Three-dimensional evaluation of mid-facial soft tissue changes after expansion using micro-implant-supported maxillary skeletal expander

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Research article

Keywords: Maxillary expansion, micro-implant-supported maxillary skeletal expander (MSE), soft tissue change

Posted Date: March 25th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-18883/v1>

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Abstract

Background The aim of this study was to assess the mid-facial soft tissue changes induced by a micro-implant-supported maxillary skeletal expander in late adolescents and young adults by cone-beam computerized tomography and the correlations between hard and soft tissue changes after expansion with maxillary skeletal expander.

Subjects and methods Twenty patients with maxillary transverse deficiency treated with maxillary skeletal expander were selected. Cone-beam computerized tomography images taken before and after expansion were superimposed to measure the changes in soft and hard tissue landmarks.

Results Anterior nasal spine, posterior nasal spine, and alveolar bone width were significantly increased after expansion with maxillary skeletal expander ($p < 0.05$). The average lateral movement of the cheek points was 1.13 ± 0.33 mm (left) and 1.41 ± 0.39 mm (right), while that of the alar curvature points was 1.07 ± 0.72 mm (left) and 1.06 ± 0.68 mm (right) ($p < 0.05$). The average forward displacement of the cheek points was 0.42 ± 0.66 mm (left) and 0.60 ± 0.58 mm (right), whereas that of the alar curvature points was 0.80 ± 0.67 mm (left) and 0.68 ± 0.56 mm (right) side ($p < 0.05$). The average downward movement of the subnasale was 0.40 ± 0.37 mm ($p < 0.05$). The changes in cheek points and alar curvature points on both sides significantly correlated with hard-tissue changes ($p < 0.05$).

Conclusions Maxillary expansion using maxillary skeletal expander resulted in significant lateral and forward movement of soft tissues of the cheek and alar curvature points on both sides and correlated with the maxillary suture opening at the anterior and posterior nasal spines.

Background

Maxillary transverse deficiency is one of the skeletal problems in the craniofacial region encountered during orthodontic treatment [1]. To correct this malocclusion, rapid maxillary expansion (RME) treatments have been used for more than a century [2-4]. Several studies have proved that RME increased arch width and perimeter to allow the correction of posterior crossbite and to provide space for alleviation of crowding of the dentition [5-7]. However, limited skeletal movement, dentoalveolar tipping, root resorption, detrimental periodontal consequences, and lack of long-term stability were reported as undesirable side effects [8].

With the widespread use of temporary anchorage devices, the micro-implant-supported maxillary skeletal expander (MSE) was recently developed to open the midpalatal suture and achieve skeletal expansion [9-14]. Numerous positive results were reported about the skeletal effects of MSE in different studies [11, 12, 15]. However, limited data have been published regarding soft tissue changes and their correlation with hard tissue changes [16].

Three-dimensional soft tissue analysis using the 3dMD Face system after MSE showed significant changes in the paranasal region, the upper lip, and in both cheeks [16]. Cone-beam computerized

tomography (CBCT) is a useful 3D imaging method for the accurate evaluation of hard and soft tissue changes [17, 18]. Progress in software development has allowed improved manipulation and visualization of CBCT images, and thus, collection of reliable and precise information [19].

The aim of this study was to assess the mid-facial soft tissue changes induced by MSE use in late adolescents and young adults by CBCT, and to evaluate the correlations between hard and soft tissue changes after expansion with MSE.

Subjects And Methods

This retrospective study analysed CBCT images of patients who received orthodontic treatment for resolution of maxillary transverse deficiency from June 2016 to January 2018 at Samsung Medical Centre and was approved by the Institutional Review Board (IRB) (Approval No. SMC MD IRB 2019-09-127-001).

A total of 20 patients with a mean age of 21.9 years (range, 15.0–27.1 years) were selected. CBCT images before the delivery of appliance (T0) and post-MSE (T1) were taken. The mean treatment duration was 48.5 days (range, 31–80 days), and the mean amount of expansion was 6.5 mm (range, 5.2–8.0 mm). The post-MSE CBCT images were acquired within 4 weeks (mean duration, 21 days; range, 1–28 days) of completion of expansion. The interval of CBCT images was 4.05 months (range, 3.5–9.1 months).

The inclusion criteria were the following: transverse maxillary deficiency; absence of any previous mid-facial trauma; absence of functional shift; lack of previous orthodontic treatment. The exclusion criteria were the following: systemic disease or syndromes; growing patients.

