Title
Evaluation of nasal septum deviation via reformatted computed tomography (CT) imaging following expansion using RPE and MARPE

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Publication Date
2022

Evaluation of nasal septum deviation via reformatted computed tomography (CT) imaging following expansion using RPE and MARPE

by
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THESIS
Submitted in partial satisfaction of the requirements for degree of
MASTER OF SCIENCE

in

Oral and Craniofacial Sciences

in the

GRADUATE DIVISION
of the
UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

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ACKNOWLEDGEMENTS –

Thank you to Dr. Angela Chan for collecting and sharing patient data, and Miranda Sun of Invivo 3D Imaging Software for creating the custom landmark analysis for this study.

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Evaluation of nasal septum deviation via reformatted computed tomography (CT) imaging following expansion using RPE and MARPE

Diana Schron

ABSTRACT

Objective: To evaluate whether rapid palatal expansion (RPE) or miniscrew-assisted rapid palatal expansion (MARPE) affects nasal septum deviation (NSD).

Materials and Methods: The study population includes 15 RPE patients ages 9.5 ± 1.4 years and 15 MARPE patients ages 17.39 ± 5.71 years with initial diagnostic cone-beam computed tomography (CBCT) scans (T0). Another CBCT scan (T1) was taken after patients underwent RPE or MARPE expansion treatment alone. NSD was evaluated three-dimensionally using a custom landmark analysis on T0 and T1 CBCT scans. Principal component analysis (PCA) and canonical variate analysis (CVA) were used to identify nasal septum shape differences before and after expansion treatment.

Results: PCA and CVA showed that while there was change in nasal septum shape from T0 to T1 for MARPE and RPE treatments, the general pattern in morphological change was not found when comparing the variety of phenotypes between individuals. The Procrustes ANOVA regression found p-values for MARPE centroid size and shape were 0.75 and 1, and RPE centroid size and shape were 0.64 and 0.25, respectively, suggesting that there were no significant differences in nasal septum size and shape following expansion. CVA found p-values were 0.99 for MARPE and 1 for RPE after 10,000 permutation tests for Procrustes distances, indicating that there were no significant differences between T0 and T1 group means for both treatment groups.

Conclusions: MARPE and RPE expansion treatments had no effect on nasal septum deviation from T0 to T1.

TABLE OF CONTENTS –

LIST OF FIGURES –

LIST OF TABLES –

INTRODUCTION –

The nasal septum is an important anatomical component of the craniofacial complex and functions to regulate airflow to allow for nasal breathing. A straight nasal septum provides shape and support to the nasal dorsum during nasal breathing, which is required for proper growth and development of the craniofacial complex. In contrast, nasal septum deviation (NSD) is deviation of either the bony or the cartilaginous septum or both from the mid-sagittal plane and can adversely affect nasal respiration airflow.[1]

The obstruction caused by NSD can lead to a sequela of adverse effects such as dryness and crusting of the nose, recurrent sinusitis and nosebleeds. If the obstruction is not corrected during development of the craniofacial complex, patients may develop adaptive characteristics such as chronic mouth breathing, causing moderate to severe maxillary constriction and a dolichofacial growth pattern characterized by long anterior lower face height, high arched palate, bilateral posterior crossbite, low tongue posture, and incompetent lips.[1]

Researchers have found it difficult to accurately quantify the amount and severity of septum deviation for each patient. No gold standard of measuring or diagnosing NSD has been identified. The decision to treat NSD depends on patient symptoms; however, clinical inquiry from patients usually lacks sensitivity and specificity. Previous studies have utilized 2D radiographs to calculate a septal deviation angle cutoff of 10º and normal internal nasal valve angle of 10-15º to distinguish NSD in qualitative analysis.[1,2] However, more research on these methods needs to be done to establish norms for different ethnicities and ages and these measurements have the downside of being a 2D snapshot of a 3D problem.

