Journal of Forensic Radiology and Imaging 12 (2018) 64–67

Contents lists available at ScienceDirect

Journal of Forensic Radiology and Imaging

journal homepage: www.elsevier.com/locate/jofri

Lack of significant volumetric alteration after rapid maxillary expansion supports the use of frontal sinuses for human identification purposes

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ARTICLE INFO

Keywords:
Computed tomography
Frontal sinus
Human identification
Rapid maxillary expansion

ABSTRACT

Aim: The present study aimed to assess the volume of the frontal sinuses before and after rapid maxillary expansion (RME).

Material and methods: The sample consisted of 12 subjects (8 females and 4 males) with maxillary deficiency aged between 10 and 15 years old. In order to treat the skeletal deficiency, RME was performed using Hyrax system. Cone Beam Computed Tomography (CBCT) scans were obtained from each subject before (T1) and 120 days after (T2) the RME. A table digitizer G-Pen F350 (Genius, Taipei, Taiwan) was used to select the area of the frontal sinuses in CBCT slices. The volume of the sinuses was quantified in T1 and T2. T-test for paired samples was used to compare the differences between the volume of the frontal sinuses before and after RME

Results: The mean volume of the frontal sinuses before and after the RME was 3.03 mm^3 (ranging from 2.20 mm^3 to 4.40 mm^3) and 3.21 mm^3 (ranging from 2.55 mm^3 to 4.52 mm^3), respectively. Differences in volume between T1 and T2 were not statistically significant ($p > .05$). The present study indicates that the frontal sinuses do not modify considerably in volume after RME.

Conclusion: From the forensic scope, this outcome supports the usefulness of the frontal sinuses for ante-mortem and post-mortem comparisons in human identification cases.

1. Introduction

The frontal sinuses consist of cavities in the frontal bone. In general, these sinuses develop around the second year of age and become visible radiographically three years later [1]. Nearly the second decade of life, the frontal sinuses grow with a more complex morphology and reach complete development [1]. The scientific literature considers the pattern of frontal sinus morphology highly distinctive among subjects [2]. For that reason, these sinuses are investigated for human identification purposes [2].

In the forensic routine human identification is founded on comparisons between ante-mortem (AM) and post-mortem (PM) data [3]. The comparisons usually include fingerprint, dental or DNA data. In 1921, radiographs of the frontal sinuses were compared for the first time for human identification [3]. Currently, they are assessed to strength the similarities between AM and PM data and consequently to support the identification process with more evidence [4]. Matching frontal sinuses AM and PM depends mainly on the medical images available and the morphology of the sinuses. While in one hand computed tomography became a powerful tool available in the forensic practice [5], on the other hand the morphology of the sinuses remained uncertain in individuals that undergo orthopedic procedures in the face.

The rapid maxillary expansion (RME) figures among the most invasive non-surgical procedures in the face. Especially in Dentistry, RME is performed to expand the maxilla through the separation of the median palatal suture [6]. The skeletal effects of this procedure involve not only sutures in the maxilla and palatal bones but also in the nasal, zygomatic and frontal bones [7]. Subjects treated with RME have the airways enlarged and breathing improved [8].

Based on the skeletal effects of the RME and on the importance of the frontal sinus for comparative human identifications, the present research aimed to assess the volume of the frontal sinuses before and after RME. Up to the present date no similar study was found in the scientific literature.

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https://doi.org/10.1016/j.jofri.2018.02.008
Received 24 September 2017; Received in revised form 14 February 2018; Accepted 20 February 2018
Available online 01 March 2018

2. Material and methods

The initial sample consisted of 424 subjects aged between 10 and 15 years old treated at a dental clinic in Brazil. These subjects underwent sampling based on the following inclusion criteria: maxillary deficiency, posterior crossbite, no systemic disease and no medical history of facial trauma. The exclusion criteria consisted of deciduous molars in the mandibular arch, missing maxillary permanent first molars, metallic restorations in the maxillary permanent first molars; periodontitis; previous orthodontic treatment; surgery in the frontal sinuses; evident facial asymmetry and malnutrition. After applying the eligibility criteria, the final sample consisted of 12 Caucasian subjects (8 females and 4 males, mean age: 12.4 years ± 1.4 years).