The MSE (BioMaterials Korea Inc., Seoul, Korea) device is a specific type of bone-borne expander using four micro-implants in the posterior area of the palate with bicortical engagement, including an 8-mm expansion jackscrew unit supported by four palatal micro-implants with diameter of 1.8 mm and length of 11 mm attached to the first molars with connecting arms and molar bands [9, 12]. The rate of expansion was two turns per day (0.20 mm per turn) until diastema appeared, after which the rate was changed to one turn per day. The expansion was stopped when the required amount of expansion was achieved. After completion, the MSE was retained for at least 3 months for stabilization.

All CBCT images were taken by the same technician using a CBCT scanner (CS 9300, Carestream Dental, Atlanta, USA) with image resolution up to 90 µm, exposure parameters of 90 kV and 4 mA, 300-µm voxel size, and volume dimension of 17 × 13.5 cm. During image acquisition, the patients were seated in a vertical position, with the Frankfort horizontal plane parallel to the floor and the patient's head stabilized by an ear rod. The images were imported as digital imaging and communications in medicine (DICOM) files using OnDemand3D software (CyberMed Inc, Seoul, Korea). Using the anatomical structures of the anterior cranial base, the superimposition of the post-expansion CBCT onto the pre-expansion CBCT was performed, as proposed by Cevitanes et al. [20–22] (Fig. 1). The superimposition method uses the voxel

grayscale and is fully automated by the 'Automatic Registration' tool of the software to avoid operator-related errors (Fig. 2), a procedure whose accuracy has been previously validated [22, 23].

The coordinate system featured three axes (x, y and z) with the origin (0, 0, 0) registered at Nasion (N). The x-axis, the transverse axis, was parallel to the Orbital (Or) line passing through the left and right Or. The y-axis, the anteroposterior axis, was perpendicular to the Or line and parallel to the right Frankfort horizontal (R FH) line. The z-axis, the vertical axis, was perpendicular to both the Or line and the R FH line (Fig. 3). Assuming the subject was in an anatomical position, positive values were to the left, posterior, and superior to the N point of the subject (Fig. 4), and negative values were to the right, anterior, and inferior to the N point. The three-dimensional coordinates (x, y, z) of any landmark represented its 3D position relative to N (0, 0, 0).

In the OnDemand3D software, landmark points were defined using the (x, y, z) Cartesian coordinate system, based on the 3 orientation planes. A series of 20 points were marked on each pre- and post-expansion CBCT. On each CBCT, three points with three pairs of soft tissue landmarks and five pairs of hard tissue landmarks were identified based on previous reports [18, 24] (Table 1; Fig. 5 and Fig. 6). Their three-dimensional changes between T0 and T1 were defined as the differences in their three coordinates. To investigate the amount of skeletal expansion, the following parameters were evaluated: amount of expansion at the anterior nasal spine (ANS) and the posterior nasal spine (PNS) [25], and alveolar width [26] (Table 2; Fig. 7A, 7B).

Statistical analysis

The normality of the data was determined using the Shapiro-Wilk test. Comparison of the coordinates of the soft tissue landmarks and hard tissue changes before and after expansion was performed using paired t-tests, according to the normality of data distribution. Pearson's correlation analysis was used to assess the correlation between hard tissue and soft tissue changes. P-values < 0.05 were considered statistically significant. All statistical analyses were performed using SPSS software, version 23 (SPSS Inc, Chicago, IL, USA).

A single examiner performed all measurements. In order to determine the intraexaminer reliability, the same examiner reanalysed ten randomly selected patients within a 2-week interval. The resultant correlation coefficient (ICC) indicated high reliability (ICC > 0.90). Cronbach's Alpha was used to evaluate the reliability of the measurements, and was equal to 0.92, showing appropriate superimposition and measurement agreement.

Results

In this study, the cheek points on left side and right side moved laterally by 1.14 and 1.41 mm and forward by 0.43 mm and 0.61 mm, respectively; these changes were statistically significant ($p < 0.001$; Table 3). The alar curvature points on both sides moved laterally by 1.11 and 1.07 mm, and forward by

0.82 and 0.70 mm, respectively and the subnasale point moved downward by 0.34 mm ($p < 0.001$; Table 3).

According to the result of superimposition of the 3D skull models, all the investigated hard tissue landmarks showed significant lateral movement ($p < 0.05$; Table 4). Furthermore, the A point, the ectocanine, and the prosthion of each half of the maxilla shifted forward ($p < 0.05$; Table 4), whereas the A point moved downward by 0.30 mm on the left side and by 0.28 mm on the right side following MSE ($p < 0.05$; Table 4).

Regarding the midpalatal suture, the amount of splits at the PNS (4.01 mm) and ANS (4.94 mm) were statistically significant ($p < 0.001$; Table 5) and the amount of PNS split corresponded to 81.17% of that of the ANS. Additionally, at the furcation of the first upper molars, the alveolar bone width after treatment showed a statistically significant expansion of 3.61 mm ($p < 0.001$; Table 5).