Maxillary transverse discrepancy is a common finding in orthodontic patients and is often evidenced by posterior crossbite, narrow nasal cavity, and crowding.[3,4] Rapid maxillary expansion (RME) is used in orthodontic practice to correct maxillary transverse discrepancy in younger patients prior to complete fusion of the mid-palatal suture.[5] Previous studies have examined the effects of RME on the nasal septum. One study of 100 children aged 5-9 years found straightening of the nasal septum by 94% in the middle and inferior third of the nasal cavity after hyrax expansion.[6] Another study found similar results that there was an increase in width of the lateral walls and downward movement of the nasal floor, consequent to an increase in septal length and reduction in septal deviation. However, in both studies, NSD was measured on a single 2D coronal view from a PA cephalogram and it was unclear if the measurements were taken at the same landmark pre- and post-expansion.[7]

In contrast, another study reported no positional change in the nasal septum in a sample of 10 children aged 13-17 years following hyrax expansion.[8] This study also analyzed the change in nasal septal deviation from RME in 2D coronal views from PA cephalograms. Two studies, however, did use 3D analysis to evaluate NSD after RME treatment. NSD was quantified based on the "degree of tortuosity" or ratio of the length of the curve to the length of an imaginary line in the MSP. They found that RME treatment had no effect on NSD.[9,10] These conflicting results on changes in NSD after RME suggest that further investigation would be valuable, especially with evaluation of the nasal septum in all three planes of space.

Traditional tooth-anchored expanders have disadvantages, which include undesirable tooth tipping, root resorption, and limited skeletal movement along the midpalatal suture especially in adult patients.[11] The miniscrew-assisted rapid palatal expansion (MARPE) is a bone-anchored expander that works to overcome these challenges by applying force directly to the basal bone, maximizing skeletal expansion.[12,13] Similar to traditional rapid maxillary expansion, MARPE shows the greatest change in the transverse dimension with minor molar and premolar buccal tipping, and the expansion gained is determined to be stable after 1 year after expansion.[14] MARPE is an effective method for correction of maxillary transverse deficiency without surgery in young adults.[14] It has been shown that MARPE can also increase the volume and cross-sectional area of the nasal cavity.[15] These findings suggest that MARPE is beneficial in expanding the nasal airway; however, no literature has been found that examines the impact of MARPE on NSD. This is an area needing further investigation and is the aim of the current study.

This study aims to evaluate the impact of MARPE and RPE expansion treatments on NSD. This study is unique in its novel approach to measuring NSD in 3D space. Previous modalities of measuring and quantifying NSD were mostly done in 2D cross sections of the nasal septum, which may not accurately represent the scope of the nasal septum deviation in all three planes of space. This novel approach to landmarking the nasal septum in 3D space and utilizing geometric morphometrics and associated methods of analysis to evaluate shape changes may be a replicable modality of evaluating NSD. The results of this study will give us clarity as to whether MARPE and RPE could be used as a treatment modality for NSD sequelae.

MATERIALS AND METHODS –

This study was approved by the Ethics Committee of the University of California San Francisco (IRB #10-00564).

The nasal septum measurements of children and adult patients from a private practice in California were assessed in a retrospective analysis of cone-beam computed tomography (CBCT) scans taken at two time points: before orthodontic treatment (T0) and after expansion therapy (T1) using RPE or MARPE from 2015 to 2020. Patients that fit our inclusion and exclusion criteria were selected for this study from this practice's completed patient records.

Inclusion Criteria

- Expansion using RPE or MARPE prior to further orthodontic treatment
- Expansion of 6-10 mm
- Expansion of .2-.266 mm per day
- Initial NSD ranged from 1.2-5.4 mm of deviation from midsagittal plane (MSP) anywhere along the nasal septum in cartilaginous or bony regions

Exclusion Criteria

- Previous expansion therapy or nasal septum surgery
- Fixed appliances in conjunction with expansion
- Syndromic patients
- Incorrect timing or distortions of CBCT
- Abandoned or unsuccessful treatment

The final sample consisted of 15 MARPE patients ages 10-31 years (mean 17.39 ± 5.71 years) and 15 RPE patients ages 7-11 years (mean 9.5 ± 1.4 years). The MARPE hybrid type, tooth-bone-borne appliance, was placed with bands on the maxillary first molars and bi-cortical engagement of screws in the palatal bone. The hyrax RPE appliance was placed with bands on the maxillary first molars and a palatal extension from distal of the canine to the first molar (Figure 1). Both MARPE and RPE appliances were placed by the same orthodontist and fabricated such that the expander screw was positioned as close to the palate as possible.

