The application of the diagnostic 3-D imaging procedures in maxillofacial orthopedics: The examination of soft tissue changes during conservative and surgical correction of the craniofacial anomalies

Ph.D. Thesis

Ali Alkhayer, DDS, M.Sc.

Supervisor

Assoc. Prof. Emil Segatto, DDS, PhD

Craniofacial Unit

Department of Oral and Maxillofacial Surgery

Clinical and Experimental Research for Reconstructive and Organ-Sparing Surgery, Doctoral School of Clinical Medicine

University of Szeged

2021

Szeged, Hungary

Scientific articles and publications

Publications related to the thesis

1. **Evaluation of the Soft Tissue Changes after Rapid Maxillary Expansion using a Handheld Three-dimensional Scanner: a prospective study**
   Alkhayer A, Becsei R, Hegedűs L, Párkányi L, Piffkó J, Braunitzer G and Segatto E. Int. J. Environ. Res. Public Health 2021, 18(7), 3379
   Article type: original article Impact Factor$_{2019}$: 2.849

2. **Accuracy of virtual planning in orthognathic surgery: a systematic review**
   Alkhayer A, Piffkó J, Lippold C, Segatto E. Head Face Med 16, 34 (2020).
   Article type: systematic review. Impact Factor$_{2019}$: 1.882

3. **Three-dimensional changes of the facial soft tissue after bimaxillary surgery of skeletal class III patients: a prospective study**
   Alkhayer A, Piffkó J, Segatto E.
   Fogorvosi Szemle. Article type: original article

4. **Evaluation of the Upper Airway Morphology in Patients with Class II Malocclusion Using 3-Dimensional Computed Tomography**
   Alkhayer A, Hasan H, Khalil F
   International Dental Journal of Student's Research, 2015; 3(4):174-183
   Article type: original article

Other publications:

1. **The Relationship of the Upper Airway Morphology with the Cephalometric Features Determining Sagittal intermaxillary Relationship in Adults Using Three Dimensional Computed Tomography.**
   Alkhayer A, Hasan H, Khalil F. Tishreen University Journal for Research and Scientific Studies, 2016; 38(2): 265-281

2. **Evaluation Of The Relationship Between The Upper Airway Morphology And Facial Growth Type In Adults of The Syrian Coast Using Three Dimensional Computed Tomography.**
   Alkhayer A, Hasan H, Khalil F
   Journal of Al Baath University, 2016; 38(3): 165-191

Cumulative impact factor = 4.731

Scientific Presentations

- **Oral presentation in a congress**
  Health Sciences and Innovation Conference- DOSZ
  January 29-30, 2021, Budapest, Hungary
  Title: Three-dimensional changes of the facial soft tissue after bimaxillary surgery of skeletal class III patients: a prospective study.
  Award: **III Prize**

- **poster presentation in a congress (international):**
  96th General Session of the International Association for Dental Research (IADR) in conjunction with the IADR Pan European Regional Congress
  (July 25 -28, 2018, London, United Kingdom)
  Title: Virtual Planning in Orthognathic Surgery - A Systematic Review

- **poster presentation in a congress (international):**
  94th Congress of the European Orthodontic Society (EOS)
  (Jun 17 - 21, 2018 Edinburgh, United Kingdom)
  Title: Evaluation of Accuracies of Virtual Planning Methods Used in Orthognathic Surgery – A Systematic Review)
  European journal of orthodontics, volume 40, Issue 5, October 2018.

- **poster presentation in a congress (international):**
  96th Congress of the European Orthodontic Society (EOS)
  (Jun 10 - 14, 2020 Hamburg, Germany)
  Title: Evaluation of the Soft Tissue Changes after Rapid Maxillary Expansion using Handheld Three-dimensional Scanner

European journal of orthodontics, volume 42, Issue 5, 2020

1. Introduction

The concept of facial beauty has changed over centuries, with more priority given to the balance among facial proportions, which in turn can influence the psychological aspects of the patients and even improve their quality of life. Thus, orthodontists should consider soft tissue adaptation and its contours during their daily orthodontic treatment.

Although several studies reported the skeletal and dental effects of rapid maxillary expansion (RME), only a few studies and scarce data have addressed alterations in the overlying soft tissue.

The importance of soft tissue assessment is not only subjective to the orthodontic treatment but also during orthognathic surgery, where the relationship between the skeletal bases and soft tissue envelope is the first concern.

In this regard, Bimaxillary surgery has been increasingly utilized, especially for patients with craniofacial deformities, since it can provide more aesthetic outcomes of the facial proportions.