Table 6 shows that while the changes in the x-coordinate of the cheek and alar curvature points on the left side were positively affected by changes in ANS and PNS, those on the right side were negatively affected ($p < 0.01$). Moreover, the changes in the y-coordinate of the cheek points and alar curvature points on both sides were negatively affected by the separation at ANS and PNS ($p < 0.05$).

The comparison of the effects of the ANS and PNS separation with the movement of cheek and alar curvature points are shown in Table 7. Only the regression coefficients between movement in the x-axis of the cheek points on both sides and the separation at ANS were statistically significant ($p < 0.05$). For these soft tissue points on both sides, the separation measured at the ANS had a stronger effect than that at the PNS.

The unstandardized coefficients produced by regression analysis, shown in Table 8, reflect the expected lateral movement of both cheek points depending on the separation at the ANS, and have high statistical significance ($p < 0.001$). Thus, they can be used to predict the lateral displacement of the cheek points from the split at the ANS using the following regression equations:

Cheek point L(x) change = $-1.377 + 0.508 \times \text{ANS separation}$

Cheek point R(x) change = $1.441 - 0.578 \times \text{ANS separation}$

Discussion

In this study, we evaluated the changes in soft tissue landmarks after MSE treatment and their correlation with changes in hard tissues in late adolescents and young adults with transverse maxillary discrepancy using CBCT. We used voxel-based registration, one of six methods to obtain a rigid registration [27], on the cranial base of pre- and post-expansion CBCT images to evaluate soft tissue displacement. A previous study indicated that CBCT overcomes the limitations of 2D radiographs without exposing the patient to high levels of radiation, and allows the simultaneous evaluation of hard and soft tissues [28].

In recent years, the evaluation of soft tissue displacement using CBCT has become more common [17, 18, 29-35].

Regarding soft tissue changes, we observed a forward and lateral movement of the cheek points and alar curvature points on both sides; and a significant downward movement of the subnasale. These trends of soft tissue displacement after MSE were similar to those observed in previous studies [16, 19]. Kim et al reported that alar soft tissue over the infraorbital foramen, and soft tissue zygion were expanded significantly after conventional RPE [17]. The anterior and lateral movement of these soft tissue landmarks could be the result of the corresponding movement of the maxilla, which could be explained by the location of the maxillary rotational fulcrum. The maxilla is located medially and anteriorly relative to this fulcrum. Due to the outward rotation of the zygomaticomaxillary complex around the proximal part of the zygomatic process, each half of the maxilla will be displaced forward and laterally [36]. Additionally, the asymmetrical lateral movement of the cheek points and the alar curvature points between the left and right side could be explained by the unequal movement of the two maxillary bones. Previous studies by Cantarella et al and Torun et al showed that the displacement of the anterior part of the maxillary bones could affect mid-facial soft tissue during maxillary expansion [33] and might result in aesthetic alterations in this region, which could become asymmetrical [25]. In this study, a downward movement of the subnasale by 0.40 mm was observed. This could be explained by the median and inferior location of the maxilla relative to the fulcrum. Due to the outward rotation of the zygomaticomaxillary complex around the frontozygomatic suture area, the maxillary halves moved downward and outward [37]. Concerning hard tissue changes, there were significant lateral movements of all evaluated hard tissue landmarks, a significant forward displacement of the A point, the prosthion, the ectocanine and a significant downward shift of the A point following MSE. These types of movement were also observed in previous studies [36, 37].

The data obtained in this study showed that the midpalatal suture was successfully split in all patients after MSE. The mean separation at the PNS was about 81.17% of that at the ANS. This ratio demonstrates that MSE created an almost parallel split of the midpalatal suture, in agreement with previous studies [25, 38]. The amount of separation at the midpalatal suture produced by MSE in this study (4.94 mm at the ANS and 4.01 mm at the PNS) was nearly equivalent to that in the study by Cantarella et al (4.8 mm and 4.3 mm at the ANS and PNS, respectively) and larger than that reported by Oh et al (4.59 mm and 3.31 mm at the ANS and PNS, respectively). In Oh's study, because of the thin posterior part of the subject's palatal bone, micro-implants were positioned more anteriorly than in Cantarella's study whereas the micro-implants in our study were placed at similar positions indicated in the latter protocol [38]. In comparison with traditional RPE, MSE produced much greater suture opening, as compared with the findings of Lione et al using the modified Hyrax-type expander (3.01 mm and 1.15 mm at the ANS and PNS, respectively), Oh et al using a tooth-anchored maxilla expander (2.97 mm, 2.26 mm at the ANS and PNS, respectively), and those of Woller et al using RME (1.82 mm at the ANS) [39]. The reason is probably found in the mechanism of action of MSE. In fact, this appliance is located in the posterior portion of the hard palate, with 4 bicortical miniscrews positioned medial to the zygomatic buttress bones, allowing the opening force to be distributed along the entire suture length [25]. As a result,

while the tooth-borne maxillary expanders (Hyrax-type expander, RME) created a V-shaped expansion pattern of the maxillary palatal suture, MSE could produce an almost parallel split at the midpalatal suture [26].