MARPE patients were instructed to turn the expander twice a day, resulting in a total of .266 mm of expansion per day. RPE patients were instructed to turn the expander once a day, resulting in .2 mm expansion per day. All patients turned the expander until adequate expansion was achieved and the transverse discrepancy was eliminated. The average time between T0 and T1 was 5.4 ± 3.72 months and 4.27 ± 3.37 months for MARPE and RPE, respectively. CBCT scans were taken with a 23 cm × 17 cm FOV and 0.3 mm voxel size (i-CAT FLX; Hatfield, PA, USA). All CBCT scans were saved in Digital Imaging Communication in Medicine format, de-identified using randomized alphanumeric identifiers and shared through secure servers. During the scan, subjects were instructed to maintain head position, avoid swallowing, and remain in centric occlusion with relaxed tongue and lip positions at end-expiration. Data was shared through the secure server at UCSF, UCSF Box, and secure UCSF emails.

Subjects were randomly assigned to one of three evaluators such that each evaluator analyzed 5 MARPE and 5 RPE CBCT images. CBCTs were uploaded to Invivo 3D Imaging Software and oriented with level zygomatic sutures and nasal spine parallel to the floor allowing for visualization of a larger cross section of the nasal septum (Figure 2), an orientation routinely used when measuring NSD using other modalities to allow for greater visualization of the nasal septum.[9]

A custom analysis was created for this study that includes 13 cranial base landmarks and 126 nasal septum landmarks (Table 1). ANS and PNS marked the anterior and posterior boundaries of the nasal septum, and Invivo generated the 50% landmark between ANS and PNS, establishing the nasal septum reference planes: 0% (ANS), 25%, 50%, 75%, and 100% (PNS) (Figure 2). In all planes, the lateral most aspects of the nasal cavity were marked. In the 25%, 50%, and 75% planes, the lateral most aspects of the nasal floor were marked. In all planes, landmarks were placed at the superior and inferior aspects of the nasal septum and 10 semi-landmarks were evenly distributed superiorly-inferiorly along the right and left sides of the nasal septum, resulting in a total of 20 semi-landmarks in each cross section (Figure 3).

Intra-rater reliability was verified by having evaluators trace landmarks 1-13 for the same subject for T0 and T1 timepoints, and re-tracing a minimum of two weeks later. Spearman correlation analysis was run at the two tracing timepoints and a correlation greater than .85 was acceptable. Landmark coordinates were re-oriented prior to exportation with nasion at (0,0,0) and the midsagittal plane defined by nasion, rhinion and sella. The horizontal plane was defined by the right and left zygomatic sutures. After re-orientation, the landmarks were exported from Invivo 3D Imaging Software to .csv file for statistical analysis. Spearman correlation analysis was run on T0 and T1 landmarks 1-13 to verify that the cranial base landmarks were placed accurately between the two timepoints and a correlation greater than .85 was acceptable.

PCA and CVA were run using MorphoJ software to describe the diversity of shapes in a sample. PCA is a method for reducing the dimensionality of multivariate data to determine what varies among individuals and to look for biological explanations for any variation found. CVA evaluates the differences between group means, comparing T0 and T1 in this study.[16]

3D segmentation and superimposition were conducted using 3D Slicer software (slicer.org, Massachusetts, USA).[17] The volume of interest (VOI) was selected manually to contain the nasal region. Semi-automatic segmentation of the structures of interest was carried out using Slicer 3D. The threshold value of the bony structure was adjusted interactively to generate segmentation including all anatomical regions. To segment the nasal septum, seed points of nasal septum were selected by one observer once every five slides in the VOI. Once seed points were selected, region growing based segmentation algorithms were used to segment nasal septum and was adjusted interactively. Landmark based registration was conducted to superimpose the T0 and T1 nasal septum of patients. Five manually labeled facial landmarks (nasion, right and left frontomalare orbitales, right and left supraorbital foramen) were placed on each sample to align T0 and T1 CT volume of each patient. Superimposed T0 and T1 segmentations were visualized for the evaluation of treatment outcomes.

RESULTS –

Each principal component (PC) is one way to explain morphologic change between two groups. In total, all principal components explain 100% of the variation between the two groups, but usually PC1 and PC2 explain most of the variation. In our study, for MARPE, PC1 and PC2 represent 32.172% and 14.611% of the variation, respectively. For RPE, PC1 and PC2 represent 28.120% and 22.875% of the variation, respectively. PCA showed that while there was change in nasal septum shape from T0 to T1 for MARPE and RPE treatment, the general pattern in morphological change was not found when comparing the variety of phenotypes between individuals as demonstrated by the overlapping ellipse confidence interval for T0 and T1 in both MARPE and RPE PCA graphs (Figure 4).

