Title

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Sphenooccipital Synchondroses and Vomer bone effects induced by Maxillary Skeletal Expander (MSE) and Hyrax appliance

A thesis submitted in partial satisfaction of the requirements for the degree

Master of Science in Oral Biology

by

Mohammed Rashed Alkahtani

2018

ABSTRACT OF THE THESIS

Sphenooccipital synchondroses and vomer bone effects induced by Maxillary Skeletal Expander (MSE) and Hyrax appliance

by

Mohammed Rashed Alkahtani

Master of Science in Oral Biology

University of California, Los Angeles, 2018

Professor Sanjay M Mallya, Chair

Introduction: The purpose of this retrospective study was to evaluate the skeleton changes induced by Maxillary Skeleton Expander (MSE) and Hyrax appliance in the Spheno-occipital Synchndroses and the vomer-bone using a Cone-Beam Computed Tomographic images (CBCT). Our hypothesis is that MSE and Hyrax result in dissimilar expansion pattern and magnitude especially in adult patients. Material and Methods: A novel methodology was developed to evaluate the changes of the SOS and vomer. Total of 23 patients were included in the study; 16 patients in the MSE group and 7 patients in the Hyrax group. CBCT scans were taken before (T0) and after treatment (T1) for every patient. The evaluation of the SOS and vomer-sphenoid joint were measured on the same CBCT cut before and after (T0:T1). The measurements of the surface area and the linear distance were recorded on both the sagittal and axial view. Dependent and independent means T tests as appropriate were used to evaluate differences in the treatment changes induced in the MSE group versus the Hyrax group. Results: A high statistical significance opening of the spheno-occipital Synchndroses were found in the MSE group despite older patients included in the treatment group. Hyrax group had younger patients and the SOS decreased. The junction between the vomer and sphenoid bone were larger in MSE and no changes were recorded in the Hyrax group.

Keywords:

Maxillary Skeletal Expander (MSE), Hyrax, maxillary expansion, skeletal changes, orthopedic effects, Sphenooccipital Synchondroses (SOS), Vomer, TADS, mini-implant, mini-screw, micro-screw, Rapid Palatal Expander (RPE), Bone-borne expander.

The thesis of Mohammed Rashed Alkahtani is approved.

Won Moon

Sotirios Tetradis

Sanjay M Mallya, Committee Chair

University of California, Los Angeles

2018

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List of abbreviations:

- RME: Rapid maxillary expansion
- MSE: Maxillary skeleton expander
- NS: Nasal septum
- S: Sella
- N: Nasion
- ANS: Anterior nasal spine
- PNS: Posterior nasal spine
- SOE: Slow orthodontic Expansion
- SARPE: Surgical assisted rapid palatal expansion
- MI: Micro implant
- Rt: Right
- Lt: Left
- Por: Porion
- MSP: Maxillary sagittal Plane

Acknowledgements

I would like to express my very great appreciation to all the people who collaborated in this research, offering their expertise and contributing to my professional growth. Particularly I would like to thank Dr. Won Moon for his expert advice and encouragement throughout this research project. I would like to thank the members of my committee, Dr. Sanjay Mallya and Dr. Sotirios Tetradis not only for their time and extreme patience, but for sharing their knowledge and agreeing to serve on my committee. I also would like to thank Dr. Daniele Canterella and Dr. Carolina Torres for their contribution in this thesis process. Finally, I am immensely grateful to my family for their unconditional encouragement and support.

Introduction:

Arch width discrepancy is a common orthodontic problem, which can cause esthetic and functional problems in both arches and it's usually accompanied by some of the following; crowding of the teeth, dark spaces in the buccal corridor upon smiling, and unilateral or bilateral posterior cross-bite. According to an epidemiologic study, around 21% of children have some form of skeletal discrepancy involving both dental arches and less than 10% in adult patients (1). The cause of maxillary construction is multifactorial (2). The correction of such a problem can be associated with advantageous therapeutic effects not only on the dental and skeletal parts but it also covers different aspects such as hearing, swallowing and nasal breathing (2-4).

When a skeletal constricted maxillary arch is diagnosed, orthopedic skeletal expansion involving separation of the midpalatal suture is the treatment of choice (4). There are various appliances and treatment protocols that have been developed over the years which includes; Slow Orthodontic Expansion (SOE), Rapid Maxillary Expansion (RME) and Surgically Assisted Rapid Palatal Expansion (SARPE). All techniques share the same objective which is to address and correct the skeletal disharmony (2, 5-7).

Rapid maxillary expansion (RME) is the most common treatment of choice in orthodontics to correct dental and skeletal discrepancy by separating the mid-palatine suture in the late mixed or early permanent dentition, where the most predictable results are typically achieved in that stage

(2, 4). Rapid Palatal Expansion was first described in the literature by E.C. Angell in 1860, who used a reciprocal jackscrew attached to premolars as a method of expanding the upper arch (Tooth-Borne Appliance). A common type of RPE appliance is a tooth bounded Hyrax appliance and it is widely used in the treatment of transverse maxillary deficiencies in order to re-direct the growth of the basal bone into a normal pattern. It is widely accepted that (RME) causes an opening in the mid-palatal suture (4), however, since the conventional (RME) appliances in nature transmit the expansion forces through the teeth, alveolar bone bending and dento-alveolar tipping is inevitable (2, 4, 5, 8).

Surgical Assisted Palatal Expansion (SARPE) have been developed to overcome these limitations that are faced in the conventional RPE especially after suture closure or completion of the transverse growth in adults (7). It is hard for the conventional RPE to separate the mid-palatine suture in adults, because of craniofacial increased rigidity as well as the existence of the synostosis bridges in the mid-palatal suture. This method was used to facilitate the orthopedic correction and minimize the unwanted dental effect by reducing the skeletal resistance. SARPE is a complex surgical procedure and it has its potential risks associated with its invasiveness (6, 7).

In recent years Micro Implant (MI) has been introduced to the field of orthodontics. New designs of RPE have been developed with the use of micro-implants as a temporary anchorage. Mini Implant Supported Palatal Expansion (MSE) is a simple modification of conventional RPE where it incorporates the micro-implants into the palatal jack screw which facilitate the palatal expansion without utilizing the dentition as an anchorage (Bone – Borne). This new concept can eliminate the unwanted results in the conventional rapid palatal expansion from tooth tipping and bone bending (9, 10).

Although it has been noticed that the forces from RPE treatment to widen the maxillary arch perimeter are accompanied with other changes affecting the neighboring structures such as the circumaxillary sutures, the nasal cavity and even the sphenoid bone of the cranial base by forces transmitted by the expander (8). Therefore, RPE may affect structures, directly and indirectly, related to the maxilla. Moreover, it has been claimed that the transverse forces generated during rapid maxillary expansion are transmitted, via the pterygomaxillary connection, to the unpaired sphenoid bone of the cranial base, where they lead to stress (11). The extent and effects of this have not yet been studied extensively, nor have they been well determined.

Limited studies have been done on the effect of RME on the Spheno-occipital Synchndroses and the studies are often dealt with experimental models based on finite element analysis (FME) and animal studies. Finding from these studies pointed out that the spheno-occipital Synchndroses appear to be affected by RME. However, the changes were small and the evidence not conclusive (4, 12, 13). This view indicates that SOS can be modulated by mechanical stress, which brings up the question of the idea of controlling the cranial base cartilage growth. In fact, it has been hypothesized that the growth of the cranial base is being influenced by the continuous presence of tensile forces generated from the expander.

Synchondroses of the cranial base is significant growth center of the craniofacial skeleton and latest sites in the cranium to terminate growth. Irregularities in synchondroses are the reason for many development and growth conditions that affect the craniofacial, such as Down syndrome (14, 18). The cranial base has received deliberation in orthodontics, due to the fact that its growth influences the maxillary-mandibular complex, some studies address the cranial base as a guiding rail for the growth of the mid-face, maxilla and the lower facial complex, and its modification could affect their development (12-14, 16, 18, 19).

In orthodontic, mechanical forces are commonly applied to the cranial base for growth modification (4). The cranial base growth continuous after birth especially at the sphenooccipital synchondroses (SOS) until adolescence (14). The sphenooccipital synchondroses (SOS) is defined as the development of a union between two bones (sphenoid - occipital) by the formation of the hyaline cartilage, which is rich during the maturation phase and then ossifies when it reaches skeletal maturation (20). A synchondroses is generally temporary and exist during the growing stage until the intervening cartilage becomes gradually thinner during skeletal maturation and at the end it becomes obliterated and transformed into bone before adult life (11, 12, 20). Studies show that SOS plays a prominent role in growth (ontogeny) due to its influence on the elongation of the basicranial axis, which defines the cranial base shape and its relation with the dento-alveolar bone development until the adult stage is reached (16).

The spheno-occipital synchondroses has received great attention because it may be visible on lateral radiograph of the skull through the period of adolescence (16). Also, SOS ossification compared with other cranial base synchondroses has a relatively late ossification, on the other hand the intersphenoidal synchondroses ossifies immediately after birth and the ethmoidal synchondroses ossifies at the age of 7 generally (14). According to the literature the SOS suture begins to fuse between 11- 14 years in females and 13-16 years in males. (14, 18, 20, 21). It has been hypothesized in some studies that the opening of the SOS could be from the downward and forward movement of the maxilla when the midpalatal suture opens, due to the maxillocranial suture displacement (4, 11, 12, 19).