The amount of expansion in the appliance (6.5 mm; range, 5.2-8.0 mm) was calculated according to the patient statement, which was greater than the increase in the PNS/ANS. It could imply errors in counting the number of appliance turns. Moreover, the possibility of deformation of the appliance could be expected.

By using Pearson's correlation analysis, several correlations were found between changes in soft tissue landmarks and the amounts of suture opening at the ANS and PNS. The lateral and forward movements of cheek points and alar curvature points on both sides correlated with the separation at the ANS and PNS. After MSE, strong and significant correlations were found between the split at the ANS and PNS on one hand, and the lateral movements of the bilateral cheek points and alar curvature points on the other.

The regression coefficients derived from these correlations were used to investigate to what extent the separation at the ANS and PNS affects the changes in soft tissue landmarks. The ANS split had greater effect than the PNS split on the cheek points and alar curvature points in the x- and y-axis. The reason could lie in the fact that the ANS is anatomically closer to the cheek points and alar curvature points than the PNS. Additionally, the only statistically significant regression coefficients were seen between the lateral movement of the cheek points on both sides and the separation at the ANS.

The prediction of soft tissue changes is crucial for treatment planning, and the results of this study imply that MSE would be beneficial in late adolescents and young patients with mid-facial deficiency, including paranasal depression without maxillary surgery. However, this study has limitations, for example relatively small subject size and short follow-up period. Further research with a larger sample size, using CBCT, is required to evaluate the long-term stability of these changes.

Conclusions

The mid-facial soft tissue landmarks, and in particular cheek points and alar curvature points on both sides, changed following MSE. These soft tissue landmarks were displaced in a forward and lateral direction. Opening of the maxillary palatal suture observed at the ANS and PNS correlated with the lateral and forward movement of cheek points and alar curvature points on both sides. Two regression equations predicting the forward movement of two cheek points were established.

Abbreviations

MSE: Maxillary skeletal expander

CBCT: Cone-beam computerized tomography

ANS: Anterior nasal spine

PNS: Posterior nasal spine

RME: Rapid maxillary expansion

R FH: Right Frankfort horizontal (R FH) line

ICC: Intraclass correlation coefficient

Declarations

Acknowledgements

Not applicable.

Funding

No specific funding was obtained for this study.

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Contributions

The individual role of each author was as follows: HN and JWS contributed equally for this manuscript. HN, HVG, JWS carried out the data collection of the study, analysis of data, interpretation of data, and

construction of the manuscript. KBK, HWC, YHK, HWC worked on the conception and design of the article. All the authors read and approved the final manuscript.

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Ethics Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board (IRB) of the Samsung Medical Center (Approval No. SMC MD IRB 2019-09-127-001). Subjects read and signed their informed consents.

Consent for publication

Not applicable.

Competing interests

There is no conflict of interest to be declared concerning this study.

Availability of data and materials

The datasets used and analysed in the current study are available from the corresponding author on reasonable requests.

References

- 1 McNamara JA: Maxillary transverse deficiency. Am J Orthod Dentofacial Orthop 2000;117:567-570.
- 2 Cross DL, McDonald JP: Effect of rapid maxillary expansion on skeletal, dental, and nasal structures: A postero-anterior cephalometric study. Eur J Orthod 2000;22:519-528.
- 3 Angell DH: Treatment of irregularity of the permanent or adult teeth. Dent Cosmos 1860;1:540-544.
- 4 Haas AJ: Palatal expansion: Just the beginning of dentofacial orthopedics. Am J Orthod 1970;57:219-255.
- 5 Gryson JA: Changes in mandibular interdental distance concurrent with rapid maxillary expansion. Angle Orthod 1977;47:186-192.
- 6 Adkins MD, Nanda RS, Currier GF: Arch perimeter changes on rapid palatal expansion. Am J Orthod Dentofacial Orthop 1990;97:194-199.