The MARPE Procrustes ANOVA regression found p-values for centroid size and shape were 0.75 and 1, respectively, suggesting that there were no significant differences in nasal septum size and shape following MARPE expansion treatment. CVA showed MARPE p-value after 10,000 permutation tests for Procrustes distances to be 0.99, indicating no significant difference between T0 and T1 MARPE group means. The RPE Procrustes ANOVA regression found p-values for centroid size and shape were 0.64 and 0.25, respectively, suggesting that there were no significant differences in nasal septum size and shape following RPE expansion treatment. CVA showed RPE p-value after 10,000 permutation tests for Procrustes distances to be 1, indicating no significant difference between T0 and T1 RPE group means.

3D nasal septum segmentation and superimposition analysis on sample MARPE and RPE subjects showed that the inferior border of the nasal septum moved along with one side of the midpalatal suture following treatment (Figure 5). Although there was lateral movement of the nasal septum following expansion, there was no change or apparent improvement in NSD.

DISCUSSION –

NSD is the most common structural cause of nasal obstruction and is a prevalent problem in the general population.[18] Due to the anatomical connection between the hard palate and the floor of the nose, it is possible that expansion could also affect the nasal cavity geometry. The purpose of this retrospective study was to evaluate the effect of MARPE and RPE treatments on patients presenting with NSD. This study did not show significant changes in NSD following treatment with MARPE or RPE.

It has been proposed that early intervention with RME in prepubescence would result in greater skeletal change. Given that most patients in this study were adolescents and some were adult patients for the MARPE treatment group, it is possible that lack of statistically significant change in NSD could be due to the subjects having more advanced craniofacial development and increased bone density. In addition, since the T1 CBCT was taken immediately following expansion, it is possible that changes in nasal septum morphology occurred after this timepoint as the bone continued to remodel after expansion. RME has been shown to open the midpalatal suture which subsequently increases the width of the maxillary bone and internasal cavity, leading to improvement in nasal breathing.[13,18] These improvements in nasal breathing seem to be associated with the increase in area and volume of the nasal cavity, rather than with changes in the nasal septum morphology as NSD was not shown to improve following expansion.

The limited sample size affected statistical significance in this study. There was no control group for this study due to ethical limitations. Future work with a larger sample size would allow for matching of patients in the treatment groups on age and pre-treatment NSD. Patient stratification would clarify if these variables had any effect on the amount of NSD improvement after expansion treatment. Therefore, this study could be considered as a pilot study to test the efficacy of the method presented to measure change in NSD.

While PCA and CVA is commonly used in geometric morphometric and speciation studies, this study appears to be the first application of PCA and CVA on evaluating shape changes in NSD and utilizes a novel method of landmarking the nasal septum in 3D space to evaluate NSD. Therefore, notwithstanding the lack of clinically significant results, this study holds value in that it could be considered a pilot study testing novel methodology. Because of its novelty, we cannot compare this study's results with those of other studies published on the topic using this same method. However, our results agree with the findings in previous studies evaluating NSD in adolescents after RPE using CBCT images, but all studies including ours had drawbacks of small sample size and variation among individual patient characteristics.[17,18] Our results differ from previous studies where NSD was measured on a single 2D coronal view from a PA cephalogram and authors found a reduction in septum deviation.[14,15] In comparison to the 2D methods where it was unclear if the measurements were taken at the same landmark pre- and post-expansion, our 3D model was more accurate in capturing the scope of deviation changes in all three planes of space.

CBCT scans allow for a more comprehensive and accurate evaluation of the anatomical variation in NSD. This study's novel approach to evaluating NSD in 3D and utilizing PCA and CVA to evaluate size and shape differences following treatment showed good reliability of CBCT scans in producing identifiable and reproducible landmarks. This methodology could be utilized in clinical practices and future research in assessing changes in nasal septum morphology. Additional 3D studies would be valuable in clarifying the effect of MARPE and RPE on NSD.

CONCLUSION –

MARPE and RPE expansion treatments had no significant effect on NSD from T0 to T1.