It is commonly accepted that rapid palatal expansion can affect the nasal passage and the nasal septum (NS). The NS is a significant support and physical structure to the nose, it is formed by the vomer and perpendicular plate of the ethmoid bone posteriorly, the quadrangular cartilage anteriorly (3). Movement of vomer of maxillopalatal arch toward both superior and ventral can cause a curvature toward lateral in the cartilage part of the septum. (3, 4, 8).

Since Cone Beam Computed Tomography (CBCT) has been introduced, dental practitioners have entered a new era in radiographic imaging. With the 3-D imaging a more sophisticated technique in having an easier and better understanding of the radiograph, it revolutionized the diagnostic methods in dental treatment and monitoring patients. 3-Dimensional assessment is a more advanced technique for the evaluation of morphological changes in the Dentofacial complex (4, 11, 21). However, the number of investigations conducted on CBCT scans are limited and we aim in this study to acquire more information on the effect of MSE and Hyrax on the sphenoccipital Synchndroses SOS and the vomer bone.

Recently, Cone Beam Computed Tomography (CBCT) has been proved to be a useful tool for the assessment of treatment effect on the spheno-occipital Synchndroses (SOS), due to the superior visualization achieved and eliminating superimposition using a 3-Dimensional imaging scan and increase diagnosis accuracy in determining the SOS, which allows clinicians and researchers to quantitatively evaluate changes to the bone with minimal distortion and lower radiation dosage. The advantages of CBCT have been investigated in various studies in recent years (4, 11, 21). However, to our knowledge the use of CBCT to evaluate the opening of the SOS after the use of an expander has not been investigated.

The aim of our study was to investigate the skeleton changes in the spheno-occipital Synchndroses and the vomer-sphenoid joint bone using a 3-D CBCT scan after RME treatment with a bone – borne (Maxillary Skeleton Expander MSE) and a tooth – borne (Hyrax) maxillary expander.

Our hypothesis is that MSE and hyrax have different expansion patterns and magnitudes on the sphenooccipital Synchndroses and the vomer bone especially in adult patients.

Materials and Methods:

The protocol for this study was approved by the Institutional Review Board at University of California Los Angeles. Patients were selected and grouped into 2 groups: Group 1 was treated with Maxillary Skeletal Expander (MSE). Group 2 were treated with conventional Hyrax palatal expander appliance. All patients were treated at the Orthodontic Clinic of the University Of California Los Angeles School Of Dentistry. This is a retrospective study and the inclusion criteria that have been applied are as follows: 1) Transverse Maxillary deficiency based on optimal tooth and arch characteristics of Andrew's transverse analysis of elements. 2) Method of treatment either with MSE or Hyrax expander appliance as a part of the overall treatment. 3) CBCT scans were taken before rapid palatal expansion (T0) and after expansion (T1). 4) The absence of craniofacial syndromes. 5) The absence of previous orthodontic treatment.

Group 1 patients were treated with MSE and they included 16 patients within the age range of 10- 28 years old. 10 males and 6 females. Group 2 consisted of 7 patients and they were treated with Hyrax and the age ranges were from 8 - 15 years old, 4 males and 3 females (Fig 1A-B).

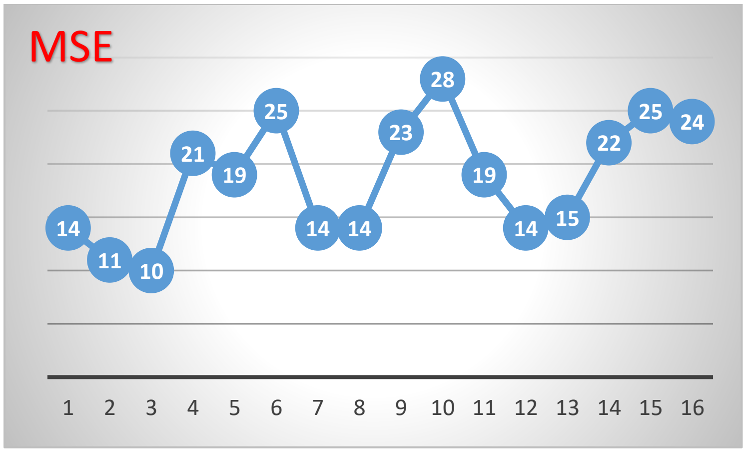


Fig 1A. Group 1: Patients treated with MSE, age range 10 – 28 years

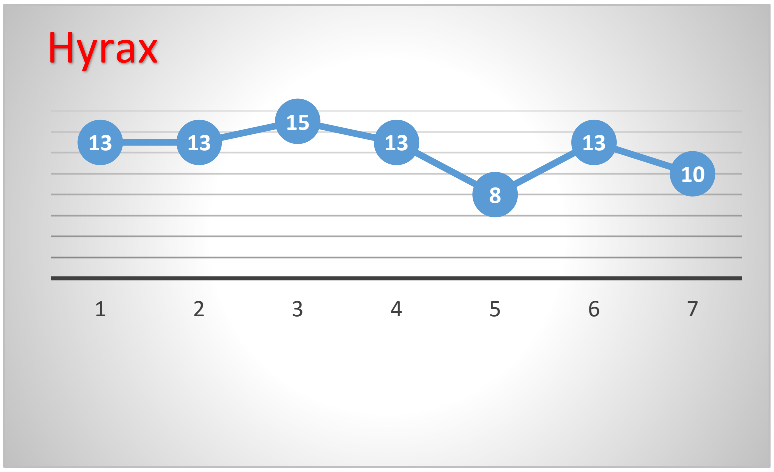


Fig 1B. Group 2: Patients treated with Hyrax, age range 8 - 15 years

The MSE appliance was created by Biomaterials Korea Inc. The MSE appliance consists of two molar bands attached to maxillary first molars and a central body containing an expansion screw as well as 4 slots of 1.5 mm in diameter and 2 mm in depth that act as a template for placing 4 micro-implants, (Bone - Borne Expander) (Fig 2 & 3).

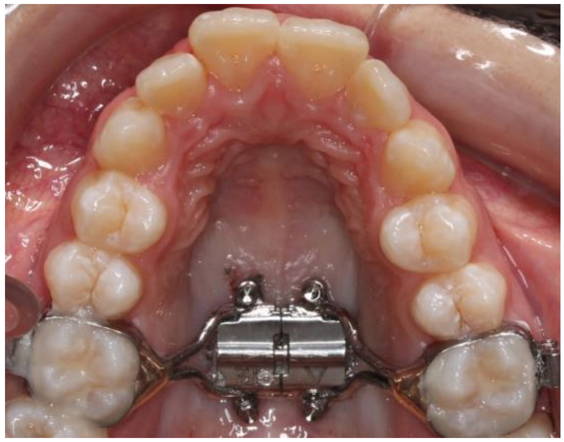


Fig 2. MSE appliance in situ

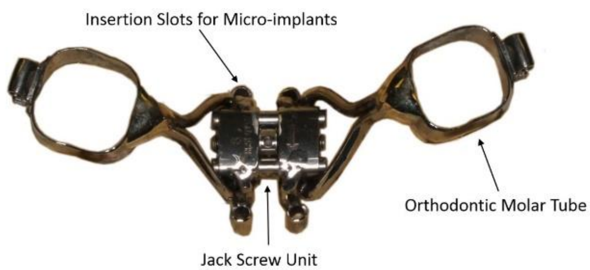


Fig 3. MSE appliance design

The insertion slot of MSE ensures a high precision fit with Micro implant (MI), which will keep the Micro Implants in a secured perpendicular position. The 11 mm length of the MI will promote the bi-cortical engagement at the palatal bone and nasal floor, which will prevent the unwanted tipping of the MI during the expansion (Fig 4).

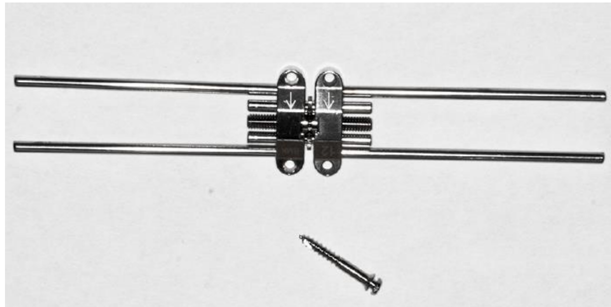


Fig 4. Prefabricated MSE appliance

All appliances were fabricated by sizing the molar bands by taking an impression (pick-up impression) and pouring it into stone material then placing the appliance 1-2 mm anterior to the junction of the hard and soft palate, and then fitting the expander to the palatal vault. The lateral arms of the appliance were soldered to the bands of the molars teeth. The central jackscrew expander was flushed against the palate and the supporting arms had 2 mm of clearance to the lateral wall of the palate. Next step, is the cementation of the appliance intra-orally, under local anesthesia, 4 micro-implants are placed at their sites. The expansion rate was selected based on a protocol designed to reach when the occlusal aspect of the maxillary lingual cusp of the permanent first molar in contact with the occlusal aspect of the mandibular facial cusp of the permanent first molar which is the desired expansion to be achieved. Each turn produces 0.25 mm of expansion.

The Hyrax appliance consists of a central expansion screw attached to the molar band on the maxillary first molars and lingual bar extensions (Fig 5). These appliances were fabricated in a similar manner as the MSE appliances and were cemented intra-orally. Patients were instructed to complete one full turn of expansion each day until the desired of expansion length was achieved, with each turn producing 0.25mm of expansion.

Fig 5. Hyrax appliance in situ

All patients were examined by CBCT scans before (T0) and after the completion of expansion (T1). NewTom 5G in an 18 x 16 Field of view with a 14-bit grayscale was taken for all patients in both groups. The time for each scan was 18 seconds (3.6 seconds emission time), 110 kV, and utilized an automatic exposure control that adjusted the milliampere based upon the patient's anatomic density. The NewTom 5G Safebeam control reduces the radiation the patient is exposed is based on the size of the patient. Data from the Cone beam computed tomography (CBCT) was reconstructed to produce 0.3 mm slices.