Until recently, changes in facial soft tissue following the orthodontic and surgical correction of craniofacial deformities were examined via two-dimensional (2D) imaging methods. However, their limitations such as- enlargement and distortion, exposure to radiation, superimposition, and magnification factors- can be avoided by using three-dimensional (3D) imaging approaches.

Noncontact optical scanning methods such as Laser surface scanning, stereophotogrammetry, and structured light systems were introduced as new 3D imaging tools, as they provide high-resolution 3D images in a short scanning time without additional radiation hazards. However, these devices are often bulky and also rather expensive, which are deterring factors

By using handheld 3D structured-light scanners, texture and color information of the face can be promptly obtained in high resolution without radiation, together with some advantages such as the short scanning time along with the flexible portability and operability. (Jung et al.2018) found that the accuracy of the structured light system compares the direct anthropometric measurements and concluded that it's a reliable method for the assessment of the facial soft tissue.

To our knowledge, only a few studies evaluated the facial soft tissues changes during the conservative and surgical correction of craniofacial deformities using a 3D facial scanner, most of these studies have examined linear and angular changes by taking measurements between designated points, however, it is more accurate to anticipate changes within an entire complex structure on a 3D basis rather than only between specified points.

2. Aim of the research

- Introducing the 3D handheld structured-light scanner as a new method for prediction of the facial soft tissue changes in maxillofacial orthopedics.
- A comprehensive evaluation of soft tissue changes in various morphological regions of the face during our orthodontic treatment of the craniofacial deformities.
- Extensive evaluation of facial soft tissue changes during our surgical correction of the craniofacial anomalies.

3. Materials and Methods

Our research consisted of two clinical studies which were approved by the Human Investigation Review Board, University of Szeged, Albert Szent-Györgyi Clinical Centre (No. 151/2019-SZTE). Patients were recruited from among the patients of the Craniofacial Unit, Department of Oral and Maxillofacial Surgery, Albert Szent-Györgyi Clinical Center, Szeged, Hungary. Informed consent was obtained from all patients/parents of the patients who agreed to participate in our research.

3.1. First Prospective Clinical Study

Evaluation of the Soft Tissue Changes after Rapid Maxillary Expansion Using a handheld Three Dimensional Scanner

A total of 25 patients were included in our study (13 females and 12males) with a mean age of 11.6 years (range: 8.1–14.4 years), requiring treatment using Rapid Maxillary Expansion (RME) as part of their full comprehensive orthodontic plan; either for a unilateral or bilateral posterior crossbite correction and/or relief of crowding. All patients went onto receive full comprehensive orthodontic treatment. The 3D facial images were acquired immediately before the appliance was cemented (T_0) and after the expansion had been completed and 6 months of retention phase (T_1) using a structured-light 3D handheld scanner (Artec Eva™; Artec Group, Luxembourg). All images were taken with the head in a natural head position, teeth in centric occlusion, and lips in repose.

Data processing and measurements

In total, 18 landmarks (5 bilateral and 8 unilateral) were located according to the literature, 4 linear measurements (Intercanthal width, nasal and nasal base width, and the mouth width) besides 3 angular measurements (Nasal tip angle, upper and lower lip angle) were performed directly on the 3D-facial images using Artec studio V.12. A full 3D deviation analysis of the face was then conducted, by transferring the 3D facial images into reverse engineering software (GOM Inspect Evaluation Software) and polygon meshes were created in stereolithographic (STL) format. The hair, ears, and the below-neck region were removed. The images obtained at the T_0 time point were aligned with the images taken at T_1 using the best-fit method. Negative values indicate that T_1 images were located behind the T_0 images (blue shades), whereas positive values indicate that T_1 images were located in front of the T_0 images (red shades). To create morphological regions, reference lines passing through different points specified on the face were determined and a 3D deviation analysis was made in six morphological regions (The total face, the upper and lower face, the upper and lower lip, and the nose region)

Results

All parameters were normally distributed. No significant errors were found when repeating the measurements. The mean value of the jackscrew activation amount and the upper arch width in our study were (7.75 and 5.46mm) respectively.

Statistically significant increases in the nasal and nasal base width and also in the mouth width were found after RME (1.02, 1.21, and 2.62 mm, $p<0.05$) respectively. We also found a significant increase in the nasal tip angle, the upper and lower lip angle (3.2, 3.47, and 3.78º, $p<0.05$) respectively.

Soft tissue changes were found in the nasal and the upper lip regions with a mean of (0.55 and .053mm) respectively. Soft tissue changes were also observed in the facial landmarks especially at the level of (bilateral Alar and Chelion points, Pronasal, Subnasal, and Sublabiale points). A significant moderate positive correlation between the jackscrew activation amount and the mouth width at the level of 5% of significance was observed.

