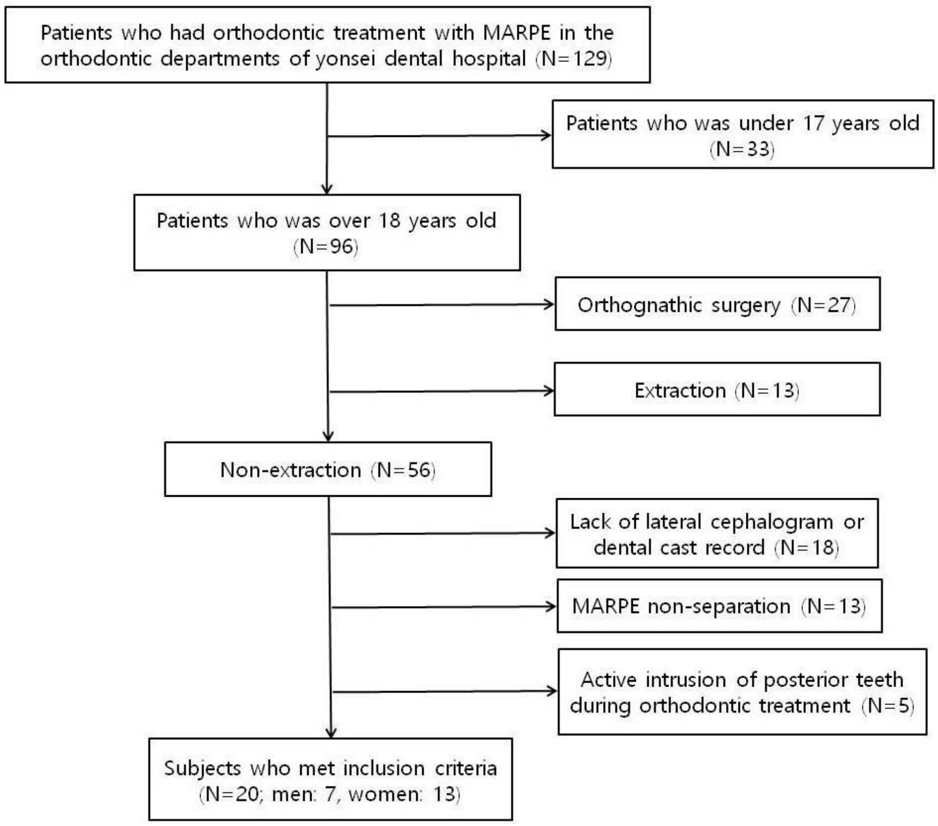

Figure 1. Sample selection flow chart

Table 1. Demographic features of the subjects

	Total (N=20)
Sex	
Men	7
Women	13
Age (years)	20.57 ± 2.38, (range, 18-26)
Treatment duration (months)	
Total (T0-T2)	25.55 ± 7.85
Initial-post expansion (T0-T1)	9.90 ± 5.72
post expansion-post treatment (T1-T2)	15.65 ± 8.05

2. Appliance and orthodontic treatment

All orthodontic treatments were performed by an orthodontist at the Department of Orthodontics, Yonsei University Dental Hospital. The MARPE appliance is composed of four rigid stainless steel wire connectors with helical hooks soldered on the base of Hyrax screws. Four miniscrews (diameter 1.8mm; length, 7.0mm, ORLUS, Ortholution, Seoul, Korea) were inserted perpendicular to the center of the helical hooks (diameter, 4.0mm) under local infiltration anesthesia after MARPE appliance was placed and cemented on maxillary dentition The heads of the miniscrews were covered by light-cured resin to connect the miniscrews with the helical hooks (Figure 2).[6]

One-quarter of a turn (0.2mm) was carried out once a day to activate the MARPE device right after its placement. The separation of midpalatal suture was confirmed by periapical view of the maxillay incisor after 2-week screw turn and the expansion was continued until the palatal cusp of either maxillary anchor teeth barely crossed over the buccal cusp of the corresponding mandibular teeth (Figure 2). After the maxillary expansion was completed successfully, the MARPE device was maintained in patient's oral cavity about 3 to 6 months to allow bone formation in the splitted suture and prevent skeletal relapse. Afterwards, MARPE was removed and planned orthodontic treatment with a straight-wire appliance was performed.