Limited methods have been used to evaluate the Spheno-occipital Synchndroses and the skeletal changes around it that are induced by the orthopedic expansion appliances. A common method that has been used in some studies to evaluate the Spheno-occipital Synchondroses is by analyzing the cephalometric of the patients and selecting some landmarks close to the selected area to determine changes before and after treatment on the cephalometric (13). However, the accuracy of this methodology is questionable, as measuring the distance between midpoint of sella turcica and the most anterior point on foramen magnum (S-Ba) and the nasion-sella-basion angle (N-S-Na^) is not reliable and the spheno-occipital synchondroses can't be quantified and measured accurately using this method. These limitations complicate the assessment of changes in the SOS before and after the treatment.

In order to solve this problem, a new methodology has been developed for quantifying the changes before and after treatment of the spheno-occipital synchondroses accurately. Data on each CBCT scan from each patient were saved as DICOM (Digital Imaging and Communications in Medicine) files. Data then were transferred to Ondemand3D software, using the Ondemand3D from Cybermed Inc. Company the post-expansion CBCT of the patient were superimposed on the pre-expansion CBCT, this is performed automatically by the software using the stable structure of the whole cranial base in adults and of the anterior cranial fossae in growing children. This automated method compares the grey level intensity of each voxel in the cranial base in order to do the superimposition (Fig 6).OnDemand3D superimposition has a high accuracy and reliability, the validation of superimposition was validated in 2015.

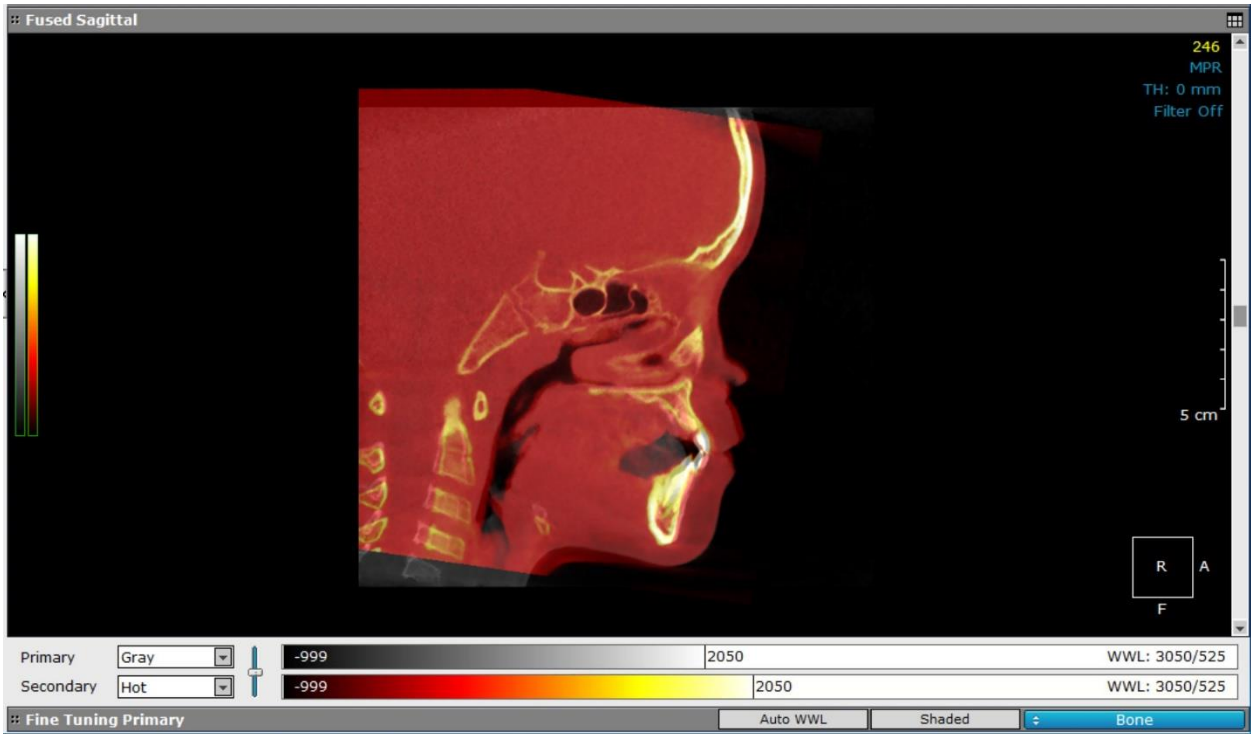


Fig 6. Post expansion (T1) superimposed on Pre expansion (T0) CBCT using Ondemand3D

Identifying the reference planes by orienting the skull according to the Maxillary sagittal plane (MSP) passing through ANS – PNS – Nasion the horizontal plane was perpendicular to MSP and then passing the horizontal plane through Nasion (N) and highest point of Porion of right auditory meatus (Rt Por) on the pre-expansion CBCT (Fig 7 - 8). We scrolled the horizontal plane vertically (up & down) and MSP horizontally (Rt – Lt) and selected the section where SOS showed the widest anterior – posterior dimension. This method allowed us to visualize the widest anterior-posterior dimension of the synchondroses on the mid-sagittal and axial planes. The measurements for each image was recorded.

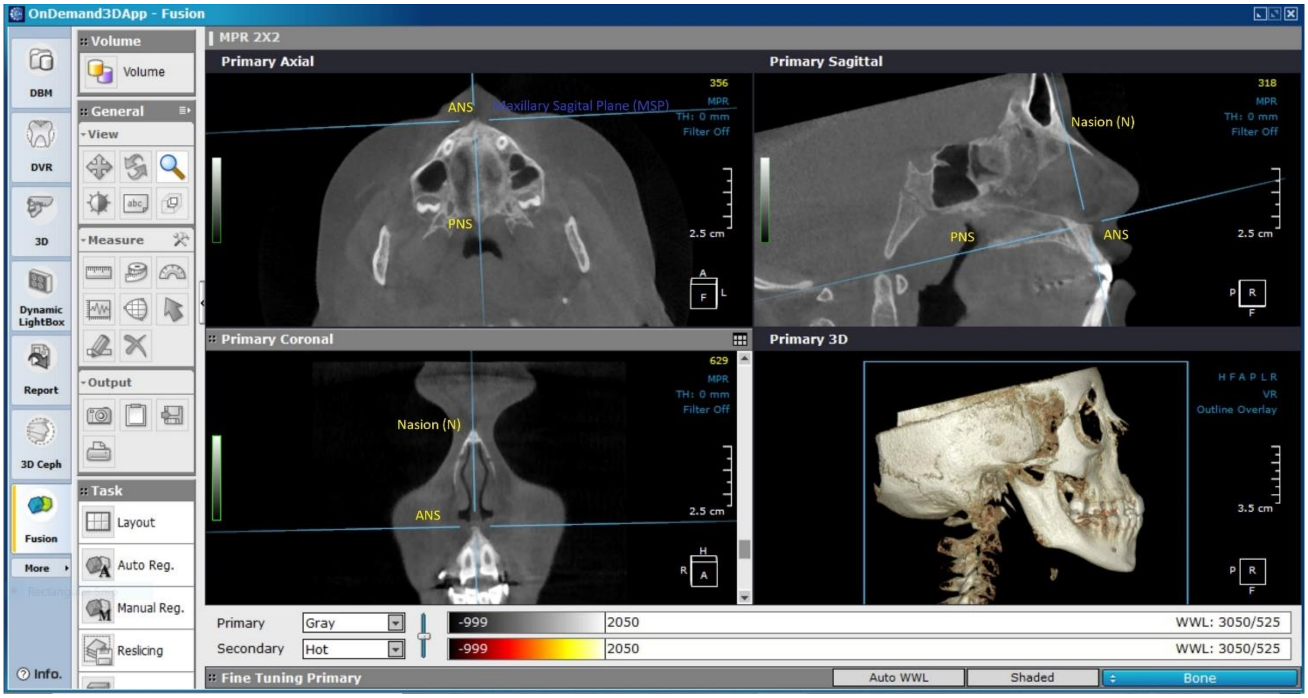


Fig 7. Orienting the skull according to the Maxillary sagittal plane (MSP) passing through ANS – PNS – Nasion