- 7 Geran RG, McNamara JA, Jr, Baccetti T, Franchi L, Shapiro LM: A prospective long-term study on the effects of rapid maxillary expansion in the early mixed dentition. *Am J Orthod Dentofacial Orthop* 2006;129:631-640.
- 8 Gurel HG, Memili B, Erkan M, Sukurica Y: Long-term effects of rapid maxillary expansion followed by fixed appliances. *Angle Orthod* 2010;80:5-9.
- 9 Lee RJ, Moon W, Hong C: Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. *Am J Orthod Dentofacial Orthop* 2017;151:887-897.
- 10 Hansen L, Tausche E, Hietschold V, Hotan T, Lagravere M, Harzer W: Skeletally-anchored rapid maxillary expansion using the dresden distractor. *Journal of orofacial orthopedics = Fortschritte der Kieferorthopadie : Organ/official journal Deutsche Gesellschaft fur Kieferorthopadie* 2007;68:148-158.
- 11 MacGinnis M, Chu H, Youssef G, Wu KW, Machado AW, Moon W: The effects of micro-implant assisted rapid palatal expansion (marpe) on the nasomaxillary complex—a finite element method (fem) analysis. *Prog Orthod* 2014;15:52.
- 12 Carlson C, Sung J, McComb RW, Machado AW, Moon W: Microimplant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult. *Am J Orthod Dentofacial Orthop* 2016;149:716-728.
- 13 Lagravere MO, Carey J, Heo G, Toogood RW, Major PW: Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: A randomized clinical trial. *Am J Orthod Dentofacial Orthop* 2010;137:304.e301-312; discussion 304-305.
- 14 Lee KJ, Park YC, Park JY, Hwang WS: Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. *Am J Orthod Dentofacial Orthop* 2010;137:830-839.
- 15 Lin L, Ahn HW, Kim SJ, Moon SC, Kim SH, Nelson G: Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. *Angle Orthod* 2015;85:253-262.
- 16 Abedini S, Elkenawy I, Kim E, Moon W: Three-dimensional soft tissue analysis of the face following micro-implant-supported maxillary skeletal expansion. *Prog Orthod* 2018;19:46.
- 17 Lee TY, Kim KH, Yu HS, Kim KD, Jung YS, Baik HS: Correlation analysis of three-dimensional changes of hard and soft tissues in class iii orthognathic surgery patients using cone-beam computed tomography. *The Journal of craniofacial surgery* 2014;25:1530-1540.
- 18 Kim KB, Adams D, Araújo EA, Behrents RG: Evaluation of immediate soft tissue changes after rapid maxillary expansion. *Dental Press Journal of Orthodontics* 2012;17:157-164.

- 19 Moss JP: The use of three-dimensional imaging in orthodontics. *Eur J Orthod* 2006;28:416-425.
- 20 Cevidanes LH, Bailey LJ, Tucker GR, Jr., Styner MA, Mol A, Phillips CL, Proffit WR, Turvey T: Superimposition of 3d cone-beam ct models of orthognathic surgery patients. *Dentomaxillofac Radiol* 2005;34:369-375.
- 21 Cevidanes LH, Heymann G, Cornelis MA, DeClerck HJ, Tulloch JF: Superimposition of 3-dimensional cone-beam computed tomography models of growing patients. *Am J Orthod Dentofacial Orthop* 2009;136:94-99.
- 22 Bazina M, Cevidanes L, Ruellas A, Valiathan M, Queresby F, Syed A, Wu R, Palomo JM: Precision and reliability of dolphin 3-dimensional voxel-based superimposition. *Am J Orthod Dentofacial Orthop* 2018;153:599-606.
- 23 Weissheimer A, Menezes LM, Koerich L, Pham J, Cevidanes LH: Fast three-dimensional superimposition of cone beam computed tomography for orthopaedics and orthognathic surgery evaluation. *Int J Oral Maxillofac Surg* 2015;44:1188-1196.
- 24 Swennen GRJ: 3-d cephalometric soft tissue landmarks; Three-dimensional cephalometry: A color atlas and manual. Berlin, Heidelberg, Springer Berlin Heidelberg, 2006, pp 183-226.
- 25 Cantarella D, Dominguez-Mompell R, Mallya SM, Moschik C, Pan HC, Miller J, Moon W: Changes in the midpalatal and pterygopalatine sutures induced by micro-implant-supported skeletal expander, analyzed with a novel 3d method based on cbct imaging. *Prog Orthod* 2017;18:34.
- 26 Lim H-M, Park Y-C, Lee K-J, Kim K-H, Choi YJ: Stability of dental, alveolar, and skeletal changes after miniscrew-assisted rapid palatal expansion. *Korean J Orthod* 2017;47:313-322.
- 27 Cevidanes LH, Motta A, Proffit WR, Ackerman JL, Styner M: Cranial base superimposition for 3-dimensional evaluation of soft-tissue changes. *Am J Orthod Dentofacial Orthop* 2010;137:S120-129.
- 28 Nur RB, Cakan DG, Arun T: Evaluation of facial hard and soft tissue asymmetry using cone-beam computed tomography. *Am J Orthod Dentofacial Orthop* 2016;149:225-237.
- 29 Brooks SL: Cbct dosimetry: Orthodontic considerations. *Seminars in Orthodontics* 2009;15:14-18.
- 30 Cakirer B, Dean D, Palomo JM, Hans MG: Orthognathic surgery outcome analysis: 3-dimensional landmark geometric morphometrics. *The International journal of adult orthodontics and orthognathic surgery* 2002;17:116-132.
- 31 Elnagar MH, Elshourbagy E, Ghobashy S, Khedr M, Kusnoto B, Evans CA: Three-dimensional assessment of soft tissue changes associated with bone-anchored maxillary protraction protocols. *Am J Orthod Dentofacial Orthop* 2017;152:336-347.