Discussion

Our findings were based on subjects who were on active growth. It has been presumed that growth might not cause large interference with the parameters evaluated during the observational period of up to 6–7 months.

The 6 months retention period was designed to dispose of the immediate positional changes resulting in the facial soft tissue. We could not perform a longer evaluation because RME was usually followed by multibracket therapy.

The effects of the sex and age of patients were not evaluated in our study because of the relatively small sample size. Previous studies found that sex and stage of maturation had no significant effect on the soft tissue changes brought by RME.

Facial Soft tissue changes

We found a statistically significant increase in the nasal, nasal base width, and nasal tip angle, which was following the results of Altorkat and colleagues, who observed in all transverse linear measurements in the nasal area including the nasal base width, alar cartridge width, nasal tip retraction, and flattening of the nasal tip following RME. However, it was reported that these changes were very small and variable.

We found a statically significant increase (2.62 mm, $p<0.05$) of mouth width after RME, probably as a result of the transverse expansion of the maxillary halves. We also found statically significant increases in the upper and lower lip angle (3.45 and 3.78^{o}, respectively). Our results correspond with the results of Altındi S et al. While Baysal et al. found no statistically significant change in this respect, this difference could be related to their small sample size (17 subjects).

Dindaroglu F et al. considered that changes measured only in these dimensions may not reflect the actual soft tissue changes properly. Therefore, volumetric analyses can provide more information on the effects of treatment in facial regions.

We found facial soft tissue changes in both the nose and the upper lip regions. We also noticed high positive and negative deviation limits in the other facial morphological regions of the face, but the mean deviation for these regions changed only to a negligible extent.

Dindaroglu F. et al. found that the positive and negative deviations were less than 2 mm in all morphological regions in the face, which is similar to our results.

Regarding the upper lip region, the mean positive and negative change in their study was (0.87 ± 0.38, -0.57 ± 0.14 mm) respectively, which was also close to our results.

Although the greatest mean deviation limits noted in our study patients in the lower lip region was (2.19 and 2.54 mm; positive and negative, respectively) the mean deviation for the whole sample in the lower lip region changed only to a negligible extent (-0.04±1.24 mm).

For a deeper understanding of the soft tissue deviations, we calculated these deviations on specific facial landmarks directly after the surface comparisons and found the greatest deviation at the right Alar point (0.72±0.45 mm). The left Alar point changed by (0.46±0.59 mm), and we also found change at the subnasal point (0.66±0.64 mm). Kim et al. evaluated the deviations at different points in various nasal regions and detected a mean deviation of less than 1 mm for all of the points, except for the ones in the subnasal region (2.21 ± 1.23 mm). They also found that the position of the left lip commissure changed by (0.65mm), whereas the position of the right lip commissure changed by a mean of (1.20 mm), which was close to our findings. However, Kim et al. found a positive change of (0.43 ± 1.24 mm) at the nasion point, which did not change in our study.

Although we found positive and negative correlations between the amount of expansion and most of the facial soft tissue variables, these correlations did not reach a significant level. Only the mouth width showed a moderately significant positive correlation with the jackscrew activation.

Conclusion:

Significant changes in the nasal region and the upper lip region were found after RME and six months of retention, and a significant positive correlation between mouth width and the amount of expansion was also observed. The outcomes show that rapid expansion causes significant soft tissue changes on the surface of the face. While our results are a good starting point, further investigations with larger sample sizes and suitable controls are necessary to allow generalizable statements about soft tissue responses after RME, especially in the long run for such measurements.

3.2. Second Prospective Clinical Study

Post-operative facial soft tissue changes after bimaxillary surgery using a 3D- handheld structured-light scanner

Our sample consisted of 12 patients (6 males and 6 females), with a mean age of (22±2.17 years, a range of 19.6-24.5). Those patients came to our department, under a functional or aesthetic compliment, with skeletal class III malocclusion as the main disorder of their craniofacial deformities, which included one of the following; anteroposterior skeletal discrepancy, cleft lip and palate, facial asymmetry and craniofacial syndromes, all of them were Caucasian ethnic background, with no further anticipated growth, and went onto receive full comprehensive orthodontic-orthognathic treatment including the pre-surgical orthodontic treatment, planning for the surgical stage, the orthognathic surgery, and the post-surgical orthodontic treatment.