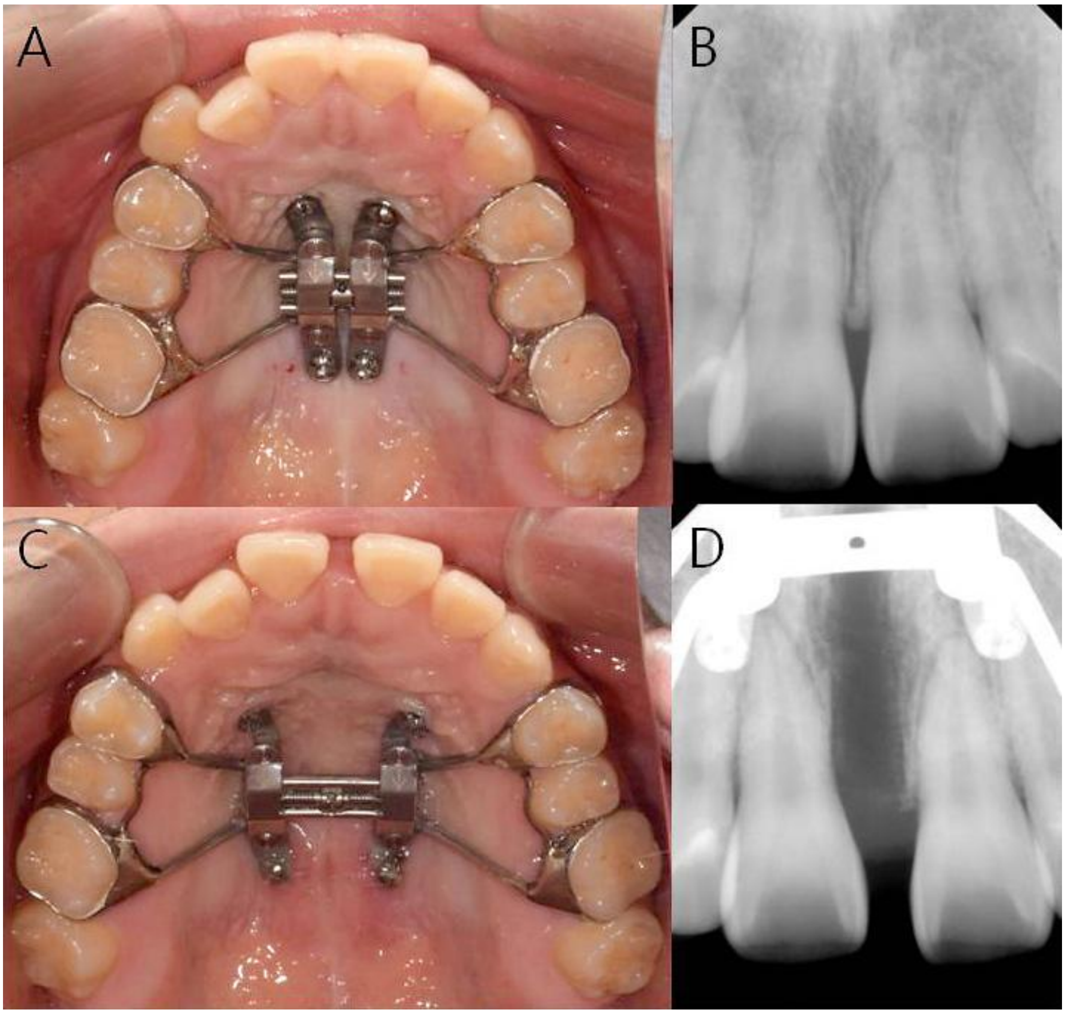

Figure 2. Cementation of the miniscrew-assisted rapid palatal expansion (MARPE) appliance and periapical view of maxillary incisor taken to confirm the suture separation. (A) Configuration of MARPE appliance (B) Initial periapical x-ray showing the midpalatal suture (C) MAPRE appliance after expansion (D) Periapical x-ray showing obvious splitting of midpalatal suture after screw turns.

3. Record acquisition and measurement

All lateral cephalograms were taken using a Cranex 3+ (Soredex, Helsinki, Finland) with a centric occlusion in the natural head position and the records at T0, T1, T2 were collected for this study. Cephalometric tracing of the total 20 samples was digitized using V-ceph 5.5 program (Osstem, Seoul, Korea) by one researcher. The definition of the landmarks corresponded to those presented by Ricketts.[19] A horizontal reference plane (HRP) was defined as a line which is below the SN line about 7° in a clockwise direction[20,21] and N perpendicular was defined as a perpendicular line against to HRP originating from Nasion. According to this landmarks and references, a total of 15 measurments were made (Table 2) and the direction of the displacement was defined as follows :

1) Sagittal skeletal (Figure 3): SNA (in degrees), SNB (in degrees), HRP to NA angle (HRP-NA, in degrees), ANS to N perpendicular (ANS-N perp, in millimeters), A point to N perpendicular (A-N perp, in millimeters), Pog to N perpendicular (Pog-N perp, in millimeters). Increases in angular measurements from T0 to T1 or from T1 to T2 were counted as positive and decreases as negative. Likewise, increases in linear measurements from T0 to T1 or from T1 to T2 were counted as positive which means a forward movement of the skeletal structure and vice versa.

2) Vertical skeletal (Figure 3): Nasion-Menton (N-Me, in millimeters), SN-MP (in degrees), ANS perp (in millimeters), PNS perp (in millimeters), SN to palatal plane (SN-PP, in degrees). Increases in angular measurements from T0 to T1 or from T1 to T2 were counted as positive and decreases as negative. Increase of the SN-PP angle means clockwise rotation of the maxilla. Increases in linear measurements from T0 to T1 or from T1 to T2 were counted as positive which means a downward movement of the skeletal structure and vice versa.

3) Dental (Figure 3): U1-NA (in degrees and millimeters), U1-SN (in degrees), U1-N perp (in millimeters). Increases in angular measurements from T0 to T1 or from T1 to T2 were counted as positive which means proclination of maxillary incisors and decreases were counted as negative which means retroclination of maxillary incisors. Increases in linear measurements from T0 to T1 or from T1 to T2 were counted as positive which means a forward movement of the maxillary incisor tip and vice versa.