TABLES –

Table 1: Landmarks

	Name/Description	Region
1	Nasion	Nasal
2	Rhinion	Nasal
3	Alare (right)	Nasal
4	Alare (left)	Nasal
5	Anterior nasal spine (ANS)	Nasal/Palatal
6	A point	Maxilla
7	Orbitale (right)	Lateral Facial
8	Orbitale (left)	Lateral Facial
9	Posterior nasal spine (PNS)	Palatal
10	Sella	Cranial Base
11	Zygomatic suture (right)	Maxilla
12	Zygomatic suture (left)	Maxilla
13	Basion	Cranial Base
14	Lateral most aspect of nasal cavity at 0% cross-section (right)	Nasal
15	Lateral most aspect of nasal cavity at 0% cross-section (left)	Nasal
16-18	Lateral most aspect of nasal cavity at 25%, 50%, 75% cross-sections (right)	Nasal
19-21	Lateral most aspect of nasal cavity at 25%, 50%, 75% cross-sections (left)	Nasal
22-24	Lateral aspect of nasal floor at 25%, 50%, 75% cross-sections (right)	Nasal
25-27	Lateral aspect of nasal floor at 25%, 50%, 75% cross-sections (left)	Nasal
28	Lateral most aspect of nasal cavity at 100% cross-section (right)	Nasal
29	Lateral most aspect of nasal cavity at 100% cross-section (left)	Nasal
30	Superior aspect of nasal septum at 0% (ANS) cross-section	Nasal Septum
31	Inferior aspect of nasal septum at 0% (ANS) cross-section	Nasal Septum
32	Superior aspect of nasal septum at 25% cross-section	Nasal Septum
33	Inferior aspect of nasal septum at 25% cross-section	Nasal Septum
34	Superior aspect of nasal septum at 50% cross-section	Nasal Septum
35	Inferior aspect of nasal septum at 50% cross-section	Nasal Septum
36	Superior aspect of nasal septum at 75% cross-section	Nasal Septum
37	Inferior aspect of nasal septum at 75% cross-section	Nasal Septum
38	Superior aspect of nasal septum at 100% (PNS) cross-section	Nasal Septum
39	Inferior aspect of nasal septum at 100% (PNS) cross-section	Nasal Septum
40-49	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the right side at 0%	Nasal Septum
50-59	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the left side at 0%	Nasal Septum
60-69	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the right side at 25%	Nasal Septum
70-79	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the left side at 25%	Nasal Septum
80-89	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the right side at 50%	Nasal Septum
90-99	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the left side at 50%	Nasal Septum
100-109	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the right side at 75%	Nasal Septum
110-119	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the left side at 75%	Nasal Septum
120-129	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the right side at 100%	Nasal Septum
130-139	10 semi-landmarks equally distributed between the superior and inferior aspects of the nasal septum on the left side at 100%	Nasal Septum