The 3D facial images were acquired one week before surgery (T_0) and 6 months after surgery (T_1) using a 3D handheld structured-light scanner (Artec Eva^{TM}). All images were taken with the head in a natural head position, teeth in centric occlusion, and lips in repose, and slightly closed eyes

Data processing and measurements

In total 20 landmarks, 13 linear and 6 angular measurements were located and measured directly on the 3D facial images (Intercanthal width, nasal and nasal base width, mouth width, nasal height, both the upper and lower lip vermilion and total height, chin height, and also the lower anterior facial height).

Similarly, 6 angular measurements (Nasal tip angle, both the upper and lower lip angle, the inter-labial angle, nasolabial angle, and the labio-mental angle) were calculated using Artec Studio V.12 software.

For the 3D deviation analysis, The images obtained at the T_0 time point were aligned with the images taken at T_1 using the best-fit method, and the deviation analysis was performed in seven morphological regions of the face (The total face, the upper and lower face, the upper and lower lip, the nose and the chin region). We also calculated the soft tissue deviation in several facial landmarks directly on the 3D inspected meshes.

Results

We found a statistically significant increase in the nasal width and widening of the alar bases after bimaxillary osteotomies (2.31mm and 2.02 mm $p<0.05$) respectively, significant increases in both the upper lip high and the upper lip vermilion height (1.47and 2.31mm) respectively.

We also found a significant decrease in the lower lip height (-1.9mm, $p<0.05$), the lower anterior facial height was also significantly increased by (1.4mm, $p<0.05$).

In regards to our angular measurements, we found a significant increase in the nasal tip angle and the lip angle (7.36 and 10.46 º, $p<0.05$) respectively, and a decrease in the Inter-labial angle (-8.81°, $p<0.05$)

We found facial soft tissue changes in the upper and lower face regions and also in the nasal region with a mean of (0.77, 0.67, and 1.03mm) respectively.

While the highest magnitude of the soft tissue changes was found in the upper lip region with a mean deviation (3.25mm). In regards to the lower lip and chin regions, we noticed soft tissue decreases with a mean of deviation (-1.21mm,-1.66mm) respectively.

We also found soft tissue changes at the level of the facial landmarks, especially at the level of (Bilateral Alar and Alar curvature points, Pronasal, Subnasal, Labiale superius, Labiale Inferius, pogonion, and Soft Tissue Menton).

Discussion

The timing of the soft tissue analysis is very critical. A period lasting 6 months after bimaxillary surgery was chosen as the T_1 stage since sufficient facial soft tissue stabilization is required to occur during this time, any subsequent modifications, such as post-operative swelling, soft tissue remodeling should be minor enough to be insignificant. Oh, and co-workers reported important changes in soft tissue 2 to 6 months after surgery and found that 6 months after surgery will be ideal for improved assessment.

To keep the malocclusion type and surgeon-related factors out of inclinations, the subjects were limited to those with skeletal class III, and all operations were performed by one surgeon (J.P.).

We couldn’t perform further analyses considering gender because of the small sample size in our study. However, C.-M. Chen and colleagues found no sex-related differences in soft tissue changes in patients with mandibular prognathism after orthognathic surgery.

Soft tissue changes

We found a statistically significant increase in the nasal width and widening of the alar bases after bimaxillary osteotomies. We can explain these increases by the remodeling and relocation of the surrounding muscles. Our results contribute to the results of Baik and colleagues who found 2 mm of nasal width increase after maxillary advancement and mandibular setback. While Altman and Oeltjen noted that all Le Fort I osteotomies cause widening of the alar bases because of the retraction of perioral muscles around the maxilla which results in detachment from their insertions during maxillary surgery.

No significant changes neither in the intercanthal width nor in the mouth width were found in our study, and that was also noted in the study of Baik and colleagues, who concluded that the increase in the lip length in some parts of the upper lip was produced by stretching the soft tissues.

In regards to the vertical plane, we found significant increase in the upper lip height, which can be explained by relocation of the orbicularis oris muscle and soft tissue tension in the upper lip region. Marsan and co-workers found elongation in the upper lip after bimaxillary surgery in their sample.

In our study, we found a statistically significant decrease in the lower lip height. The upward and backward movement of the mandible may play a role in this regard. A similar result was also found in the study of Marsan and colleagues. While the findings of Kim and colleagues suggested that the lower lip could be under the influence of the muscle rather than the bone, and this might be related to the inherent differences in soft tissue between lip and chin.

In regards to the angular measurements, we found a statistically significant increase in the Nasal tip angle, which could be affected by the lateral movements of the alar landmarks and the increase in the nasal and nasal base width, due to the relocation of the nasalis muscle after surgery.