The subjects underwent RME using Hyrax system with 4 orthodontic bands (attached in the first premolars and first molars). The orthodontic/orthopedic system was installed and activated with a complete turn. During the treatment, the device was activated daily in the morning and in the evening (¼ turn each). The treatment was conducted until the palatal cusps of the maxillary first molars touch the vestibular cusps of the mandibular first molars. Once the treatment was concluded, the device was kept stable for 120 days as an orthodontic retained. During this period the subjects was monitored monthly. Opening of the palatal suture was confirmed clinically with the midline diastema in the maxilla. After retaining for 120, the orthodontic system was removed.

Cone-Beam Computed Tomography (CBCT) scans were obtained from each patient before (T1) and after (T2, when the system was removed) RME (n = 24). ICat Vision™ (Imaging Sciences International, Hatfield, PA, USA) device was used with 120kVP, 37mAs, time of acquisition of 14.7 s, 0.2 voxel size and slice thickness of 0.5 mm. The CBCT scans were imported as DICOM files in OsiriX® v.5.5.2 32-bit (Pixmeo, Geneva, Switzerland) software package. Sella-nasion distance was used as reference to set the position of the image and establish the area of interest in sagittal slices (Fig. 1). With the area of interest established in three dimensions, a 2D/3D segmentation tool provided by the software was used. To quantify the volume of the sinuses, the minimum threshold was set in −1.000 and the maximum in −400 (Fig. 2). It is important to note that because the subjects sampled were younger than 20 years of age (the frontal sinuses are still developing), normal growth rates expected during the 120 days after RME were consulted in the scientific literature [9] (Table 1) and reduced from the final volume of the frontal sinuses. All the measurements taken in the software were performed twice with an interval of 20 days. Intra-examiner agreement was calculated. Finally, the morphology of the frontal sinuses of each individual was classified according to Guerram et al. [10].

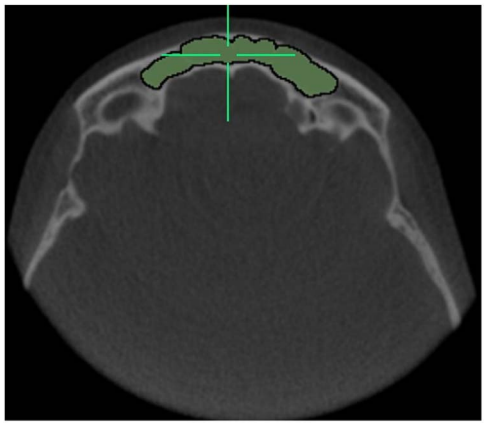

Fig. 2. Axial slice showing the frontal sinuses highlighted and selected for the quantification of volume.

Table 1
Frontal sinus growth according to Yun et al. [9].

Age	Mean volume	Annual growth	Growth in 4 months
10	1.98	–	–
11	2.36	19.2	6.4
12	3.28	39.0	13.0
13	4.61	40.5	13.5
14	5.48	18.9	6.3
15	5.73	4.6	1.5

Age expressed in years, mean volume expressed in mm^3, Annual and 4-month growth expressed in percentage (%).

To assess intra-examiner agreement, paired t-test was used. To determine the casual error intra-examiner Dahlberg's methods was adopted. The outcomes were expressed in tables as means and standard deviations of the sinus volume. Kolmogorov-Smirnov test was used to investigate sample normality. T-test for paired samples was used to compare the sinuses before and after RME. Statistica 13.0 (StatSoft Inc., Tulsa, USA) software package was used for all the statistical procedures considering a significance level of 5%.