The pre-treatment (T0) and post-treatment (T2) dental casts of the total 20 subjects were acquired and the maxillary intermolar width(IMW) which is the distance between the central fossa of bilateral maxillary first molar was measured with an electric vernier calipers on each dental cast by the same researcher (Figure 3). Increase in IMW measurement from T0 to T2 was counted as positive, and decrease was counted as negative. Also, the angle between two lines drawn across the mesiobuccal and mesiopalatal cusp tips of both right and left first molars was measured using stainless steel digital angle ruler. This measurement representing the axial inclination of the teeth was defined by Brust as the maxillary first molar angulation (Figure 3).[22] The more the maxillary first molar was uprighted, the more angular measurement increased. Therefore, the positive value of angular change meant uprighting of the first molar, and negative value meant buccal tipping of it. All of the maxillary first molars in the measured dental casts had not undergone any prosthetic treatment between T0 and T2 which can compromise axial inclination of the teeth.

Table 2. Definitions of the cephalometric measurements

Measurement	Definition
Sagittal skeletal measurements	
SNA(°)	Angle between Sella-Nasion line and Nasion-A point line
SNB(°)	Angle between Sella-Nasion line and Nasion-B point line
HRP-NA (°)	Angle between HRP and Nasion-A point line
ANS-N perp(mm)	Distance between ANS and N-perpendicular line
A-N perp (mm)	Distance between A point and N-perpendicular line
Pog-N perp(mm)	Distance between Pogonion and N-perpendicular line
Vertical skeletal measurements	
N-Me (mm)	Distance between Nasion and Menton
SN-MP (°)	Angle between Sella-Nasion line and Gonion-Menton line
ANS perp (mm)	Distance from ANS to HRP (perpendicular to HRP)
PNS perp (mm)	Distance from PNS to HRP (perpendicular to HRP)
SN-PP (°)	Angle between Sella-Nasion line and ANS-PNS line
Dental measurements	
U1-NA (◦)	Angle between Nasion-A point line and axis of the maxillary central incisor
U1-NA (mm)	Distance between Nasion-A point line and the maxillary central incisor tip
U1-SN (°)	Angle between Sella-Nasion line and axis of the maxillary central incisor
U1-N perp (mm)	Distance between N-perpendicular line to the maxillary central incisor tip

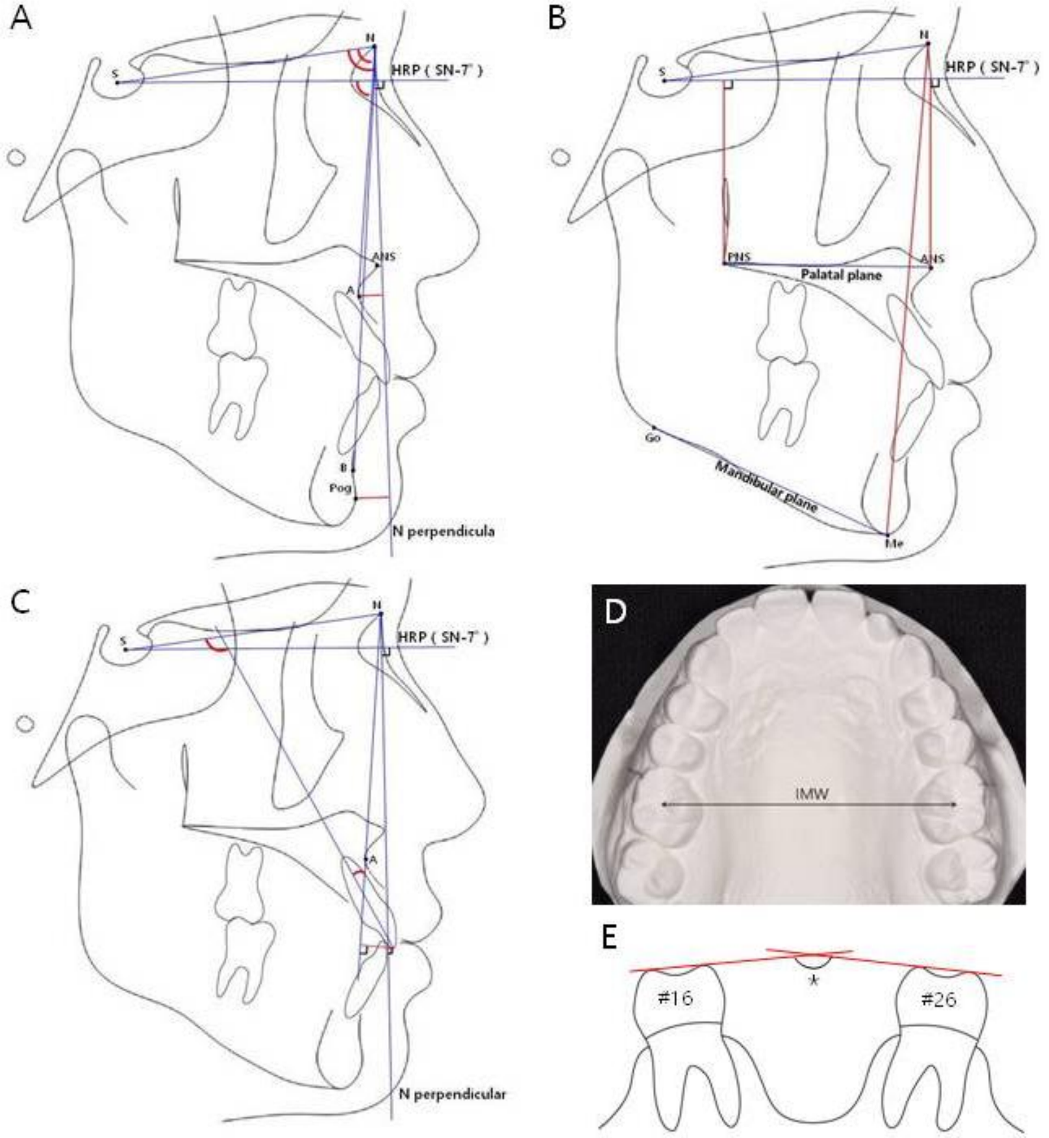

Figure 3. Cephalometric tracing illustrating total 15 cephalometric measurements, and schematic view of dental cast measurements. (A) Sagittal skeletal measurements (B) Vertical skeletal measurements (C) Dental measurements (D) IMW measurement (E) Maxillary first molar axial angulation (*) (view at distal side)