- 32 Solem RC, Marasco R, Guiterrez-Pulido L, Nielsen I, Kim SH, Nelson G: Three-dimensional soft-tissue and hard-tissue changes in the treatment of bimaxillary protrusion. *Am J Orthod Dentofacial Orthop* 2013;144:218-228.
- 33 Torun GS: Soft tissue changes in the orofacial region after rapid maxillary expansion : A cone beam computed tomography study. *Journal of orofacial orthopedics = Fortschritte der Kieferorthopadie : Organ/official journal Deutsche Gesellschaft fur Kieferorthopadie* 2017;78:193-200.
- 34 Almeida RC, Cevidanes LH, Carvalho FA, Motta AT, Almeida MA, Styner M, Turvey T, Proffit WR, Phillips C: Soft tissue response to mandibular advancement using 3d cbct scanning. *Int J Oral Maxillofac Surg* 2011;40:353-359.
- 35 Koerich L, Brunetto DP, Ohira ETB: The effect of hard tissue surgical changes on soft tissue displacement: A pilot cbct study. *Dental Press J Orthod* 2017;22:39-46.
- 36 Cantarella D, Dominguez-Mompell R, Moschik C, Sfogliano L, Elkenawy I, Pan HC, Mallya SM, Moon W: Zygomaticomaxillary modifications in the horizontal plane induced by micro-implant-supported skeletal expander, analyzed with cbct images. *Progress in orthodontics* 2018;19:41-41.
- 37 Cantarella D, Dominguez-Mompell R, Moschik C, Mallya SM, Pan HC, Alkahtani MR, Elkenawy I, Moon W: Midfacial changes in the coronal plane induced by microimplant-supported skeletal expander, studied with cone-beam computed tomography images. *Am J Orthod Dentofacial Orthop* 2018;154:337-345.
- 38 Oh H, Park J, Lagravere-Vich MO: Comparison of traditional rpe with two types of micro-implant assisted rpe: Cbct study. *Seminars in Orthodontics* 2019;25:60-68.
- 39 Woller JL, Kim KB, Behrents RG, Buschang PH: An assessment of the maxilla after rapid maxillary expansion using cone beam computed tomography in growing children. *Dental press journal of orthodontics* 2014;19:26-35.

Tables

Table 2. Definitions of the parameters used in this study

Table 1. Definitions of the landmarks used in this study

	Landmarks	Description
Soft tissue	Subnasale	The midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip
	Alar curvature point	The point located at the facial insertion of the alar base
	Soft tissue A point	The most posterior midpoint of the philtrum
	Labrale superius	The midpoint of the vermilion line of the upper lip
	Cheilion	The point located at each labial commissure
	Cheek point	The point located at the centre of the cheek area
Hard tissue	A point	The most posterior and deepest point on the anterior contour of the maxillary alveolar process
	Prosthion	The most antero-inferior point on the maxillary alveolar margin in the mid-sagittal plane
	Ectocanine	The most infero-lateral point on the alveolar ridge opposite the centre of the maxillary canine
	Ectomolare	The most infero-lateral point on the alveolar ridge opposite the centre of the maxillary first molar
	Processus Zygomaticus	The most infero-lateral point of the processus zygomaticus

Parameter	Section for measurements	Definition
ANS width	Axial section passing through ANS	Distance between right and left halves of ANS
PNS width	Axial section passing through PNS	Distance between right and left halves of PNS
Alveolar width	Coronal section passing through M1 furcations	Distance between the R and L buccal alveolar bones on a line connecting the R and L M1 furcations

ANS, Anterior nasal spine; PNS, Posterior nasal spine; R, right; L, left; M1, maxillary first molar.

Table 3. Changes in soft tissue landmarks in the maxilla, assessed in the transverse (x), sagittal (y), and vertical (z) planes, after expansion (mm).

