RESEARCH

Pharyngeal airway space and frontal and sphenoid sinus changes after maxillomandibular advancement with counterclockwise rotation for class II anterior open bite malocclusions

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Objectives: The purpose of this study was to cephalometrically evaluate the pharyngeal airway space and frontal and sphenoid sinus changes after maxillomandibular advancement counterclockwise rotation for class II anterior open bite malocclusion.

Methods: The study included 49 patients (98 lateral telerradiographs; 36 females and 13 males) who were analysed in the pre-operative (1 week before surgery) and post-operative (6 months after surgery) periods. In each lateral telerradiography, the dimensions of the inferior and superior pharyngeal airway space, TB-PhW1 [the point between the posterior aspect of the tongue to the dorsal pharyngeal wall (oropharynx) (TB) and the point on the dorsal pharyngeal wall closest to TB (PhW1)] and UP-PhW2 [and the point between the posterior aspect of the soft palate to the dorsal pharyngeal wall (nasopharynx) (UP) (PhW2)] measurements were evaluated, as well as the dimensions of the frontal and sphenoid sinuses. The differences between the two operative times were evaluated by Student's *t*-test.

Results: All measurements showed excellent reproducibility for the intraclass correlation coefficient (ICC > 0.9; *p* < 0.0001). There was an increase in the measurements TB-PhW1 and UP-PhW2 and a decrease in the dimensions of the frontal and sphenoid sinuses after orthognathic surgery.

Conclusions: The morphology of the superior and inferior pharyngeal airway space and frontal and sphenoid sinuses changes after 6 months of maxillomandibular advancement counterclockwise rotation for class II anterior open bite malocclusion.

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Introduction

Malocclusions and craniofacial deformities are morphological alterations related to the growth and development of the facial skeleton resulting from genetic polymorphisms that change the harmony of the craniofacial complex.¹

Angle class II malocclusion is the most common dentofacial deformity, characterized by the retrusive

position of the mandible in relation to the maxilla or by mandibular atrophy.²

Orthognathic surgery is capable of correcting dento-facial discrepancies and modifies the maxillomandibular relationship.³ Surgical procedures such as mandibular advancement and mandibular setback modifies the dimensions of the pharyngeal airway space^{3–6} and changes the air flow patterns, but its effects on dimensions of other areas of the craniofacial skeleton, such as the paranasal sinuses, are almost unknown.⁶

Mavropoulos⁷ affirmed that mechanical forces generated by masticatory muscles stimulate bone tissue formation directly or indirectly, showing an intrinsic

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relationship between dissipation of masticatory forces and craniofacial skeleton shape.

Because of the maxillomandibular changes caused by orthognathic surgeries and the direct relationship between masticatory force and craniofacial shape, the aim of this study was to evaluate the morphological changes of the pharyngeal airway space and the frontal and sphenoid sinuses after maxillomandibular advancement counterclockwise rotation for class II anterior open bite malocclusion.

Materials and methods

Sample

A total of 98 lateral telerradiographs of 49 patients (36 females and 13 males) with angle class II malocclusion with anterior open bite who had been submitted to maxillary and mandibular advancement surgery with counterclockwise rotation were analysed.

Pharyngeal airway space and frontal and sphenoid sinus dimensions were evaluated, comparing the periods of 1 week before and 6 months after maxillomandibular advancement with counterclockwise rotation. The mean age of patients was 26.5 years (± 4.4) for females and 24.8 years (± 3.4) for males.

The following inclusion and exclusion criteria were used in this study:

- only patients with complete permanent dentition and absence of other craniofacial deformities, syndromes or abnormalities were selected as any change in bone physiology as well as the positioning of bony structures could interfere with the results;
- the diagnosis of angle class II malocclusion with anterior open bite was performed based on clinical, radiographic and dental cast analysis;
- in all cases, the maxilla was fixed with 04 plates of the 2.0 system and the mandible was fixed with plates and bicortical screws; and
- patients with basilar osteotomy of the chin, turbinectomy or genioplasty concomitant with maxillary and mandibular advancement surgery were excluded from this study.

Patients had radiographic examinations before and 6 months after surgery, which were performed under the same conditions using the same radiographic equipment. Lateral cephalometric radiographs were obtained with the patient's head in the cephalostat position according to the following orientation: Frankfort horizontal plane parallel to the floor and mid-sagittal plane perpendicular to the horizontal plane; teeth in maximal intercuspitation; lips relaxed and in the natural position; vertebral column erect; olives of the cephalostat encased in the external acoustic meatus and nasion of the cephalostat in the region of the frontonasal suture corresponding to the nasion point. This positioning is

recommended for obtaining lateral telerradiographic images and made it possible to standardize them and record them at different periods.