4. Reliability analysis

All lateral cephalometric tracing and measurements were performed by the same investigator. For the intra-examiner reliability, lateral cephalograms and dental casts of the 7 subjects (35% of the total subjects) were randomly selected, retraced, and remeasured by the same examiner 2 weeks after the first measurement. The intra-class correlation coefficient was over 0.95 in the intra-examiner reliability test.

5. Statistical analysis

All statistical analyses were performed with IBM SPSS software, version 20.0 (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov method was used to confirm the normality of the data. As the data showed the normal distribution, a repeated measures ANOVA was applied to verify whether the cephalometric measurements at the 3 different time points (T0, T1, T2) showed any significant difference (Table 3). Afterwards, post hoc test was done to find out which time periods (T1-T0, T2-T1, T2-T0) showed statistically significant difference (Table 4). To examine whether the sagittal and vertical displacement of the structures had any correlation with transverse changes and vertical skeletal pattern, the 15 cephalometric measurement changes between T0 and T2 were analyzed with changes of the dental cast measurements and initial mandibular plane angle using bivariate correlation analysis (Table 5).

III. Results

1. Changes in the cephalometric measurements at different time periods

The 14 cephalometric measurements except SN-PP (°) showed statistically significant difference in repeated measures ANOVA (Table 3). As a post hoc analysis, multiple comparison with bonferroni correction was done for the 14 cephalometric measurements.

For sagittal skeletal effects, SNA, HRP-NA, A-N perp, and ANS-N perp showed statistically significant increase at T1-T0, T2-T0 (SNA increased 0.45°, 0.44°; HRP-NA increased 0.46°, 0.43°; A-N perp increased 0.53mm, 0.50mm; ANS-N perp increased 0.80mm, 0.70mm respectively). SNB, Pog-N perp showed significant decrease (-0.52°, -1.23mm) only at T1-T0. All measurements showed no statistically significant change at T2-T1 (Table 4).

For vertical skeletal effects, N-Me, SN-MP showed statistically significant increase (0.95mm, 0.85°) at T1-T0, but significant decrease (-0.81mm, -0.77°) at T2-T1. Accordingly, N-Me, SN-MP showed no significant change at T2-T0. ANS perp, PNS perp had a statistically significant increase at T1-T0, T2-T0 (ANS perp increased 0.72mm, 0.74mm; PNS perp increased 0.90mm, 0.77mm respectively), but SN-PP showed no significant changes at all three time intervals (Table 4).

All dental measurements related to the maxillary incisors showed significant decrease at T1-T0, T2-T0 (U1-NA (°) decreased -3.59°, -4.25°; U1-NA (mm) decreased -1.17mm, -1.29mm; U1-SN (°) decreased -3.22°, -3.91°; U1-N perp (mm) decreased -0.78mm, -1.23mm respectively). These measurements also showed the decrease in their mean values at T2-T1, but it was not statistically significant (Table 4).

Table 3. Mean and standard deviation of the cephalometric measurements at different time points

	T0	T1	T2	
	Mean ± SD	Mean ± SD	Mean ± SD	P
Sagittal skeletal				
SNA (º)	79.76 ± 3.93	80.21 ± 3.90	80.20 ± 3.87	0.002*
SNB (º)	78.44 ± 4.05	77.92 ± 4.00	78.18 ± 4.06	0.005*
HRP-NA (º)	86.82 ± 3.91	87.28 ± 3.90	87.25 ± 3.87	0.002*
A-N perp (mm)	-3.67 ± 4.65	-3.14 ± 4.65	-3.16 ± 4.59	0.002*
ANS-N perp (mm)	0.97 ± 4.28	1.78 ± 4.15	1.66 ± 4.10	0.000*
Pog-N perp (mm)	-10.04 ± 9.26	-11.27 ± 9.19	-10.49 ± 9.69	0.003*
Vertical skeletal				
N-Me (mm)	135.18 ± 8.77	136.14 ± 8.42	135.33 ± 8.34	0.002*
SN-MP (º)	37.42 ± 5.40	38.27 ± 5.66	37.50 ± 5.71	0.000*
ANS perp (mm)	59.29 ± 3.77	60.01 ± 4.04	60.03 ± 4.15	0.000*
PNS perp (mm)	56.44 ± 3.93	57.34 ± 3.99	57.21 ± 4.04	0.000*
SN-PP (º)	10.12 ± 3.34	9.88 ± 3.22	9.97 ± 3.36	0.431
Dental				
U1-NA (º)	31.72 ± 6.67	28.12 ± 8.05	27.46 ± 6.42	0.000*
U1-NA (mm)	7.94 ± 2.74	6.77 ± 2.63	6.65 ± 2.19	0.000*
U1-SN (◦)	111.55 ± 6.61	108.34 ± 7.41	107.65 ± 5.82	0.000*
U1-N perp (mm)	3.00 ± 6.05	2.21 ± 5.91	1.77 ± 6.30	0.000*