We also noticed a decrease in the Inter-labial angel, which also can be explained by the relocation of the orbicularis oris muscle, the upper and lower lips after bimaxillary osteotomies. While the significant increase found in the Lower lip angle after bimaxillary surgery could refer to the movement of the /Li/ landmark.

We can interpret the decrease found in our study in the Labio-mental angle after surgery by the backward and upward movement of the lower lip.

Al-Gunaid and colleagues found an increase in the nasolabial angle, a decrease in the labio-mental angle, and an improvement of the dentofacial aesthetics, they also reported that the soft tissue facial profiles and the posture of the lips were improved.

For better analysis of the facial changes by involving the whole facial regions in our post-operative study instead of being admired to just some linear and angular measurements, we calculated the deviation analysis on the facial meshes in seven morphological regions of the face. Although the high positive and negative deviation limits observed in the total face region in our study, the mean deviation of all landmarks forming this region didn't exceed (0.52±0.25mm), this small magnitude can be explained by the multidirectional soft tissue changes in the facial parts forming the overall facial envelope. Previous studies reported more soft-tissue movement in the central parts than in the lateral parts with bimaxillary surgery.

We found facial soft tissue changes in both the upper face and lower face regions with a mean of (0.77, 0.67mm) respectively, while the mean deviation at the nasal region was (1.03mm). Gjorup and co-workers found that no changes appeared in the cheeks, and they refered that the influence of the muscles and soft tissue tension decreased as the distance from the area where the hard tissue changes increased.

The highest magnitude of the soft tissue changes was found in the upper lip region with a mean deviation (3.25mm), while the Lower lip and Chin regions decreased with a mean deviation of (-1.21mm,-1.66mm) respectively.

Baik et al. suggested that the semicircular shapes of the maxilla and the mandible correspond to the fewer changes in the sub-commissural region, a lateral part, than in the labio-mental or chin region, a central part.

We also calculated the deviation on the facial landmarks after the surface comparison. The magnitude of deviation at the level of bilateral Alar points (1.26, 0.85mm) for the right and left respectively, emphasizes the lateral and anterior movement that we previously mentioned.

A similar movement can be anticipated at the level of bilateral Alar curvature landmarks (1.36, 1.14mm), indicating soft tissue changes in the nasal region, along with the deviation noticed at the level of Pronasal and subnasal (1.93 and 3.83mm) respectively.

Regarded the upper lip area, a positive deviation (3.44mm) was found at the level of Labiale Superius landmark, indicating Anterior moment of this point after bimaxillary surgery. While deviations at the level of (Labiale Inferius, Soft tissue pogonion, and Soft tissue Menton; -3, -2.5, -1.3 mm) respectively, were reported in our study, which may indicate a posterior movement of the soft tissue in both the lower lip and chin regions after bimaxillary osteotomies, and confirm our previous results in the linear and angular measurements.

Even though the sample size is small, which is one of the limitations, our study is giving relevant and important information regarding three-dimensional soft tissue changes. It would be a great advancement for the clinical research to consider the gender-related effects of bimaxillary surgery on the facial soft tissue within a larger sample size.

Conclusion

In our present comprehensive 3D-evaluation, we succeeded to quantify and visualize the post-operative soft tissue changes after 6 months of bimaxillary surgery. Bearing in mind the limitations of the small sample size, the middle third of the face, especially the nose and upper lip will be influenced by bimaxillary surgery compared to the other facial structures. This must be taken into account in the course of treatment planning and that patients must be informed accordingly. Further investigations with larger sample size and appropriate controls are necessary for a more accurate evaluation of soft tissue responses after bimaxillary surgery

4. Conclusion of the research

- 3D handheld structured- light scanner seems to be an effective method in maxillofacial orthopedics, especially for prediction of the soft tissue changes during the conservative and surgical correction of the craniofacial anomalies.
- Statistically significant soft tissue changes were found in various morphological regions of the face during our orthodontic and surgical treatment of the craniofacial deformities in all 3D planes of space, especially in the middle third of the face, the nose and upper lip regions.

5. Recommendations

- Further investigations with a larger sample size and appropriate controls are necessary for a more accurate evaluation of the facial soft tissue changes during the orthodontic and surgical treatment.
- More studies to predict the correlation between the hard and soft tissue changes after merging CBCT scans, intraoral and facial 3D scans to visualise a 3D virtual patient.
- Further studies to inspect the accuracy of 3D handheld structured-light scanner in maxillofacial orthopedics.
- Further studies for soft tissue evaluation using other types of 3D scanning methods, taking into consideration the facial expression and the jaw motion during our treatment.