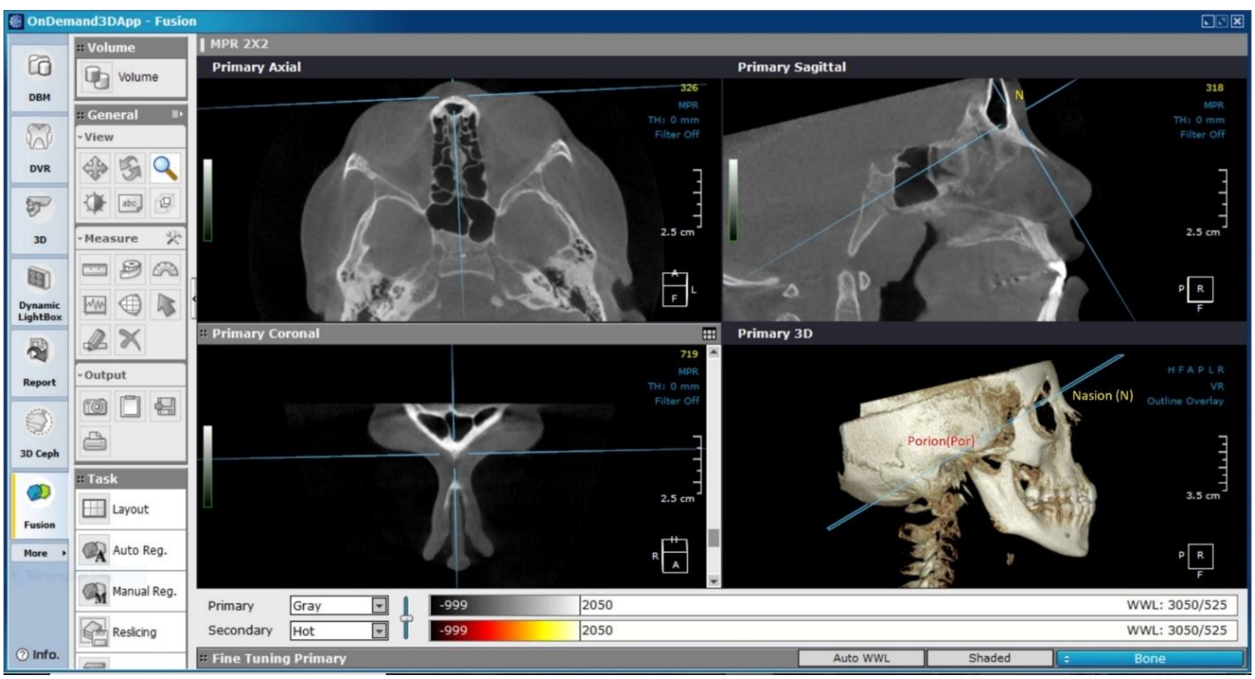
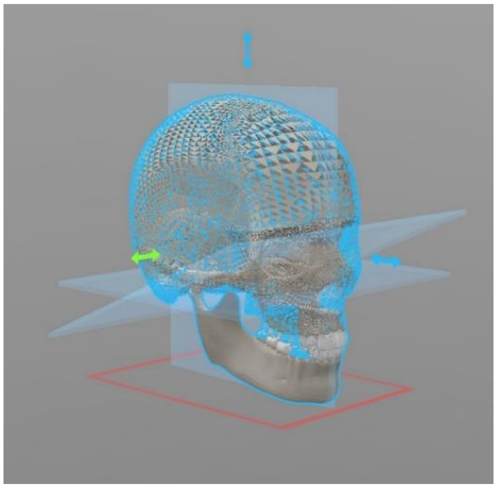


Fig 8. Horizontal plane passing through Nasion (N) and highest point of Porion of right auditory meatus (Rt Por)



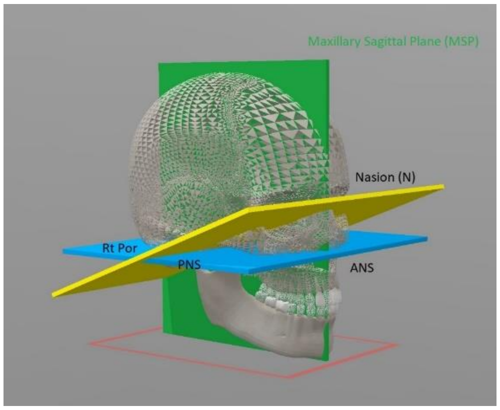


Fig 9 & 10. Schematic representation of the three main reference planes utilized in the study to evaluate the displacement Sphenooccipital synchondrosis (SOS) and the vomer sphenoid joint.

Dimensional changes occurring in the spheno-occipital synchondroses (SOS) and vomer-sphenoid joint before (T0) and after (T1) RME were evaluated both on the sagittal and axial views (Table 1).

Sagittal measurements include the anterior-posterior width of the surface area (Fig 11), the mean anterior-posterior linear distance of SOS (Fig 12), the vomer-sphenoid joint mean linear width distance (Fig 13) and the vomer surface area (Fig 14). Axial measurements included; the anterior-posterior width of the surface area (Fig 15) and the anterior-posterior mean width in millimeter on the axial view (Fig 16).

Table1. Table of measurements:

1	The Anterior posterior width of the surface area on the sagittal view.
2	The Anterior posterior width of the surface area on the axial view.
3	The anterior posterior width in millimeter on the sagittal view (Linear distance).
4	The anterior posterior width in millimeter on the axial view (Linear distance).
5	Vomer-sphenoid joint surface area.
6	Vomer-sphenoid joint width in millimeter (Linear distance).