T0, pre-treatment; T1, postexpansion; T2, post-treatment; N=20

* indicate statistical significance in repeated measures ANOVA

Table 4. Changes in cephalometric measurements at different time periods

	T1-T0		T2-T1		T2-T0	
	Mean ± SD	P	Mean ± SD	P	Mean ± SD	P
Sagittal skeletal						
SNA (º)	0.45 ± 0.57	0.007*	-0.01 ± 0.46	1.000	0.44 ± 0.70	0.033*
SNB (º)	-0.52 ± 0.65	0.006*	0.26 ± 0.66	0.287	-0.26 ± 0.66	0.283
HRP-NA (º)	0.46 ± 0.57	0.006*	-0.03 ± 0.46	1.000	0.43 ± 0.70	0.040*
A-N perp (mm)	0.53 ± 0.70	0.010*	-0.02 ± 0.51	1.000	0.50 ± 0.81	0.035*
ANS-N perp (mm)	0.80 ± 0.65	0.000*	-0.11 ± 0.61	1.000	0.70 ± 0.98	0.014*
Pog-N perp (mm)	-1.23 ± 1.62	0.009*	0.78 ± 1.57	0.114	-0.45 ± 1.36	0.471
Vertical skeletal						
N-Me (mm)	0.95 ± 1.26	0.009*	-0.81 ± 1.26	0.030*	0.14 ± 1.08	1.000
SN-MP (º)	0.85 ± 1.06	0.006*	-0.77 ± 0.93	0.005*	0.08 ± 0.92	1.000
ANS perp (mm)	0.72 ± 0.60	0.000*	0.01 ± 0.45	1.000	0.74 ± 0.60	0.000*
PNS perp (mm)	0.90 ± 1.00	0.002*	-0.13 ± 0.56	0.963	0.77 ± 0.83	0.002*
SN-PP (º)	-0.24 ± 1.02	0.903	0.09 ± 0.60	1.000	-0.15 ± 0.93	1.000
Dental						
U1-NA (º)	-3.59 ± 3.28	0.000*	-0.66 ± 4.39	1.000	-4.25 ± 4.41	0.001*
U1-NA (mm)	-1.17 ± 1.31	0.002*	-0.12 ± 1.21	1.000	-1.29 ± 1.70	0.009*
U1-SN (◦)	-3.22 ± 3.22	0.001*	-0.69 ± 4.01	1.000	-3.91 ± 4.03	0.001*
U1-N perp (mm)	-0.78 ± 1.00	0.007*	-0.45 ± 1.15	0.298	-1.23 ± 1.28	0.001*

T0, pre-treatment; T1, postexpansion; T2, post-treatment; N=20

* Indicate statistical significance in post hoc analysis with Bonferroni correction

2. Dental cast measurements

The mean values of maxillary IMW at T0, T2 were 46.8 ± 3.14mm and 50.75 ± 2.62mm respectively. The mean value of the maxillary IMW change between T0 and T2 was 3.95 ± 1.88mm. The mean values of the maxillary first molar axial angulation at T0, T2 were 162.39 ± 11.37° and 164.68 ± 9.26° respectively. The mean change of the maxillary first molar axial angulation between T0 and T2 was 2.29 ± 8.09° (Table 5).

3. Correlation between the cephalometric measurements and transverse changes, vertical skeletal pattern.

Bivariate correlation analysis was applied to evaluate whether the change of the cephalometric measurements had any correlation with the change of the IMW, maxillary first molar axial angulation between T0 and T2 and initial mandibular plane angle which means vertical skeletal pattern. As a result, none of the cephalometric measurements had a significant linear correlation with the amount of the maxillary IMW increase except PNS perp (mm). A PNS perp showed mild positive linear correlation with the maxillary IMW change ($P < 0.05$). There was no statistically significant correlation between the vertical and sagittal cephalometric measurements and changes of the maxillary first molar inclination. Likewise, vertical skeletal pattern of the patients was not correlated to the displacement pattern of the structure except

PNS perp (mm), SN-PP(°) which showed positive and negative linear correlation respectively ($P < 0.05$) (Table 6).

Table 5. Denal cast measurements

		T0	T2	T2-T0
	N	Mean ± SD	Mean ± SD	Mean ± SD
IMW (mm)	20	46.80 ± 3.14	50.75 ± 2.62	3.95 ± 1.88
MFMAA (°)	20	162.39 ± 11.37	164.68 ± 9.26	2.29 ± 8.09

IMW, intermolar width; MFMAA, maxillary first molar axial angulation

T0, pre-treatment; T2, post-treatment

Table 6. Pearson's correlation coefficients between cephalometric measurements and transverse changes, vertical skeletal pattern

T2-T0	Intermolar width	Maxillary first molar axial angulation	Mandibular plane angle (T0)
SNA (°)	0.127	0.257	-0.221
SNB (°)	0.092	-0.325	-0.204
HRP-NA (°)	-0.136	-0.253	-0.201
A-N perp (mm)	0.197	0.215	-0.126
ANS-N perp (mm)	0.354	0.036	0.207
Pog-N perp (mm)	-0.032	-0.181	-0.364
N-Me (mm)	-0.376	0.283	0.030
SN-MP (°)	-0.178	0.407	0.264
ANS perp (mm)	0.296	0.168	0.079
PNS perp (mm)	0.476*	-0.013	0.506*
SN-PP (°)	-0.249	0.054	-0.448*
U1-NA (°)	-0.130	-0.130	0.174
U1-NA (mm)	-0.225	0.043	0.135
U1-SN (°)	-0.105	-0.119	0.163
U1-N perp (mm)	-0.403	-0.015	-0.069
IMW (mm)	-	-0.273	0.210