3. Results

The systematic and casual errors intra-examiner are reported in

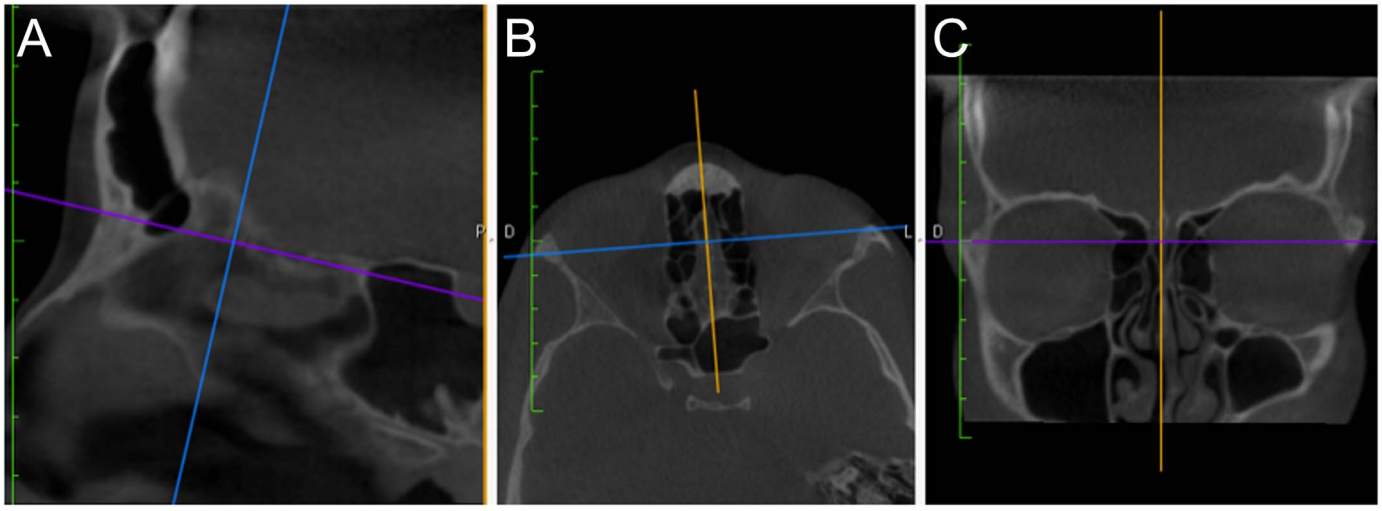

Fig. 1. Areas of interest set with the image positioned in the sagittal (A), axial (B) and coronal (C) views based on the Sella-Nasion line.

Table 2
Mean, standard deviation, paired t-test and Dahlberg's error outcomes expressing the systematic and casual errors.

Measurement	1st measurement		2nd measurement		*t*	*p*	Error
	mean	SD	mean	SD			
Before RME	3.03	0.84	2.97	0.87	0.136	0.136	0.10
After RME	3.21	0.77	3.20	0.78	0.233	0.820	0.07

RME: Rapid maxillary expansion; SD: standard deviation; t and p: paired *t*-test values (statistical significance set at 0.05).

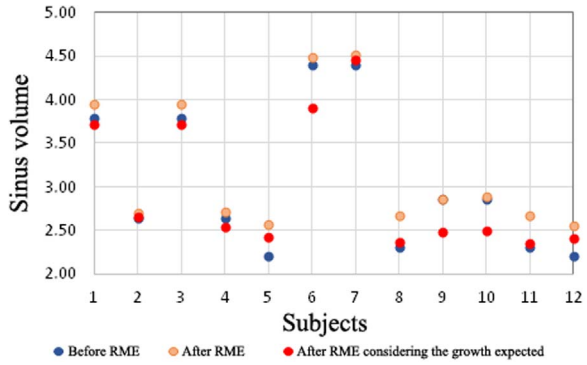

Fig. 3. Distribution of sinus volume before and after rapid maxillary expansion (RME) for each subject sampled in the present study.

Table 2. No differences statistically significant were observed between the first and second measurements of the sinuses before (p = .136) and after (p = .820) RME.

Individual data for each subject of the present study are reported in Table and Fig. 3. The volume of the sinuses before and after the RME ranged from 2.20 to 4.40 mm^3 and from 2.55 to 4.52 mm^3, respectively. (Table 3)

In Table 4 the outcomes of the comparison of the mean volume of the frontal sinuses before (3.03 mm^3) and after (3.21 mm^3) RME are expressed. Differences statistically significant were observed (p = .001).