Landmarks		D Coordinate	Mean $\pm$ SD (mm)	p value
Subnasale		Dx	-0.10 $\pm$ 0.69	0.519
		Dy	-0.13 $\pm$ 0.51	0.266
		Dz	-0.40 $\pm$ 0.37	0.000*
Soft tissue A point		Dx	-0.25 $\pm$ 0.70	0.122
		Dy	-0.08 $\pm$ 0.90	0.700
		Dz	-0.35 $\pm$ 1.85	0.403
Labiale superius		Dx	-0.17 $\pm$ 0.90	0.408
		Dy	-0.06 $\pm$ 1.19	0.813
		Dz	-0.39 $\pm$ 1.01	0.101
Cheilion	Left	Dx	0.05 $\pm$ 1.81	0.899
		Dy	-0.30 $\pm$ 1.79	0.470
		Dz	0.18 $\pm$ 1.53	0.609
	Right	Dx	-0.41 $\pm$ 1.36	0.197
		Dy	-0.10 $\pm$ 1.81	0.813
		Dz	0.22 $\pm$ 1.28	0.443
Cheek point	Left	Dx	1.13 $\pm$ 0.33	0.000*
		Dy	-0.42 $\pm$ 0.66	0.01*
		Dz	-0.48 $\pm$ 1.30	0.112
	Right	Dx	-1.41 $\pm$ 0.39	0.000*
		Dy	-0.60 $\pm$ 0.58	0.000*
		Dz	-0.56 $\pm$ 1.21	0.055
Alar curvature point	Left	Dx	1.07 $\pm$ 0.72	0.000*
		Dy	-0.80 $\pm$ 0.67	0.000*
		Dz	-0.24 $\pm$ 0.78	0.195
	Right	Dx	-1.06 $\pm$ 0.68	0.000*
		Dy	-0.68 $\pm$ 0.56	0.000*
		Dz	-0.13 $\pm$ 0.66	0.380

*Statistical significance with $p < 0.05$.

SD, Standard deviation

Table 4. Changes in hard tissue landmarks in the maxilla, assessed in the transverse (x), sagittal (y), and vertical (z) planes, after expansion (mm).

Landmarks		D Coordinate	Mean $\pm$ SD (mm)	p value
A point	To Left side	Dx	2.70 $\pm$ 1.21	0.000*
		Dy	-0.71 $\pm$ 0.41	0.000*
		Dz	-0.30 $\pm$ 0.45	0.007*
	To Right side	Dx	-2.32 $\pm$ 0.78	0.000*
		Dy	-0.80 $\pm$ 0.38	0.000*
		Dz	-0.28 $\pm$ 0.39	0.004*
Prosthion	To Left side	Dx	2.85 $\pm$ 1.07	0.000*
		Dy	-0.76 $\pm$ 0.86	0.001*
		Dz	-0.28 $\pm$ 1.07	0.249
	To Right side	Dx	-2.70 $\pm$ 1.09	0.000*
		Dy	-0.83 $\pm$ 0.52	0.000*
		Dz	-0.13 $\pm$ 0.80	0.490
Ectocanine	Left	Dx	2.27 $\pm$ 0.91	0.000*
		Dy	-0.56 $\pm$ 0.73	0.003*
		Dz	-0.26 $\pm$ 0.62	0.080
	Right	Dx	-2.04 $\pm$ 0.91	0.000*
		Dy	-0.68 $\pm$ 0.80	0.003*
		Dz	-0.32 $\pm$ 0.78	0.080
Ectomolar	Left	Dx	2.08 $\pm$ 0.76	0.000*
		Dy	-0.15 $\pm$ 0.88	0.459
		Dz	-0.25 $\pm$ 1.41	0.444
	Right	Dx	-1.94 $\pm$ 0.69	0.000*
		Dy	-0.18 $\pm$ 1.07	0.459
		Dz	-0.37 $\pm$ 0.80	0.053
Processus Zygomaticus	Left	Dx	1.87 $\pm$ 0.52	0.000*
		Dy	-0.36 $\pm$ 0.77	0.052
		Dz	0.25 $\pm$ 0.99	0.277
	Right	Dx	-1.62 $\pm$ 0.90	0.000*
		Dy	-0.27 $\pm$ 0.60	0.058
		Dz	0.07 $\pm$ 0.97	0.768

*Statistical significance with $p < 0.05$.

SD, Standard Deviation

Table 5. Lateral displacement of ANS and PNS, and alveolar bone width following expansion.

Parameter	Before		After		Difference		p value
	Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD	
ANS width	0.00	0.00	4.94	0.64	4.94	0.64	0.000*
PNS width	0.00	0.00	4.01	0.58	4.01	0.58	0.000*
Alveolar bone width	62.17	2.48	65.80	3.46	3.64	1.29	0.000*

ANS, Anterior nasal spine; PNS, posterior nasal spine; SD, standard deviation.