T0, pre-treatment; T2, post-treatment; N=20; *, $P < 0.05$; **, $P < 0.01$

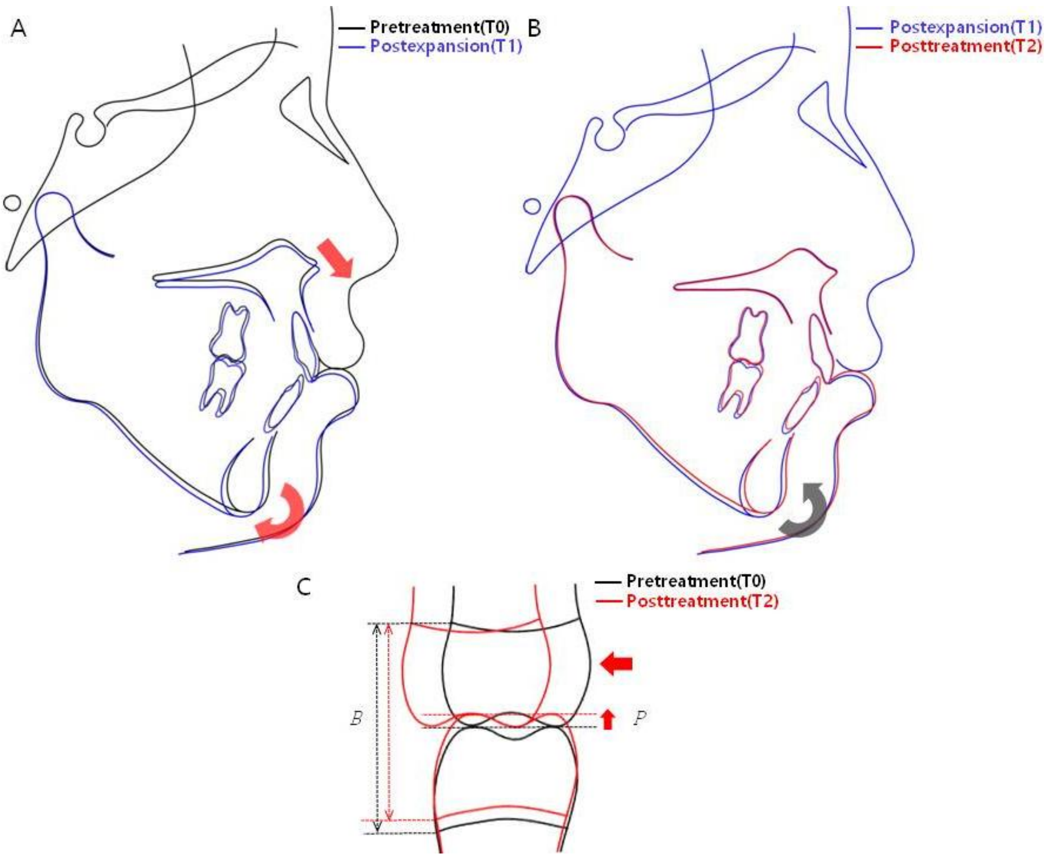

Figure 4. Schematic view of sagittal and vertical changes at different time points. (A) Sagittal view of skeletal changes between pretreatment and postexpansion (B) Sagittal view of skeletal changes between postexpansion and posttreatment (C) Schematic view showing the decrease of vertical dimension in denture as occlusal settling was achieved via maxillary expansion and subsequent orthodontic treatment.

IV. Discussion

The objective of this study was to evaluate the sagittal and vertical effects of the non-surgical rapid palatal expansion using MARPE in adults whose growth almost ended, and investigate whether the amount of sagittal and vertical cephalometric changes had any linear correlation with the intermolar width, maxillary first molar inclination change and one's vertical skeletal pattern. In this study, we selected non-extraction samples whose treatment barely resulted in the displacement of the anterior teeth because A and B point are the skeletal reference points which can be changed by the bone remodeling depending on the anterior tooth movement.[23,24] Also, we excluded patients who underwent orthognathic surgery or subsequent orthodontic treatment including active intrusion of the posterior teeth because surgery accompanies dislocation of the skeletal structure and intrusion of the posterior teeth results in counter-clockwise rotation of the mandible.[25,26]

Our results clearly demonstrated that there was statistically significant forward and downward displacement of the maxilla on the lateral cephalogram after MARPE consolidation period (SNA, HRP-NA, A-N perp, ANS-N perp, ANS perp, PNS perp increased at T1-T0; $P<0.05$). This finding was in agreement with Haas,[1] Davis and Kronman,[13] Wertz,[14] Chung and Font,[11] and Habeeb et al[12]. Howerever, our data didn't concur with those of Silva Filho et al[15] who reported only downward movement of the maxilla in young patients treated with RPE, and with those of Sarver and Johnson[27] who claimed a backward displacement of the maxilla in young patients after the bonded RPE treatment. Besides, Chung et al[17] reported only forward movement of the maxilla in adults after the SARPE procedure disagreeing with our study result. SN-PP (º) showed no significant difference at three different time interval, which means that the maxilla was displaced downward without any rotational movement after orthopedic maxillary expansion. This result concurs with Haas,[1] Davis and Kronman,[13] Wertz,[14] Chung and Font,[11] and disagrees with Silva Filho et al,[15] Habeeb et al[12] who reported the maxilla was displaced downward with clockwise rotation in young patients. According to our study, forward and downward displacement of the maxilla was maintained at the end of the treatment (SNA, HRP-NA, A-N perp, ANS-N perp, ANS, PNS increased at T2-T0; $P<0.05$). This result implies that only minor skeletal relapse of the maxillary displacement occurred during the subsequent orthodontic treatment.