FIGURES –

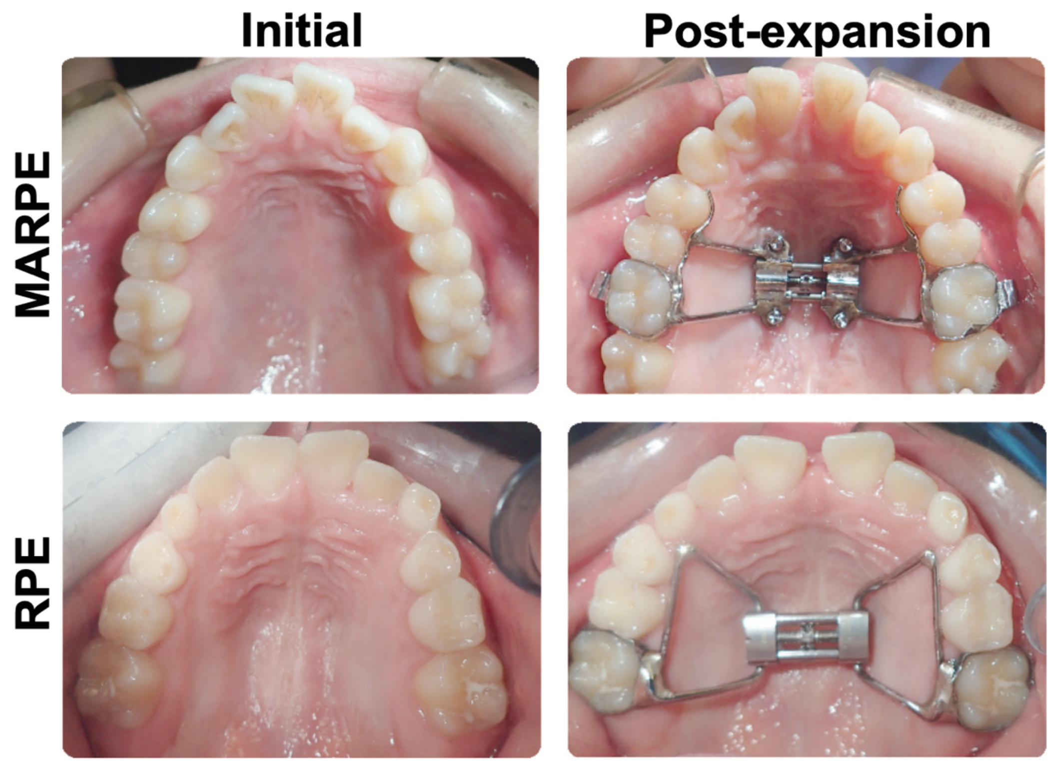

Figure 1: MARPE and RPE Appliances

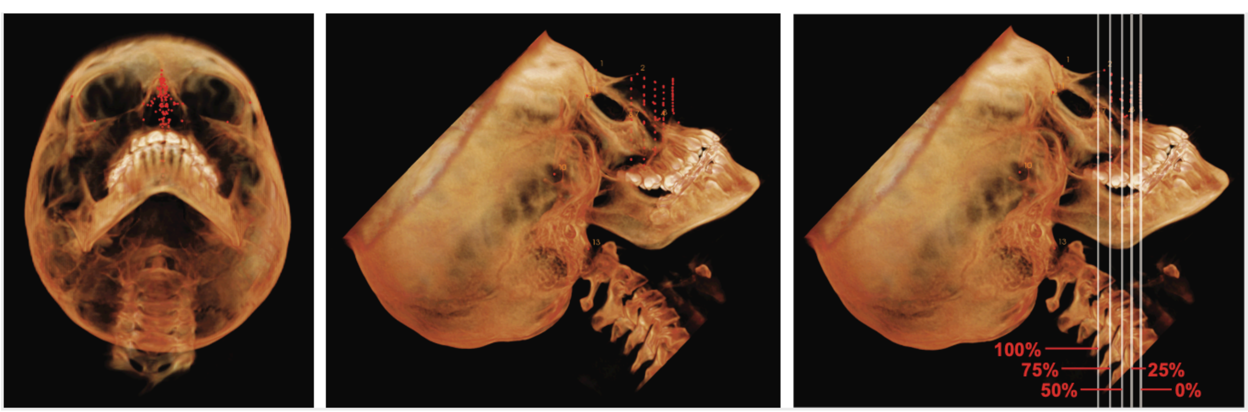

Figure 2: CBCT orientation and cross sections of the nasal septum

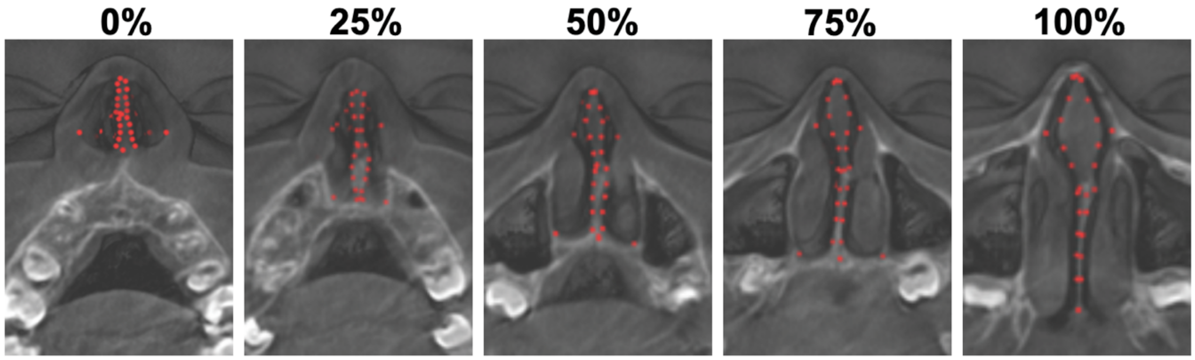

Figure 3: Landmark placement