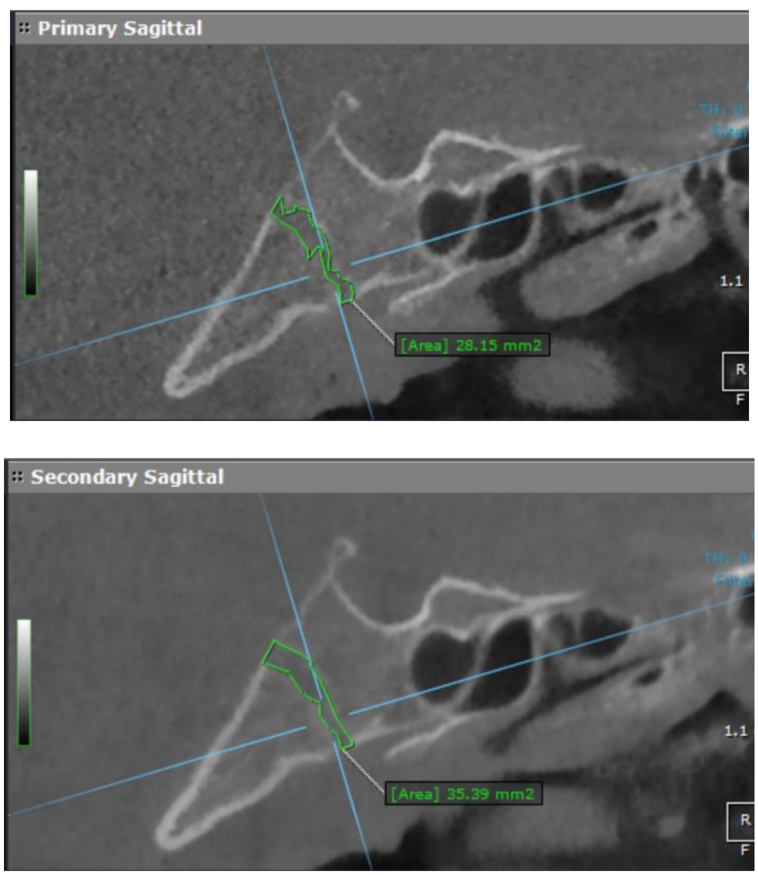


Fig 11. The anterior – posterior width of the surface area T0-T1

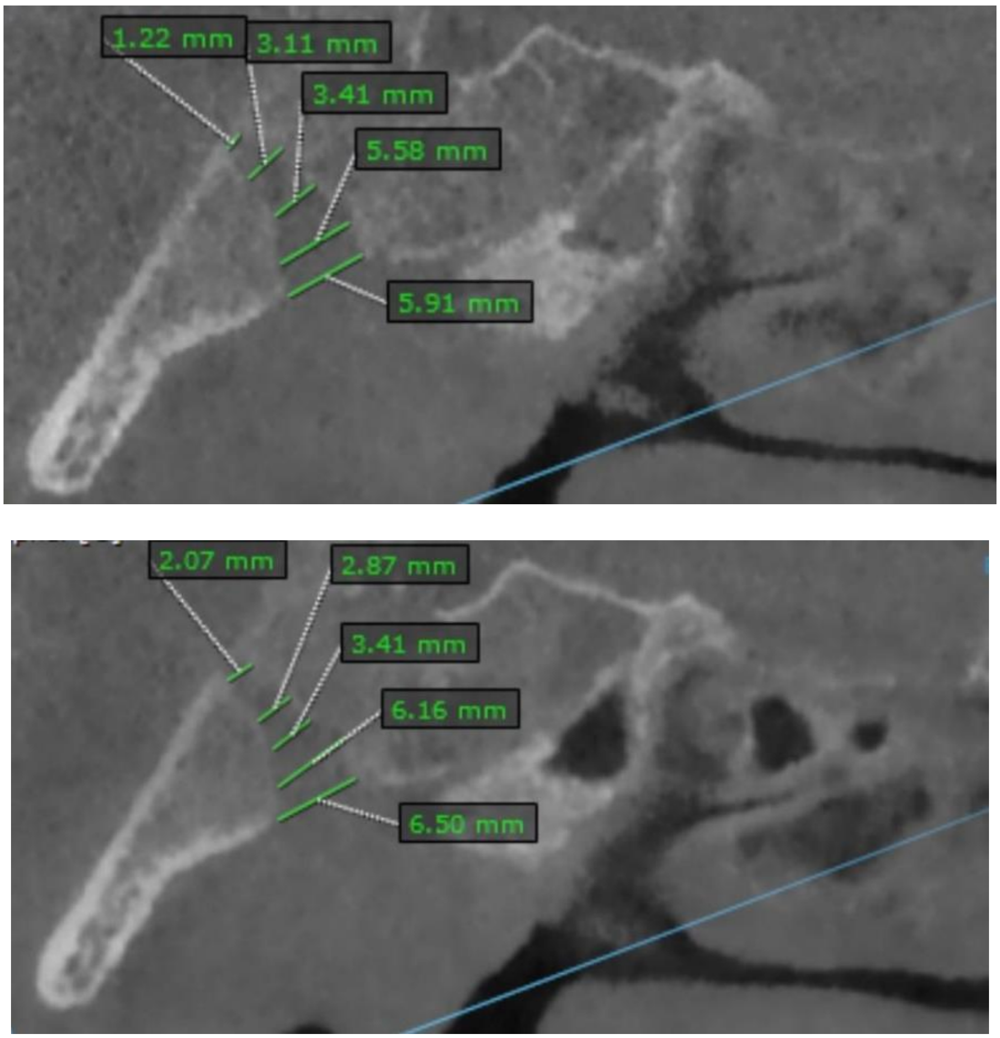


Fig 12. The anterior posterior linear distance T0- T1

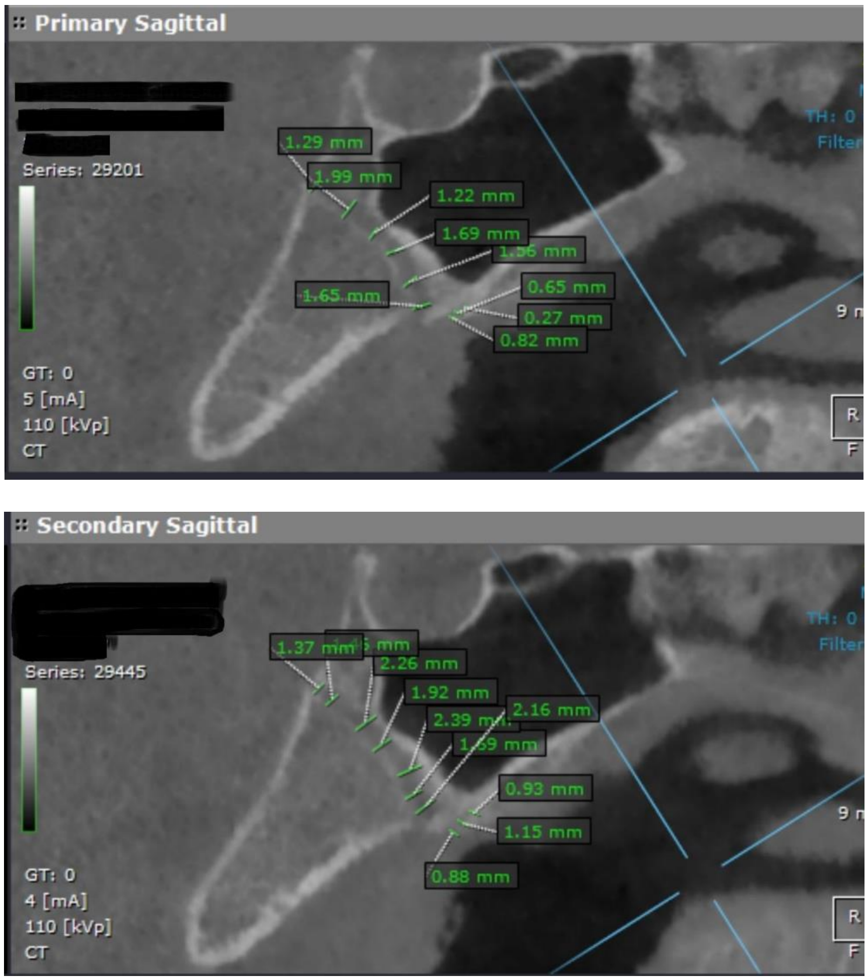


Fig 13. The anterior posterior linear distance of SOS and Vomer-sphenoid joint width T0- T1

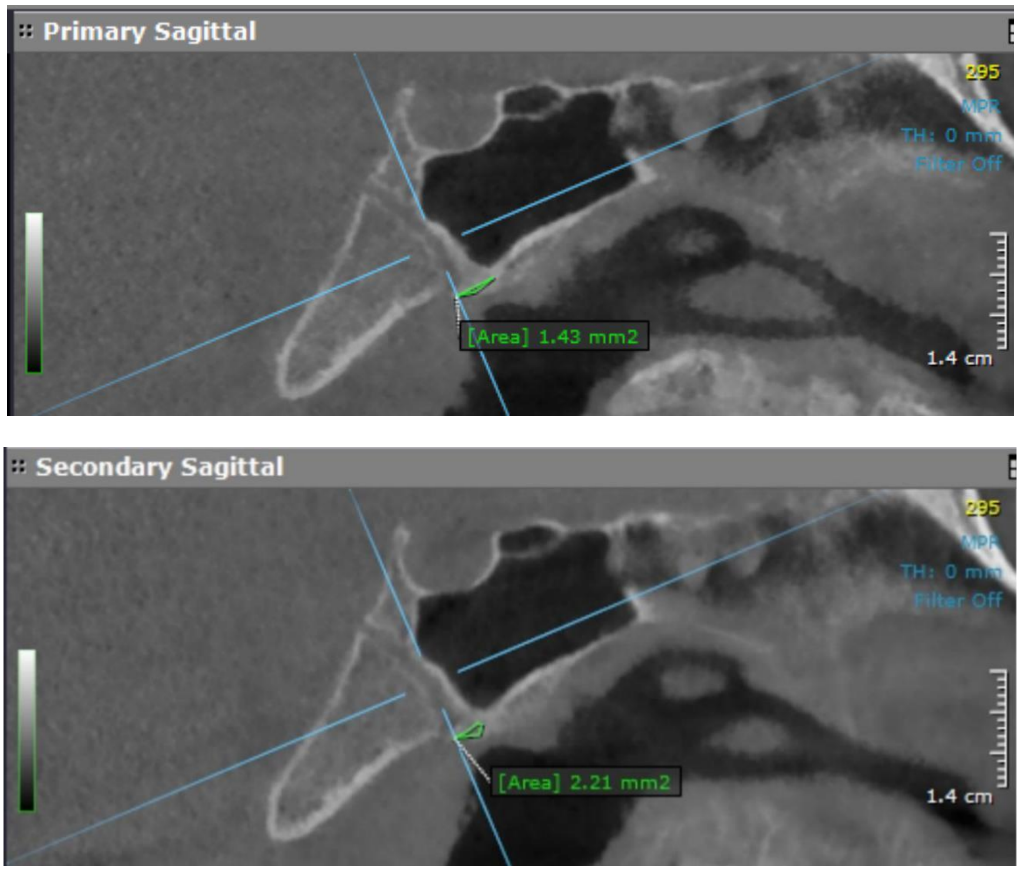


Fig 14. The vomer-sphenoid joint surface area T0- T1

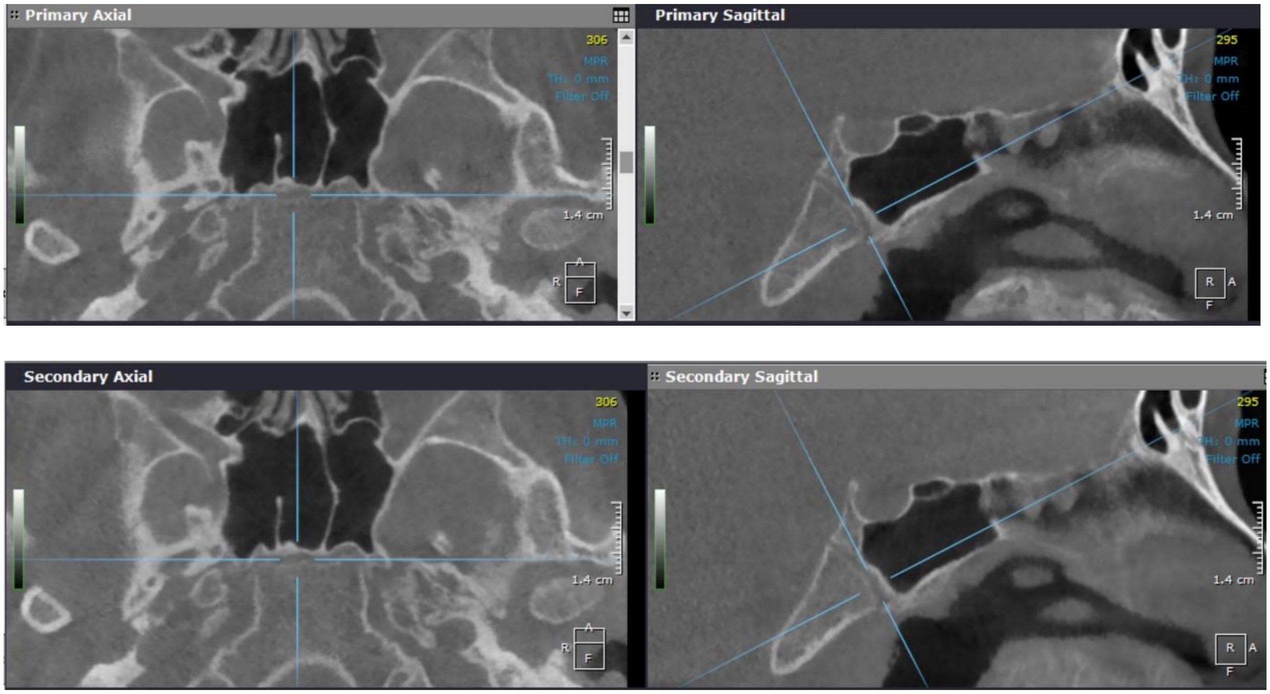
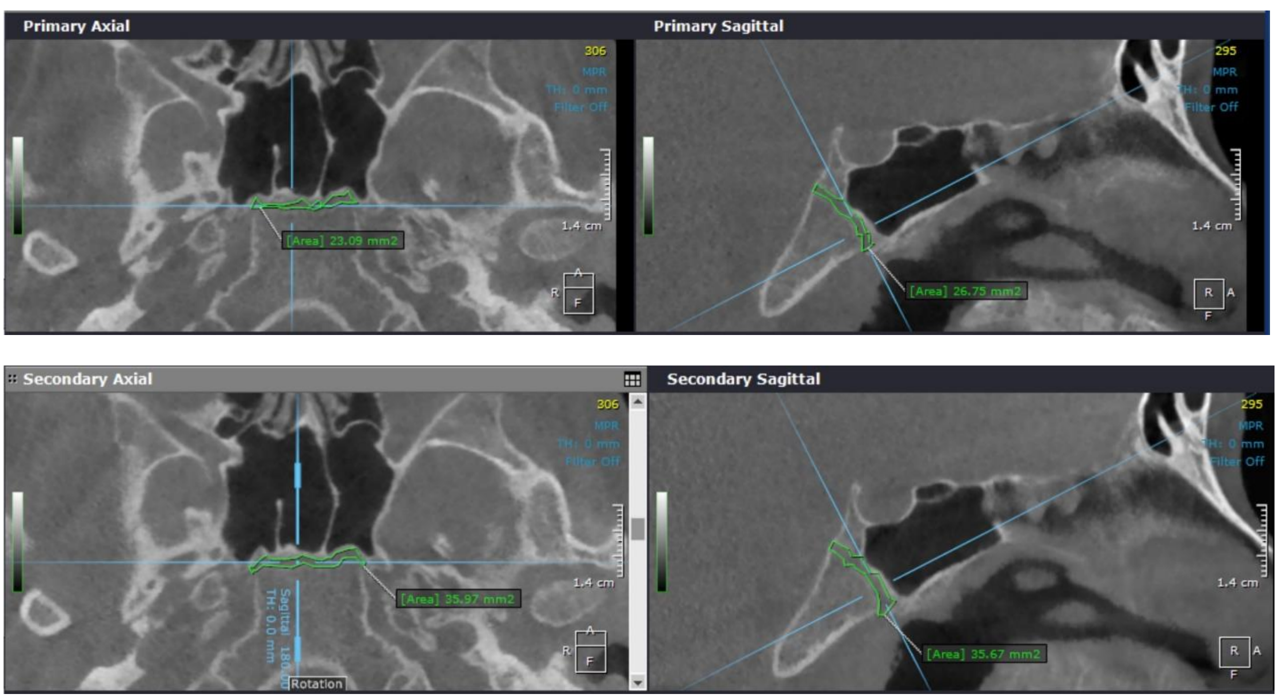