Evaluation of the superior and inferior pharyngeal airway space and craniofacial skeleton

The lateral telerradiographs were copied by a scanner with a transparency reader, Arcus II® from AGFA (Agfa-Gevaert, NV, Mortsel, Belgium), with a fixed resolution of 1200 dpi and 100% scale in the Sharp Black and White Photo mode. They were then transferred to the software Corel 8 Photo-Paint® (Corel Corporation Limited, Dublin, Ireland), which was responsible for the capture and new transfer of the image to the software Radiocef 2.0® (Radio Memory Ltda., Belo Horizonte, MG, Brazil) where the following points were traced and measured:

Skeletal points:

- sella (S)—point situated in the geometric centre of the sella turca;
- nasion (N)—most anterior point of the frontonasal suture;
- menton (Me)—point located at the intersection between the outer cortical bone of the menton and the lower cortical bone of the mandibular body;
- anterior nasal spine (ANS)—point situated at the end of the anterior nasal spine;
- gonion (Go)—point located at the intersection of the angle bisector formed by the tangents of the posterior and inferior borders of the mandible with the gonial angle;
- point A—deepest point of the outline of the premaxilla located between the ANS and porion; and
- point B—deepest point in the most internal part of the contour of the mandible in the region between the incisors and Me.

Pharyngeal points according to Ramesh *et al*⁸:

- TB—point between posterior aspect of the tongue and the dorsal pharyngeal wall (oropharynx);
- UP—point between the posterior aspect of the soft palate and the dorsal pharyngeal wall (nasopharynx);
- PhW1—point on the dorsal pharyngeal wall closest to TB (oropharynx); and
- PhW2—point on the dorsal pharyngeal wall closest to UP (nasopharynx).

The linear measurement between TB and PhW1 was calculated parallel to the Frankfort horizontal plane pre-operatively and post-operatively at an interval of 6 months. Similarly the linear measurement between UP and PhW2 was calculated parallel to the Frankfort horizontal plane pre-operatively and post-operatively at an interval of 6 months. Pre-operative and post-operative SNA (the angle formed by S, N and point A), SNB (the angle formed by S, N and point B) and

gonial angles were measured and recorded. Similarly pre-operative and post-operative linear measurements for Me-ANS (lower anterior facial height), Me-N (anterior facial height) and S-Go (posterior facial height) were measured and recorded. Figure 1 shows a diagram of a lateral cephalometric image with all the relevant anatomic landmarks labelled.

All linear and angular measurements and areas of the frontal and sphenoid sinuses were performed three times by the same examiner with an interval of 2 weeks between each measurement.

Methods for evaluating the areas of the frontal and sphenoid sinuses

The contour of the frontal and sphenoid sinuses of each lateral teleradiograph was outlined on a sheet of tracing paper on a table X-ray viewer (Konex®, São Paulo, Brazil; 25 × 30 cm), according to the criteria of Ertürk⁹ and Ferreira and Oliveira¹⁰ (Figures 2 and 3). A standard reference measure of 1 cm required for application of the software was also added.

Based on the outline of the frontal and sphenoid sinus areas, the images were digitized on a Scan Maker II SP scanner with a transparency reader (Microtek International, Inc., Hsinchu, Taiwan) and were calibrated for greyscales with a 300 dpi resolution and

Figure 1 Diagram of lateral cephalometric image with all the relevant anatomic landmarks labeled. A, deepest point of the outline of the pre-maxilla located between the anterior nasal spine and porion; B, deepest point in the most internal part of the contour of the mandible in the region between the incisors and Me; Go, gonion; Me, menton; N, nasion; PhW1, point on the dorsal pharyngeal wall closest to TB; PhW2, the point on dorsal pharyngeal wall closest to UP; S, sella; TB, point between posterior aspect of tongue to dorsal pharyngeal wall (oropharynx); UP, point between posterior aspect of soft palate to dorsal pharyngeal wall (nasopharynx)

Figure 2 Outline of the periphery of the frontal sinus on lateral cephalograms according to criteria of Ertürk.⁹ N, nasion point; S, sella point; Sh, most superior point of the frontal sinus contour; SI, most inferior point of the frontal sinus contour

100% image size. Later the images were differentiated into distinct colours using Microsoft® paint version 5.1 software (Redmond, WA) to facilitate their analysis.

After definition of the frontal and sphenoid sinus areas in each teleradiograph, these areas were calculated and the number of pixels was converted into square centimetres by SIARCS@ 3.0 software (Integrated System for Roots and Soil Coverage Analysis, Embrapa Agricultural, Instrumentation Brasília, DF, Brazil).