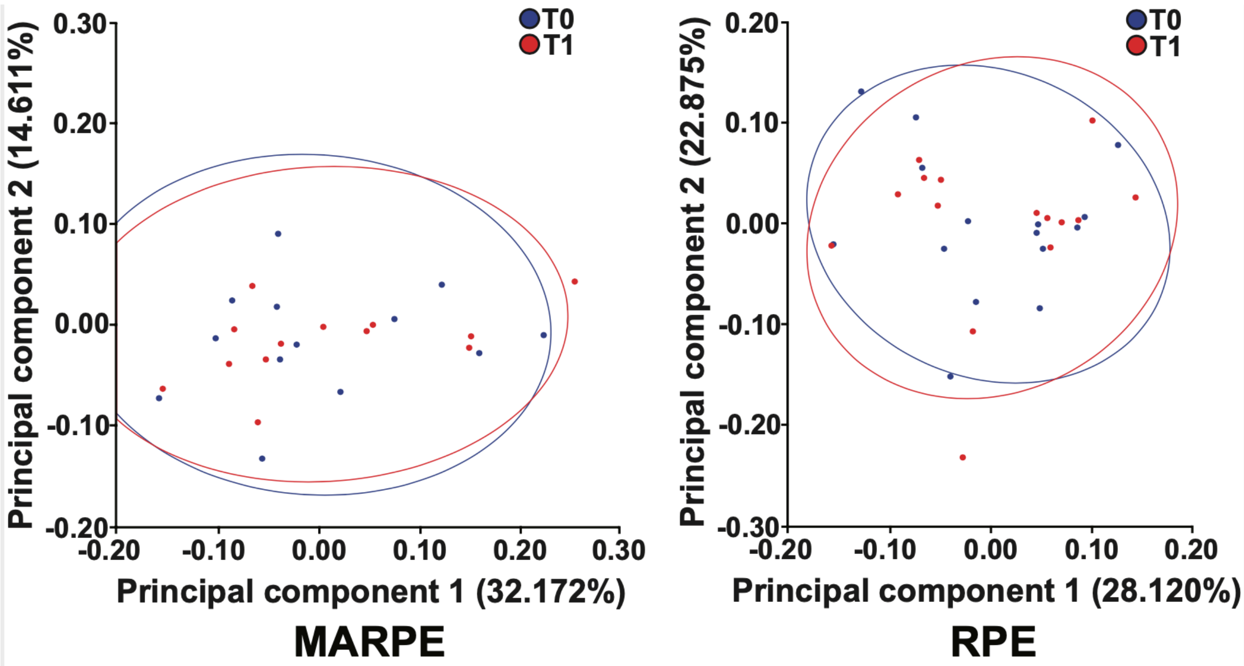

Figure 4: PCA results

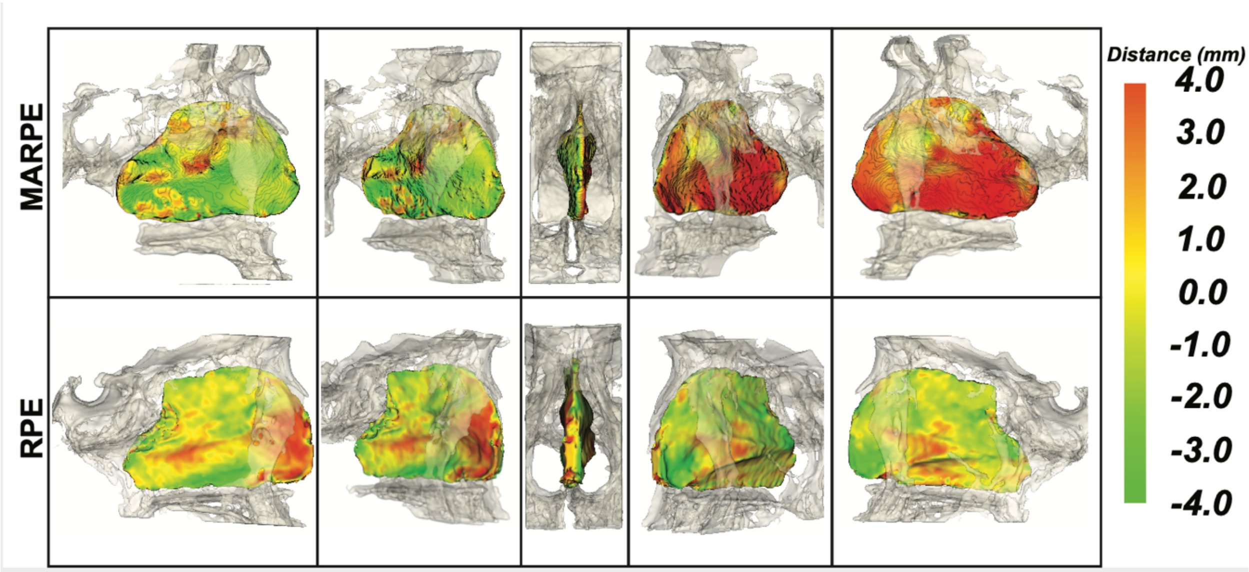

Figure 5: 3D superimposition analysis

REFERENCES –

[1] Orlandi RR. A systematic analysis of septal deviation associated with rhinosinusitis. *The Laryngoscope*. 22 July 2010.