Fig 15. The anterior posterior width of the surface area T0-T1 on the sagittal and axial view.



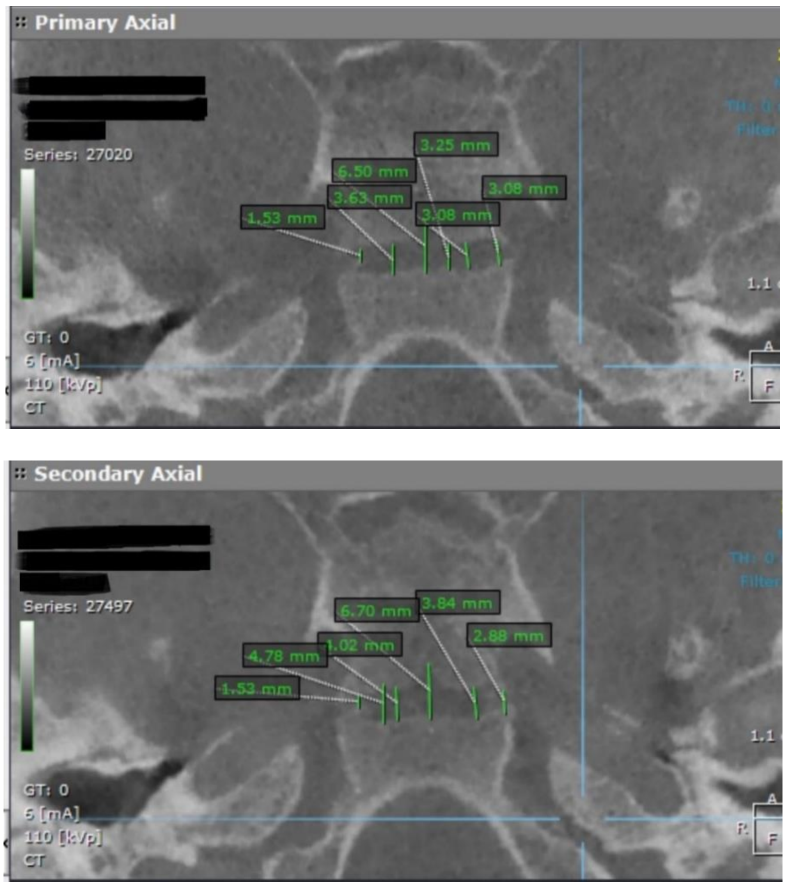


Fig 16. The anterior posterior width in millimeter T0- T1 on an axial view (The mean of 6 linear measurements).

Statistical Analysis

Assessments of variables between and within groups: Variables were compared from pretreatment (T0) to posttreatment (T1) within each group parametrically using the paired 2 dependent mean T-test. Furthermore, MSE to Hyrax in each variable were compared between groups parametrically using the 2 independent means t-test.

Reliability assessments: Measurements were obtained for all variables. Two different raters have done the measurements to produce stable and consistent results.

Reliability was evaluated in two ways: 1- by computing the coefficient of variation (Relative Standard deviation) and 2- by computing the intra class correlation coefficient (ICC), to evaluate reproducibility.

Results:

Analysis of the spheno-occipital synchondroses on the sagittal section:

Surface Area on the sagittal section:

MSE:

Before MSE treatment (T0), the mean surface area of the spheno-occipital synchondroses was 12.74 mm^2. After the expansion (T1) the mean surface area of the synchondroses increased in every patient with a mean of 17.02 mm^2 (Table 2). This indicates a difference of 4.28 mm^2 between T0 and T1. When changes between T0 and T1 were evaluated, a statistically significant difference was found of t value equal to 4.128627, and p value equal to 0.000893. The result is highly significant at $p \leq 0.001$.

Table 2:

	Surface Area (Sagittal) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	1.32	-2.96	8.79
2	12.53	8.25	67.99
3	6.4	2.12	4.48
4	5.1	0.82	0.67
5	13.85	9.57	91.5
6	0.25	-4.03	16.28
7	8.01	3.73	13.88
8	1.26	-3.02	9.15
9	0.93	-3.35	11.25
10	1.36	-2.92	8.55
11	0.8	-3.48	12.14
12	1.33	-2.95	8.73
13	3.27	-1.01	1.03
14	2.9	-1.38	1.92
15	5.59	1.31	1.7
16	3.65	-0.63	0.4
	M: 4.28		S: 258.45

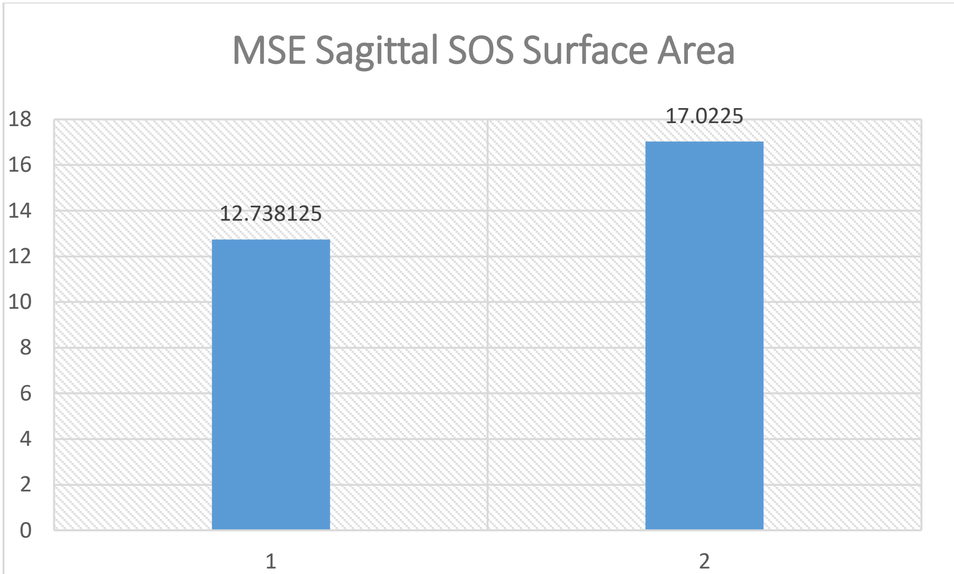


Fig 17. A 33.7% increase in the SOS T0-T1

Hyrax:

Before Hyrax treatment (T0), the surface area of the sphenooccipital synchondroses was 23.8 mm^2. After the expansion (T1) the surface area of the synchondroses decreased in every patient with a mean of 17.39 mm^2 (Table 3). This indicates a difference of -6.41 mm^2 between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found t value equal to -3.180422, and p value equal to 0.019066. The result is significant at $p \leq 0.05$.