In the present study, we found downward and backward displacement of the mandible after MARPE consolidation period in adults (SNB, Pog-N perp decreased at T1-T0, N-Me, SN-MP increased at T1-T0; $P<0.05$). It could be interpreted that the mandible rotated clockwise in response to the downward maxillary displacement and the cusp-to-cusp occlusion induced by the overexpansion of the MARPE. This outcome concurs with Chung and Font,[11] though the backward movment of the mandible was not statistically significant in their study. Previous studies by Davis and

Kronman,[13] Wertz,[14] Silva Filho et al[15] reported an increase in the mandibular plane angle and Silva Filho et al,[15] Sandikcioglu and Hazar[28] reported a decrease in SNB immediately after the RPE treatment in young patients. On the other hand, Sarver and Johnson[27] found that the mandible was not displaced downward and backward right after the bonded RPE treatment. According to our post-treatment results, the mandible showed statistically no significant difference in SNB (º), Pog-N perp (mm), anterior facial height (N-Me (mm)), mandibular plane angle (SN-MP (º)) at T2-T0, which means the relocation of the mandible occurred during the subsequent orthodontic treatment; N-Me, SN-MP decreased significantly at T2-T1 ($P<0.05$), and SNB, Pog-N perp increased but showed no statistical significance at T2-T1. Within the limitation of this study, it is presumed that counterclockwise rotation of the mandible was induced by continuous mastication force and occlusal settling which resolved cusp-to-cusp occlusion in the process of the subsequent orthodontic treatment.[10,29] Proffit et al[29] mentioned that occlusal force is accountable for the relocation of the mandible in orthognathic surgery with downward movement of the maxilla, and Lim et al[30] reported that in the buccal tipping of the maxillary first molar itself occurred immediately after the maxillary expansion, but it did not show any significant changes in inclination 1 year after the MARPE procedure in cone-beam computed tomographic study. Also, Handelman[10] concurred with this result reporting that there was no significant change of the mandibular plane angle and lower facial height after the RPE procedure and standard edgewise treatment in adults.

As for the dental effect in our study, the maxillary incisors were significantly retroclined and retruded after consolidation period, and this displacement pattern was maintained, or even developed at the end of the treatment (U1-NA in degrees and millimeters, U1-SN, U1-N perp decreased at T1-T0, T2-T0; $P<0.05$). Similarly, Habeeb et al,[12] Wertz,[14] Sandikcioglu and Hazar,[28] and Akkaya et al[16] reported the retroclination of maxillary incisor after the maxillary expansion in young patients. This implies that clinicians should care about controlling the axis of the maxillary incisor during the following orthodontic treatment in certain circumstances such as skeletal Class II division 2 cases.

None of the sagittal and vertical measurements of skeletal structures except PNS perp showed a significant correlation with the amount of the maxillary expansion in the bivariate correlation analysis. However, there was a limitation that maxillary IMW difference measured on the pre-treatment and post-treatment dental cast did not completely represent the actual amount of orthopedic maxillary expansion due to buccal tipping of the anchor teeth during the expansion and subsequent orthodontic treatment resolving intrinsic posterior dental compensation.[6,7] Therefore, if PA cephalogram or CT image is used to evaluate the exact amount of maxillary skeletal expansion after the MARPE procedure, we can obtain more reliable results about the correlation between the amount of expansion and displacement pattern of skeletal structures.[7,30] The change of the maxillary first molar axial angulation also showed no significant correlation with the cephalometric measurements, which implies the change of the molar axial inclination was not closely related to the displacement pattern of the skeletal and dental structure between pre-treatment (T0) and post-treatment (T2). Additionally, change of the IMW and maxillary first molar axial angulation showed no significant correlation, which means an increase of intermolar width was not correlated to the change of molar axial incliation.

There has been a thought that the vertical skeletal pattern is related to mastication force,[31] and based on this concept, sagittal and vertical displacement of the structures could be affected by one's vertical skeletal pattern. As a result, vertical skeletal pattern had no correlation with the sagittal and vertical cephalometric measurements except PNS perp (mm), SN-PP (°) in our study. Chung et al[32] supports this result reporting that there was no significant correlation between one's vertical skeletal pattern and occlusal force considering the variation of occlusal contact area according to the skeletal pattern.