[2] Englhard AS, Wiedmann M, Ledderose GJ, et al. Imaging of the internal nasal valve using long-range Fourier domain optical coherence tomography. *Laryngoscope*. 2016;126(3):E97–E102. doi:10.1002/lary.25785

[3] Harrison JE, Ashby D. Orthodontic treatment for posterior crossbites. Cochrane Database Syst Rev 2002; 1: CD000979.

[4] Ramires T, Maia RA, Barone JR. Nasal cavity changes and the respiratory standard after maxillary expansion. *Braz J Otorhinolarygol* 2008; 74: 763-9.

[5] Haas AJ. The treatment of maxillary deficiency by opening of the midpalatal suture. *Angle Orthodontics*. 1965; 35:200-17.

[6] Farronato G, Giannini L, Galbiati G, Maspero C. RME: influences on the nasal septum. *Minerva Stomatol*. 2012; 61(4): 125-34.

[7] Maspero C, Galbiati G, Del Rosso E, Farronato M, Giannini L. RME: effects on the nasal septum. A CBCT evaluation. *European Journal of Paediatric Dentistry*. 2019. Vol 20/2.

[8] Altug-Atac AT, Atac MS, Kurt G, Karasud HA. Changes in nasal structures following orthopaedic and surgically assisted rapid maxillary expansion. I*nt J Oral Maxillofac Surg*. 2010; 39(2) 129-35.

[9] Aziz T, Wheatley FC, Ansari K, Lagravere M, Major M, Flores-Mir C. Nasal septum changes in adolescent patients treated with rapid maxillary expansion. *Dental Press J Orthod*. 2016;21(1):47-53. doi:10.1590/2177-6709.21.1.047-053.oar.

[10] Bruno G, Stefani A, Benetazzo C, Cavallin F, Gracco A. Changes in nasal septum morphology after rapid maxillary expansion: a Cone-Beam Computed Tomography study in pre-pubertal patient. *Dental Press J Orthod*. 2020;25(5):51-56. doi:10.1590/2177-6709.25.5.051-056.oar.

[11] Erverdi N, Okar I, Kucukkeles N, Arbak S. A comparison of two different rapid palatal expansion techniques from the point of root resorption. *Am J Orthod Dentofacial Orthop* 1994; 106: 47-51.

[12] Seong EH, Choi SH, Kim HJ, Yu HS, Park YC, Lee KJ. Evaluation of the effects of miniscrew incorportation in palatal expanders for young adults using finite element analysis. *Korean Journal of Orthodontics*. 1 July 2017.

[13] Lim HM, Park YC, Lee KJ, Kim KH, Choi YJ. Stability of dental, alveolar, and skeletal changes after miniscrew-assisted rapid palatal expansion. *Korean Journal of Orthodontics*. 2017 April 24.

[14] Park JJ, Park YC, Lee KJ, Cha JY, Tahk JH, Choi YJ. Skeletal and dentoalveolar changes after miniscrew-assisted rapid palatal expansion in young adults: A cone-beam computed tomography study. *Korean Journal of Orthodontics*. 2016 July 13.

[15] Kim S, Park Y, Lee K, Lintermann A, Han S, Yu H, Choi YJ. Assessment of changes in the nasal airway after nonsurgical miniscrew-assisted rapid maxillary expansion in young adults. *Angle Orthod* 1 July 2018; 88 (4): 435–441.

[16] Zelditch ML, Swiderski DL, Sheets HD. 2012. Geometric morphometrics for biologists: a primer, 2nd Edition. Elsevier Academic Press, San Diego, CA.

[17] Kikinis R, Pieper SD, Vosburgh K (2014) 3D Slicer: a platform for subject-specific image analysis, visualization, and clinical support. Intraoperative Imaging Image-Guided Therapy, Ferenc A. Jolesz, Editor 3(19):277–289.

[18] Wertz RA. Changes in nasal airflow incident to rapid maxillary expansion. *Angle Orthod*. 1968;38(1):1-11.

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