In Table 5 the outcomes of the comparison of the mean volume of the frontal sinuses before (3.03 mm^3) and after (2.96 mm^3) RME are expressed. Specifically in this table, the natural growth expected in the subjects of the present study during the 4 months of observation is considered. Differences statistically significant were not observed (p = .304).

Table 3
Volume of the frontal sinuses before and after RME for each subjects sampled in the present study, their respective growth expected in four months and the final sinus volume.

Subject #	Sex	Age before RME	Age after RME	Volume before RME	Volume after RME	Expected growth*	Final volume
1	F	10y4m	10y8m	3.79	3.95	0.24	3.71
2	F	14y9m	13y1m	2.64	2.70	0.04	2.66
3	F	13y1m	13y5m	3.79	3.95	0.24	3.71
4	M	13y4m	13y8m	2.64	2.71	0.17	2.54
5	M	13y0m	13y4m	2.20	2.56	0.14	2.43
6	F	11y5m	11y9m	4.40	4.48	0.57	3.91
7	F	14y0m	14y4m	4.40	4.52	0.07	4.45
8	F	11y9m	12y1m	2.30	2.67	0.30	2.37
9	F	12y6m	12y10m	2.85	2.87	0.39	2.48
10	M	12y7m	13y1m	2.86	2.88	0.39	2.49
11	M	12y6m	12y10m	2.31	2.67	0.31	2.36
12	F	10y1m	10y5m	2.20	2.55	0.14	2.41

RME: rapid maxillary expansion; F: female; M: male; y: years; m: months; *: expected growth of the frontal sinuses according to Yun et al. [9]. Final sinus volume = volume measured in the present study + expected sinus growth.

Table 4
Comparison between the sinus volume before and after RME not considering the natural growth expected for each subject.

Before RME		After RME		t	*p*
Mean	SD	Mean	SD		
3.03	0.84	3.21	0.77	4.276	0.001*

RME: Rapid maxillary expansion; SD: standard deviation; t and p: paired t-test values (statistical significance set at 0.05).

Table 5
Comparison between the sinus volume before and after RME considering the natural growth expected for each subject.

Before RME		After RME		t	*p*
Mean	SD	Mean	SD		
3.03	0.84	2.96	0.75	1.077	0.304

RME: Rapid maxillary expansion; SD: standard deviation; t and p: paired t-test values (statistical significance set at 0.05).

Table 6
Classification of the frontal sinuses according to Guerram et al. [10].

Subject #	Classification	
	Age before RME	Age after RME
1	Medium	Medium
2	Medium	Medium
3	Medium	Medium
4	Medium	Medium
5	Hypoplasia	Hypoplasia
6	Medium	Medium
7	Medium	Medium
8	Medium	Medium
9	Medium	Medium
10	Medium	Medium
11	Medium	Medium
12	Hypoplasia	Hypoplasia

RME: rapid maxillary expansion.

In Table 6 the frontal sinuses of all the individuals sampled in the present study were classified based on their morphology. According to Guerram et a. [10] the sinuses were classified as medium-size in 10 subjects (83.33%) and with hypoplasia in 2 subjects (16.67%). The classification remained the same after RME.

4. Discussion

With the popularization of forensic radiology, the frontal sinuses became valuable tools for human identification in the routine of medico-legal services [5]. The distinctive morphology [2] of the sinuses between different individuals may support and confirm other primary means of identification, such as the comparison of dental data. Investigating the potential limitations behind the analysis of the frontal sinuses is an essential step in the contemporary forensic practice. The present study considered as null hypothesis the lack of alteration in the volume of the frontal sinuses after the RME.

The outcomes expressed after statistical analysis revealed a significant (p > .05) increase the volume of the frontal sinuses after RME. The scientific literature indicates that modifications occur in the lower third of the face, in the nasopharyngeal airway and in the maxillary sinuses after RME [11]. However, specific investigations in the behavior of the frontal sinuses after this procedure were not attempted previously.