Table 3:

	Surface Area (Sagittal) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	-1.31	5.1	26.01
2	-19.2	-12.79	163.58
3	-4.34	2.07	4.28
4	-1.28	5.13	26.32
5	-4	2.41	5.81
6	-6.03	0.38	0.14
7	-8.71	-2.3	5.29
	M: -6.41		S: 231.44

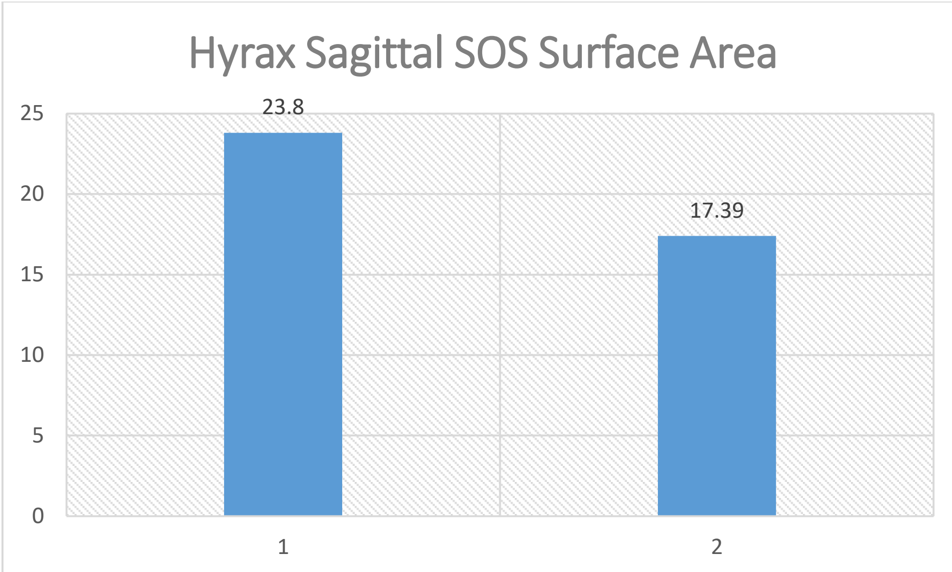


Fig 18. A 26% decrease in the SOS T0-T1

Linear Measurement on the sagittal section:

MSE:

Before MSE treatment (T0), the mean anterior-posterior width of the spheno-occipital synchondroses was 1.49 mm. After the expansion (T1) the width of the synchondroses increased in every patient with a mean of 2.14 mm (Table 4). This indicates a difference of 0.66 mm between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to 4.919375, and p value equal to 0.000185. The result is highly significant at $p \leq 0.001$

Table 4:

	Linear (Sagittal) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	0.42	-0.24	0.06
2	0.61	-0.05	0
3	0.95	0.29	0.09
4	0.63	-0.03	0
5	0.35	-0.31	0.09

6	0.12	-0.54	0.29
7	0.33	-0.33	0.11
8	0.06	-0.6	0.36
9	0.34	-0.32	0.1
10	0.7	0.04	0
11	0.3	-0.36	0.13
12	0.2	-0.46	0.21
13	2.1	1.44	2.08
14	0.9	0.24	0.06
15	1.2	0.54	0.29
16	1.3	0.64	0.41
	M: 0.66		S: 4.28

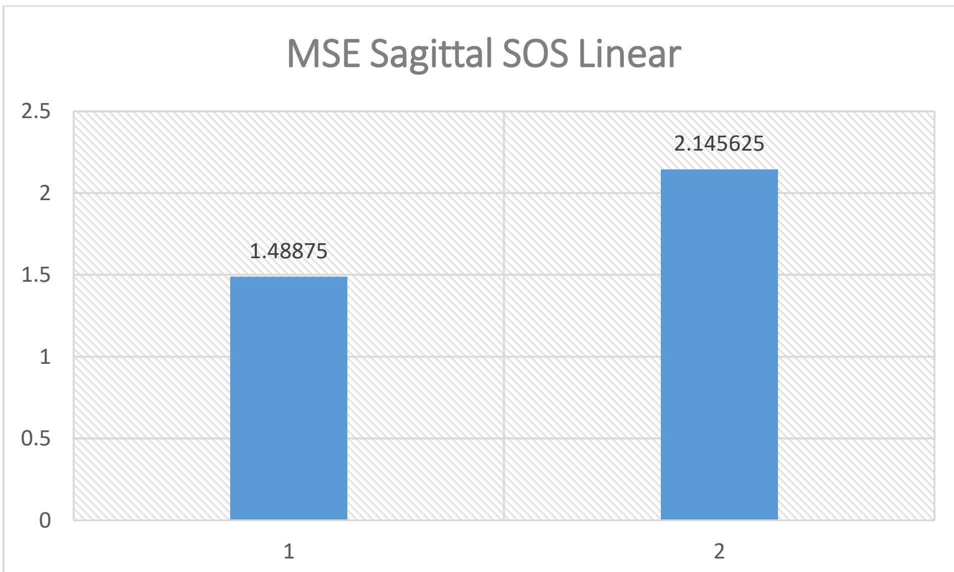


Fig 19. A 44% increase in the SOS T0-T1

Hyrax:

Before Hyrax treatment (T0), the mean anterior-posterior width of the spheno-occipital synchondroses was 2.44 mm. After the expansion (T1) the width of the synchondroses decreased in every patient with a mean of 1.58 mm (Table 5). This indicates a difference of - 0.86 mm between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to -3.909452, and p value equal to 0.007897. The result is significant at $p \leq 0.05$.

Table 5:

	Linear (Sagittal) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	-0.6	0.26	0.07
2	-0.86	0	0
3	-0.03	0.83	0.68
4	-1.05	-0.19	0.04
5	-1.66	-0.8	0.64
6	-1.44	-0.58	0.34
7	-0.36	0.5	0.25
	M: -0.86		S: 2.02

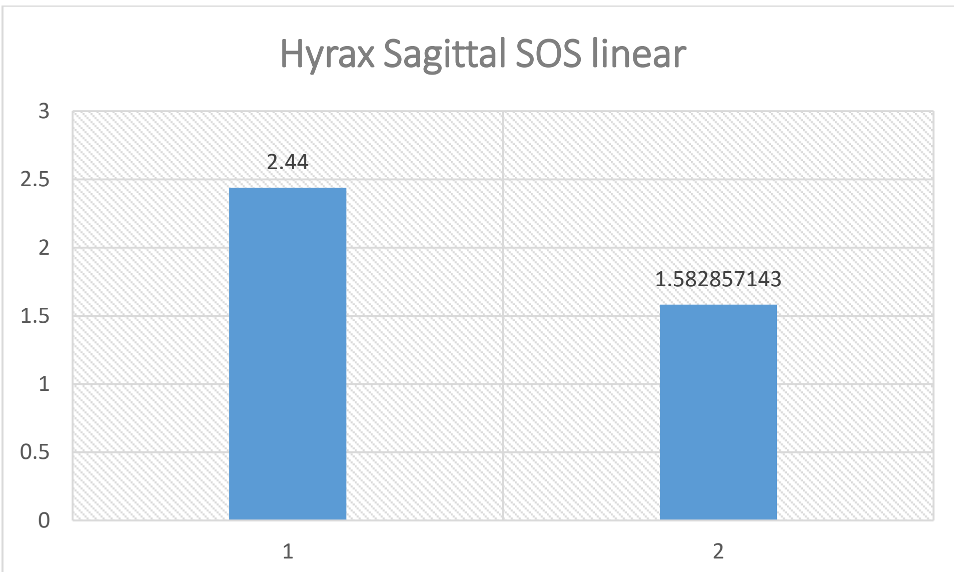


Fig 20. A 35% decrease in the SOS T0-T1

Analysis of the spheno-occipital synchondroses on the axial section:

Surface Area on the axial section:

MSE:

Before MSE treatment (T0), the mean surface area of the spheno-occipital synchondroses was 17.00 mm^2. After the expansion (T1) the mean surface area of the synchondroses increased in every patient with a mean of 20.62 mm^2 (Table 6). This indicates a difference of 3.62 mm^2 between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to 3.792649, and p value equal to 0.00177. The result is significant at $p \leq 0.05$.

Table 6:

	Surface Area (Axial) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	2.9	-0.72	0.51
2	10.78	7.16	51.34
3	5.09	1.48	2.18
4	2.63	-0.98	0.97
5	0.37	-3.24	10.53
6	0.14	-3.48	12.08
7	13.52	9.9	98.11
8	0.47	-3.14	9.89
9	0.64	-2.98	8.85
10	1.26	-2.36	5.55
11	0.7	-2.92	8.5
12	1.64	-1.98	3.9
13	5.18	1.56	2.45
14	4.28	0.66	0.44
15	5.18	1.56	2.45
16	3.06	-0.56	0.31
	M: 3.62		S: 218.04

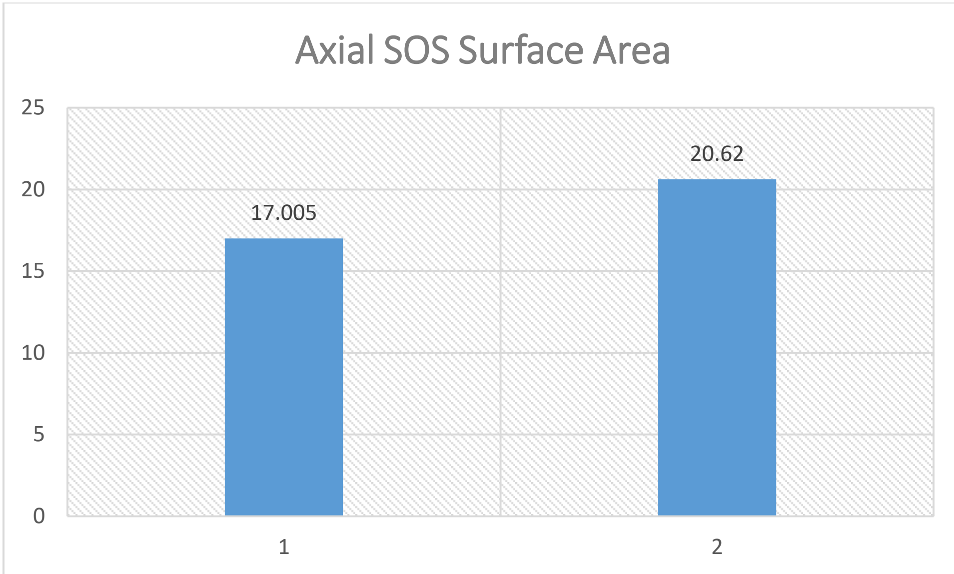


Fig 21. A 21% increase in the SOS T0-T1

Hyrax:

Before Hyrax treatment (T0), the surface area of the spheno-occipital synchondrosis was 26.39 mm^2. After the expansion (T1) the surface area of the synchondroses decreased in every patient with a mean of 21.28 mm^2 (Table 7). This indicates a difference of -5.11 mm^2 between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to -3.180422, and p value equal to 0.019066. The result is significant at $p \leq 0.05$.