In the clinical point of view, Haas[3] suggested that the downward and forward movement of the maxilla induced by the orthopedic maxillary expansion improved the Class III hypodivergent skeletal pattern. On the other hand, Chung and Font[11] claimed that the amount of the maxillary displacement was so small that it is illogical for clinicians to expect the RPE to correct a skeletal Class III malocclusion. In our study, the mean values of sagittal and vertical displacement of the maxilla and mandible measured by the lateral cephalograms were also within 1 mm and it could be considered insignificant in perspective of the orthopedic treatment. However, in perspective of the non-surgical orthodontic treatment, just 1mm alteration of the tooth position can make it difficult to improve the patients' facial profile depending on the type of tooth movement needed for camouflaging their inborn skeletal patterns, such as molar intrusion in patients who have severe openbite, and retraction of incisors in patients who have severe maxillary alveolar protrusion. Fortunately, there was no significant vertical change at the end of the orthodontic treatment despite forward and downward displacement of the maxilla. Hence, in the process of orthodontic treatment including rapid palatal expansion, it is presumed that clinicians do not need to be concerned about the patient's vertical dimensional change. I hope this study would be a help for orthodontists to comprehend sagittal and vertical changes of orofacial structure after non-surgical maxillary expansion when treating patients who have maxillary transverse deficiency.

V. Conclusion

In this study, we evaluated the sagittal and vertical skeletal and dental changes after the orthopedic palatal expansion by MARPE appliance and investigated whether there was a correlation between the displacement pattern of skeletal, dental structures and other factors such as the amount of maxillary expansion, maxillary first molar axial angulation, and vertical skeletal pattern. The outcomes were as follows :

1. The maxilla showed forward and downward displacement after MARPE consolidation period and the displaced position of maxilla was maintained at the end of the entire treatment ($p<0.05$). There was no significant change of the SN-PP(°) demonstrating that the maxilla moved downward without rotational movement.

2. The mandible showed backward and downward displacement after consolidation period but it showed tendency of relocation in forward and upward direction during the subsequent orthodontic treatment ($p<0.05$). Eventually, the position of mandible showed no significant changes between the pre-treatment (T0) and post-treatment (T2) phase.

3. The rapid palatal expansion resulted in retrusion and retroclination of the maxillary incisors after consolidation period and the altered position was maintained at the end of the subsequent orthodontic treatment ($p<0.05$).

4. There was no statistically significant correlation between the change of the intermolar width and that of the skeletal and dental cephalometric measurements in T2-T0 except PNS perp (mm). PNS perp (mm) showed mild positive linear correlation with the IMW ($p<0.05$).

5. There was no statistically significant correlation between the change of the maxillary first molar axial angulation and that of the skeletal and dental cephalometric measurements in T2-T0.

6. There was no statistically significant correlation between the vertical skeletal patterns of the patients and change of the skeletal and dental cephalometric measurements in T2-T0 except PNS perp (mm), SN-PP (°). PNS perp (mm) showed positive linear correlation and SN-PP (°) showed negative linear correlation with initial mandibular plane angle ($p<0.05$).

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국문요약

성인에서의 비수술적 미니스크류 보강형 급속 구개 확장에 따른 시상적, 수직적 변화

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홍 현 기

본 후향적 연구에서는 미니스크류 보강형 급속 구개 확장(MAPRE) 치료를 받은 성인에서 상악, 하악, 그리고 상악 전치부의 시상적, 수직적 변화를 알아보고, 이런 시상적, 수직적 두부 방사선 계측치 변화가 석고 모형 상에서 측정한 상악골 확장량, 상악 제1 대구치의 치축 경사도 변화, 그리고 수직적 골격적 패턴과 상관관계가 있는지 알아보고자 하였다.

본 연구는 2004년 이후로 MARPE 술식이 포함된 교정 치료를 시작하여 2018년까지 치료가 종료된 129명의 환자 중에서 18세 이상이며, 비발치, 비수술, 그리고 적극적인 구치부 함입이 포함되지 않은 교정 치료를 받은 20명의 환자 (평균

나이, 20.57 ± 2.38 세)를 대상으로 하였다. 대상들의 치료 전 (T0), MARPE consolidation 후 (T1), 치료 종료 직후 (T2) 채득된 측모 두부 방사선 사진과 석고 모형을 이용해 계측을 시행하였다.

결과적으로, 악정형적 상악골 확장은 상악골의 전, 하방 이동을 유발하며, 그 과정에서 유의미한 상악골의 회전은 일어나지 않았다. 또한 이로 인해 시계 방향의 회전인 하악골의 후, 하방 이동이 야기되었지만, 뒤이은 교정 치료가 종료된 시점에서 하악골은 결국 반시계 방향으로 재위치되었다. 상악 전치는 MARPE를 통한 상악골 확장 후 후방 이동 및 후방 경사되었다. 그러나 상악골의 확장량과 그로 인해 발생되는 상악골, 하악골, 상악 전치의 시상적, 수직적 변화량 사이에 유의미한 상관관계는 없었다. 마찬가지로, 상악 제1 대구치 치축 경사도 변화와 환자의 수직적 골격적 패턴은 상악골, 하악골, 상악 전치의 이동 양상과 유의미한 상관관계가 없었다.

급속 구개 확장 후 상악골이 전하방으로 이동하였으나, 뒤이은 교정 치료 과정에서 하악골의 재위치가 일어나면서 전체 치료 종료 시점에서 유의미한 수직적 안면 고경 변화는 없었다. 뿐만 아니라 구조물들의 시상적, 수직적 이동 양상은 횡적 변화와 수직적 골격 패턴과 같은 다른 요소들과 유의미한 상관관계를 보이지 않았다. 본 연구는 임상가들이 상악골 횡적 부조화를 가진 환자의 치료에서 비수술적 급속 구개 확장 후의 상악골과 하악골의 이동 양상을 이해하는 데에 도움이 될 것이다.

핵심이 되는 말: 미니스크류 보강형 급속 구개 확장 (MARPE), 비수술적 급속 구개 확장, 시상적, 수직적 변화, 성인