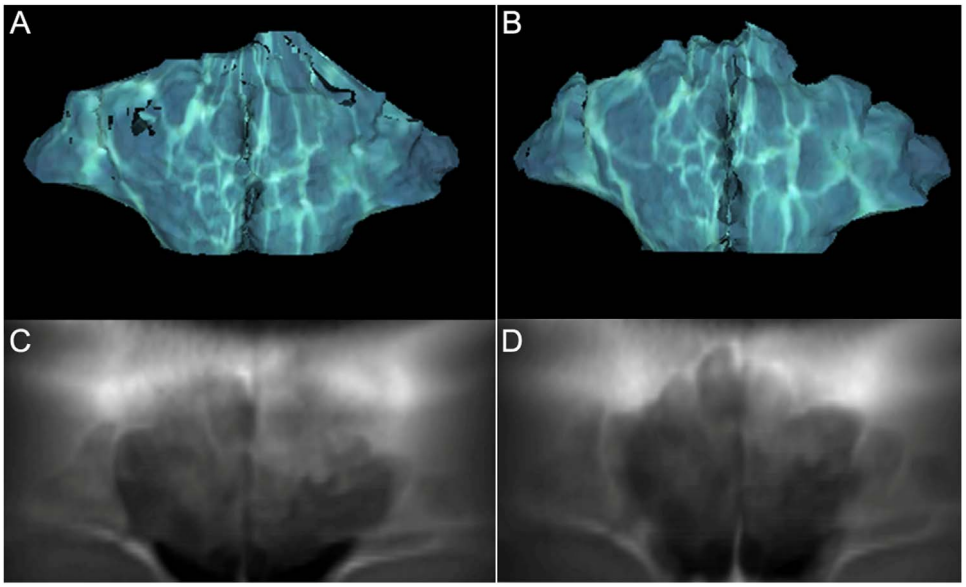

Fig. 4. Three-dimensional reconstructions of the frontal sinuses before (A and C) and after (B and D) rapid maxillary expansion and their anatomic relation with the adjacent bone in the frontal view.

Apart the increase in the volume of the frontal sinuses, it is important to note that the present study sampled subjects aged between 10 and 15 years old, which is an age range justified for RME treatment [6,7]. As expected, these patients are ongoing growth and development. Consequently, natural increase of the frontal sinuses is expected [9]. Knowing the mean natural growth of the frontal sinuses with age became important to overcome this limitation in the present study. Based on that, the scientific literature was consulted and the study performed by Yun et al. [9] was used as reference. In specific, the volume of the frontal sinuses measured in T2 was decreased considering the natural growth expected for each patient in a period of four months (time lapse between T1 and T2). Thus, according to the literature [9] the volume of the frontal sinuses in the age range of 10 and 15 years ranges progressively from 1.98 and 5.73 mm^3. The mean volume of the frontal sinuses observed in the present study was 3.03 mm^3. This outcome fits within the range described in the literature and suggests that despite the ethnical differences, the scientific literature may be used to predict the natural growth expected for each subject.

The lack of differences statistically significant in the volume of the frontal sinuses before and after RME supports and gives reliability for the forensic applications. Specifically, CBCT scans of the frontal sinuses may be matched for human identifications even if the supposed victim presents previous medical history of RME. However, it is highly important to note that despite not different with statistical significance, the morphology of the frontal sinuses may differ before and after RME with clinical importance in the forensic practice (Fig. 4). A single lobe enlargement or even reduction may hamper ante-mortem and post-mortem comparisons. In this circumstance, knowing the previous history of RME would allow classifying the sinuses within an explainable discrepancy. On the other hand, the lack of information of previous medical history would result in a non-explainable discrepancy and consequently hamper the human identification founded on the comparison of sinus morphology.

The frontal sinuses and their applications in the forensic practice should be investigated continuously in the future. Studies in the quantification of volume should be performed preferably in subjects in older age ranges, in which the natural growth expected is reduced; bidimensional radiographic investigations should be performed to support human identification in medico-legal institutes with less technological facilities and devices; the shape (outline) of the frontal sinuses should be investigated in association with the process of ageing; and the anthropological applications of the frontal sinuses should be explored (e.g. for the estimation of sex, age and ancestry).

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