Analysis of data

The data were submitted to Student's *t*-test with a 5% level of significance using BioEstat 5.0 software (Mamirama Foundation, Belém, PA, Brazil). The reproducibility of measurements was determined by the intraclass correlation coefficient (ICC).

Results

The difference between the male and female mean age was not significant (*t*-test, $p = 0.2174$). All linear and

Figure 3 Outline of the periphery of the sphenoid sinus on lateral cephalograms according to criteria of Ferreira and Oliveira¹⁰

Figure 4 Means ($\pm$ standard deviation) of the measurement of the point between posterior aspect of tongue to dorsal pharyngeal wall (oropharynx) (TB) and point on the dorsal pharyngeal wall closest to TB (PhW1) and the measurement of UP and the point on dorsal pharyngeal wall closest to the point between the posterior aspect of soft palate to dorsal pharyngeal wall (nasopharynx) (UP) (PhW2) at the two operative periods (*t*-test)

angular measurements presented excellent reproducibility ($ICC > 0.9$; $p < 0.0001$), indicating that the measurements taken by the operator were reproducible and reliable. Figure 4 shows the means of the pre- and post-operative measurements of TB-PhW1 and UP-PhW2. The analysis of data (*t*-test) demonstrated statistically significant differences between two operative periods considering TB-PhW1 ($p = 0.0007$) and UP-PhW2 ($p < 0.0001$) measurements. Figures 5 and 6 showed the means for pre- and post-operative for the SNA, SNB and Go measurements, respectively.

Highly significant differences were observed between the two operative periods for SNA and SNB ($p < 0.0001$) measurements. However, there was no statistically significant difference between the two operative periods for Go measurement ($p = 0.1184$).

Figure 5 Means ($\pm$ standard deviation) of measurements of the angle formed by sella point (S), nasion point (N) and point A, the angle formed by S, N and point B, and gonial at the two operative periods (*t*-test). Point A, deepest point of the outline of the premaxilla located between the anterior nasal spine and porion; point B, deepest point in the most internal part of the contour of the mandible in the region between the incisors and menton

Figure 6 Means ($\pm$ standard deviation) of the measurements of anterior nasal spine (ANS)-menton (Me), Me-nasion (N) and sella (S)-gonion (Go) at the two operative periods (*t*-test)

Figure 6 shows the means of the pre- and post-operative for the ANS-Me, Me-N and S-Go measurements.

The analysis of the results showed that ANS-Me, Me-N and S-Go measurements do not show statistically significant differences between the two operative periods (*t*-test, $p > 0.05$). Figure 7 shows the means of the measurements of the frontal and sphenoid sinus areas before and after surgery.

The analysis of the results shows that the frontal and sphenoid sinus measurements showed highly significant differences between the two operative periods (*t*-test, $p < 0.0001$).

Discussion

Pharyngeal airway space is a three-dimensional (3D) structure and was evaluated by radiographic cephalometry because this method allows direct visualization and easy execution, is low cost and provides minimal radiation exposure.¹¹ Validation of this method was obtained by the optimal correlation between pharyngeal airway space dimensions measured using lateral telerradiographs, a two-dimensional method and 3D CT.¹² Currently both lateral cephalometric radiography and 3D CT have been clinically used for orthognathic surgery and otolaryngologists in a sleep apnoea context.¹³

Normal values of the inferior pharyngeal airway space in telerradiographs were determined as 10 mm to 12 mm.¹⁴ In the present study there was a significant increase in inferior pharyngeal airway space dimensions post-operatively ($p = 0.0007$), which increased from 11.89 mm to 13.63 mm. Inferior pharyngeal airway space changed after 6 months of maxillomandibular advancement counterclockwise rotation for class II anterior open bite malocclusion. Previous studies^{15,16} reported a dimensional increase in inferior pharyngeal airway space after maxillomandibular advancement.

Figure 7 Means ($\pm$ standard deviation) of the means of the frontal and sphenoid sinuses before and after surgery (*t*-test)

Pereira Filho *et al*¹⁷ showed an enlargement of inferior pharyngeal airway space in 70% of the cases produced by the anterior repositioning of the supra-hyoid musculature and hyoid bone. Inferior pharyngeal airway space is surrounded by soft tissue and mandible depending on the volume and position of the tissues.¹¹ The amount of mandibular ramus in the antero-posterior direction determines the major or minor increase in inferior pharyngeal airway dimensions.⁵

The normal value for the superior pharyngeal airway space based on skull lateral telerradiographs is 17.4 mm.¹⁰ In the present study the superior pharyngeal airway space increased from 17.82 mm to 20.23 mm after surgery. The superior pharyngeal airway morphology changed 6 months after surgery. Similar results were reported previously.^{1,15,17} Such findings can be attributed to the advancement of the soft palate and pharynx after maxillary advancement.¹⁸