*Statistically significant at $p < 0.05$.

Table 6. Pearson's correlation between the changes in soft tissue landmarks and those of the parameters used in the study

Parameter			ANS		PNS		Alveolar bone	
Landmark	Coordinate		Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value
Subnasale	Z		-0.241	0.306	-0.240	0.308	-0.168	0.478
Cheek point	Left	X	0.983	0.000*	0.976	0.000*	0.272	0.247
		Y	-0.471	0.036*	-0.464	0.039*	0.224	0.343
	Right	X	-0.956	0.000*	-0.943	0.000*	-0.292	0.211
		Y	-0.460	0.041*	-0.459	0.042*	0.169	0.478
Alar curvature point	Left	X	0.891	0.000*	0.890	0.000*	0.180	0.447
		Y	-0.676	0.001*	-0.669	0.001*	0.006	0.980
	Right	X	-0.816	0.000*	-0.806	0.000*	-0.341	0.141
		Y	-0.621	0.003*	-0.614	0.004*	0.025	0.918

x, x-axis, the transverse axis; y, y-axis, the anteroposterior axis; z, z-axis, the vertical axis; ANS, Anterior nasal spine; PNS, Posterior nasal spine

*Statistically significant at $p < 0.05$.

Table 7. Regression coefficients between the changes of the cheek points, the alar curvature points on both sides, and the ANS and PNS separation

Variables			Model	Standardized coefficients		p-value
Landmark	Coordinate			Beta		
Cheek point	Left	X	ANS	0.668		0.005*
			PNS	0.321		0.138
		Y	ANS	-0.422		0.698
			PNS	-0.051		0.963
	Right	X	ANS	-0.810		0.035*
			PNS	-0.149		0.677
		Y	ANS	-0.257		0.814
			PNS	-0.207		0.849
Alar curvature point	Left	X	ANS	0.493		0.374
			PNS	0.406		0.462
		Y	ANS	-0.516		0.571
			PNS	-0.163		0.857
	Right	X	ANS	-0.650		0.365
			PNS	-0.170		0.811
		Y	ANS	-0.498		0.606
			PNS	-0.126		0.896

x, x-axis, the transverse axis; y, y-axis, the anteroposterior axis; ANS, Anterior nasal spine; PNS, Posterior nasal spine

*Statistically significant at $p < 0.05$.

Table 8. Regression coefficients between the changes in the cheek points on both sides and the separation at the ANS

Variables			Model	Unstandardized coefficients		P-value
Landmark	Coordinate			Beta	SD	
Cheek point	Left	X	Constant	-1.377	0.110	0.000*
			ANS	0.508	0.022	0.000*
	Right	X	Constant	1.441	0.208	0.000*
			ANS	-0.578	0.042	0.000*

x, x-axis, the transverse axis; ANS, Anterior nasal spine

*Statistically significant at $p < 0.05$.

Figures

Figure 1

OnDemand 3D voxel-based superimposition on the cranial base. The yellow box is used to determine the area of the cranial base to be used as a reference for the superimposition.

Figure 2

Superimposed pre- and post-expansion CBCT following MSE (Primary CBCT, violet; Secondary CBCT, red).
CBCT: Cone-beam computerized tomography; MSE: maxillary skeletal expander

Figure 3

The coordinate system consists of three axes (x, y, z) with their origin (0,0,0) registered at Nasion (N). 1, Nasion; 2 and 3, Orbitale, right and left; 4, Porion, right.

Figure 4

Positive values are to the left, posterior, and superior to the N point of the subject

Figure 5

Soft tissue landmarks used in this study. 1 and 2, Alar curvature points, right and left; 3, Subnasale; 4, Soft tissue A point; 5, Labrale superius; 6 and 7, Cheilion, right and left; 8 and 9, Cheek points, right and left (the intersection point of the vertical and horizontal blue line. The vertical blue line is the line passing through the mid-canthus parallel to the z axis. The horizontal blue line is perpendicular to the vertical line passing through the Alare); A and B, Alare, right and left (the most lateral point on each alar contour); C and D, Endo-canthus, right and left; E and F, Exo-canthus, right and left; G and H, Mid-canthus, right and left.

Figure 6

Hard tissue landmarks used in this study. 1 and 2, A-point, right and left; 3 and 4, Prosthion, right and left; 5 and 6, Ectocanine, right and left; 7 and 8, Ectomolare, right and left; 9 and 10, Processus zygomaticus, right and left.

Figure 7

(A) ANS and PNS width after expansion. (B) Alveolar width after expansion. ANS: Anterior nasal spine; PNS: Posterior nasal spine