The results of the present study do not state that changes in the pharyngeal airway space are permanent. Although 6 months is probably too short an interval to provoke permanent changes in airway space, it still remains a controversial result in the scientific literature. Similarly, longitudinal studies^{19,5} observed an increase in pharyngeal airway dimensions from 6 months to 14 months after maxillomandibular advancement. Other studies⁴ observed a reduction in the dimensions of pharyngeal airway space 12 years after surgery. Achilleos *et al*²⁰ evaluated cephalometric radiographs pre-operatively and post-operatively (6 months and 3 years) of patients who underwent mandibular advancement and observed a more superior and anterior position of the hyoid bone and an increase in oropharyngeal airspace in the post-operative period.

One of the current clinical indications of maxillomandibular advancement surgery is the treatment of obstructive sleep apnoea patients.¹⁶ The results of this study can be helpful and valuable for orthognathic

surgery and otolaryngology in the sleep apnoea area. Maxillomandibular advancement surgery increases the pharyngeal airway space and strengthens the supra-hyoid and palatopharyngeal musculature to alter its bone fixations.^{16,21} This morphological change interrupts the repetitive collapse and consequently reduces hypopnoea and apnoea, normalizing the cardio-respiratory functions.²¹

There are no records about dimensional changes of the frontal and sphenoid sinuses 6 months after maxillary and mandibular advancement surgery with counterclockwise rotation for class II correction. The frontal and sphenoid sinus morphology has never been employed as a reference point for the evaluation of the morphofunctional changes resulting from modifications in the maxillomandibular relation. The results of this research show very small changes in the frontal and sphenoid sinus morphology statistically related with maxillomandibular advancement counterclockwise rotation for class II anterior open bite malocclusion.

The biological role of the paranasal sinuses is not well understood. Two sets of proposals have been put forward to explain the possible functions of the paranasal sinuses. While some are convinced that the sinuses contribute to respiratory physiology, others regard these structures to have been developed in response to the biomechanical necessities of skull architecture.^{22,23} The relationship between skull morphology and pneumatization is not clear.

The craniofacial skeleton is formed of interrelated skeletal units where the modifications that occur in one region affect other distant areas.^{7,24} Masticatory forces act on the craniofacial skeleton, remodelling and modifying its structure.²⁵ Based on those concepts, Throckmorton and Ellis²⁶ affirm that after orthognathic surgery a more harmonic maxillomandibular relationship is established. This harmony promotes a significant improvement in the performance of the stomatognathic system with an increase in the number of occlusal contacts and strength of bite that can favour the dissipation of tension by the craniofacial skeleton.²⁶

Diminution of the frontal and sphenoid sinus areas (Figure 7) after maxillomandibular advancement with counterclockwise rotation for class II anterior open bite malocclusion can also be attributed to the bone remodelling. After surgery, a new maxillomandibular relationship is established and the number of occlusal contacts favouring the transmission of the mechanical stress is increased.^{23,26} It should be pointed out that paranasal sinuses are functional spaces surrounded by thin walls of compact bone located between skull bony pillars.²³ The new maxillomandibular relationship represents a response to biomechanical requirements of the craniofacial architecture²² and masticatory stress.¹²

Bony tissue is highly organized and complex and is composed of an extracellular matrix, organic and inorganic components, and cells which are responsible for its maintenance.¹⁵ The principal function is to provide structural resistance suitable for functional demand.

Bones adapt extraordinarily well to functional changes.⁴ The skull works synergistically with the masticatory muscles, articulations and teeth,⁵ and mechanical forces are the key element for the bone formation.²⁷ Those aspects²⁶ can explain the dimensional changes in the frontal and sphenoid sinuses in the present study.

We also considered that the small changes in the sinuses size may be caused by change in air flow patterns. Patients with class II maxillomandibular relationships are the most common type of patients with nasal airway obstruction (secondary to hypertrophied turbinates and/or nasal septal deviation or spurring) and decreased oropharyngeal airway. After counterclockwise rotation of the maxillomandibular complex, the nasal airway should be more open and the posterior nasal airway will be significantly improved. Any patients undergoing orthognathic procedures could also have turbinectomies or nasal septoplasties performed at the same time as these procedures would contribute to improvements in the nasal airway. Thus, change in air flow patterns may be another plausible reason for changes in the frontal and sphenoid sinuses at 6 months post surgery.

Procedures such as maxillary advancement have a potentially beneficial effect on breathing because they increase the nasopharyngeal space, widen the nasal valve and make the nasal septum vertical, thus enhancing nasal respiration.^{28–31} Obstructive sleep apnoea is the most common sleep-related breathing disorder with periodic reduction or cessation of airflow during sleep.

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