Table 7:

	Surface Area (Axial) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	-3.6	1.51	2.29
2	-9.54	-4.43	19.6
3	-2.38	2.73	7.47
4	-3.85	1.26	1.59
5	-12.59	-7.48	55.91

6	-1.13	3.98	15.86
7	-2.7	2.41	5.82
	M: -5.11		S: 108.54

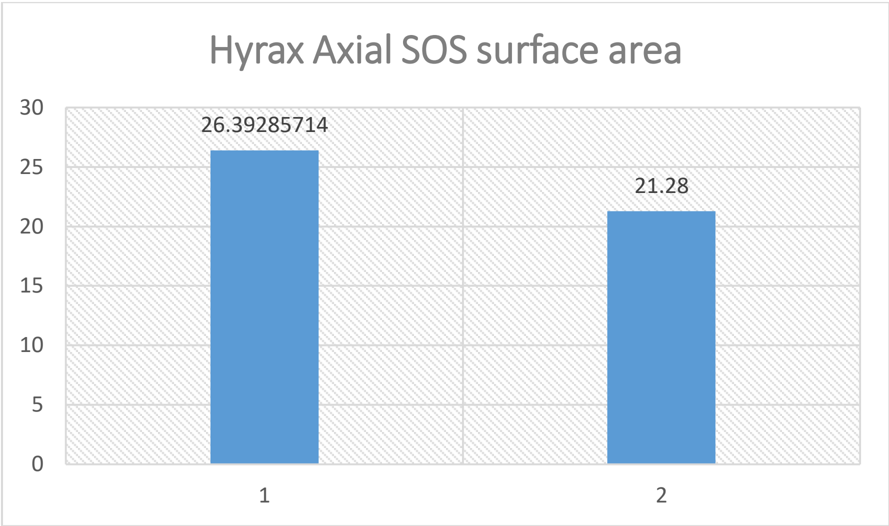


Fig 22. A 19% decrease in the SOS T0-T1

Linear Measurement on the axial section:

MSE:

Before MSE treatment (T0), the mean anterior-posterior width of the spheno-occipital synchondroses was 1.32 mm. After the expansion (T1) the width of the synchondroses increased in every patient with a mean of 1.80 mm (Table 8). This indicates a difference of 0.48 mm between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to 7.503378, and p value < 0.00001. The result is highly significant at $p \leq 0.001$.

Table 8:

	Linear (axial) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	0.18	-0.3	0.09
2	1	0.52	0.28
3	0.7	0.22	0.05

4	0.6	0.12	0.02
5	0.45	-0.02	0
6	0.2	-0.28	0.08
7	0.3	-0.18	0.03
8	0.37	-0.1	0.01
9	0.2	-0.28	0.08
10	0.6	0.12	0.02
11	0.3	-0.18	0.03
12	0.2	-0.28	0.08
13	0.5	0.02	0
14	0.8	0.32	0.11
15	0.4	-0.08	0.01
16	0.8	0.32	0.11
	M: 0.48		S: 0.96

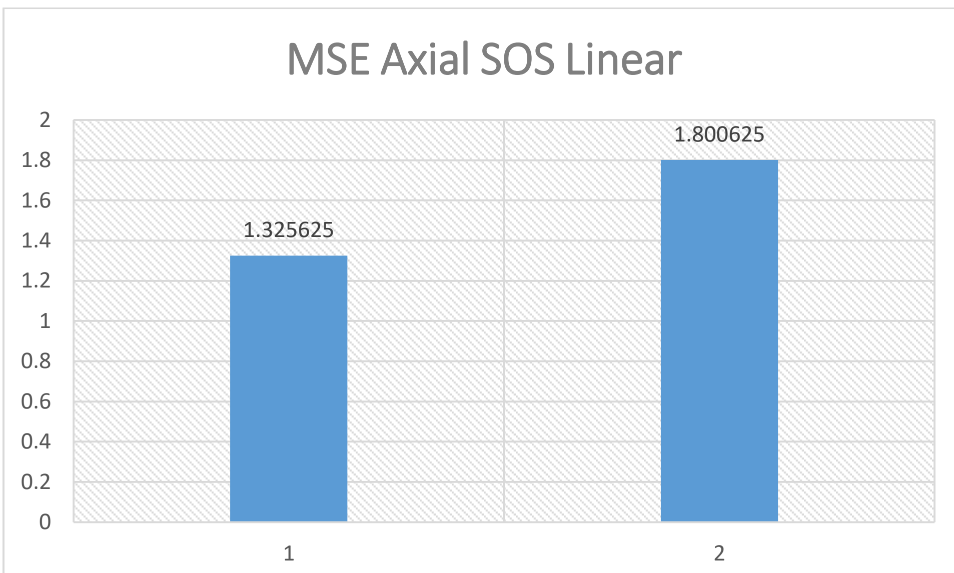


Fig 23. A 36% increase in the SOS T0-T1

Hyrax:

Before Hyrax treatment (T0), the mean anterior-posterior width of the spheno-occipital synchondroses was 1.5 mm. After the expansion (T1) the width of the synchondroses decreased in every patient with a mean of 0.93 mm (Table 9). This indicates a difference of - 0.57 mm between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to -6.758070, and p value equal to 0.000512. The result is highly significant at $p \leq 0.001$.

Table 9:

	Linear (axial) T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	-0.48	0.09	0.01
2	-0.8	-0.23	0.05
3	-0.3	0.27	0.07
4	-0.57	0	0
5	-0.85	-0.28	0.08
6	-0.68	-0.11	0.01
7	-0.3	0.27	0.07
	M: -0.57		S: 0.30

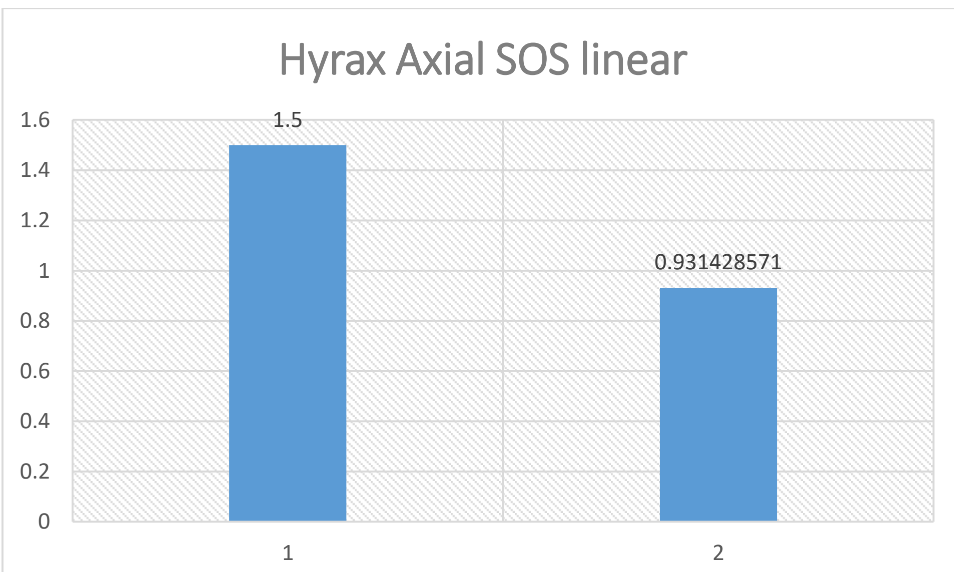


Fig 24. A 38% decrease in the SOS T0-T1

Analysis of the Vomer-sphenoid joint:

Surface Area:

MSE:

Before MSE treatment (T0), the mean surface area of the vomer-sphenoid joint was 3.63 mm^2. After the expansion (T1) the mean surface area of the vomer-sphenoid joint increased in every patient with a mean of 4.84 mm^2 (Table 10). This indicates a difference of 1.20 mm^2 between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to 4.509846, and p value equal to 0.000415. The result is highly significant at $p \leq 0.01$.

Table 10:

	Vomer-sphenoid joint Surface Area T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	0.68	-0.52	0.27
2	0.59	-0.61	0.38
3	2.64	1.44	2.07
4	3.36	2.16	4.65
5	0.88	-0.32	0.1
6	0.44	-0.76	0.58
7	0.55	-0.65	0.43
8	1.5	0.3	0.09
9	0.91	-0.29	0.09
10	0.47	-0.73	0.54
11	0.5	-0.7	0.49
12	1.11	-0.09	0.01
13	0.61	-0.59	0.35
14	3.57	2.37	5.61
15	0.03	-1.17	1.37
16	1.4	0.2	0.04
	M: 1.20		S: 17.06

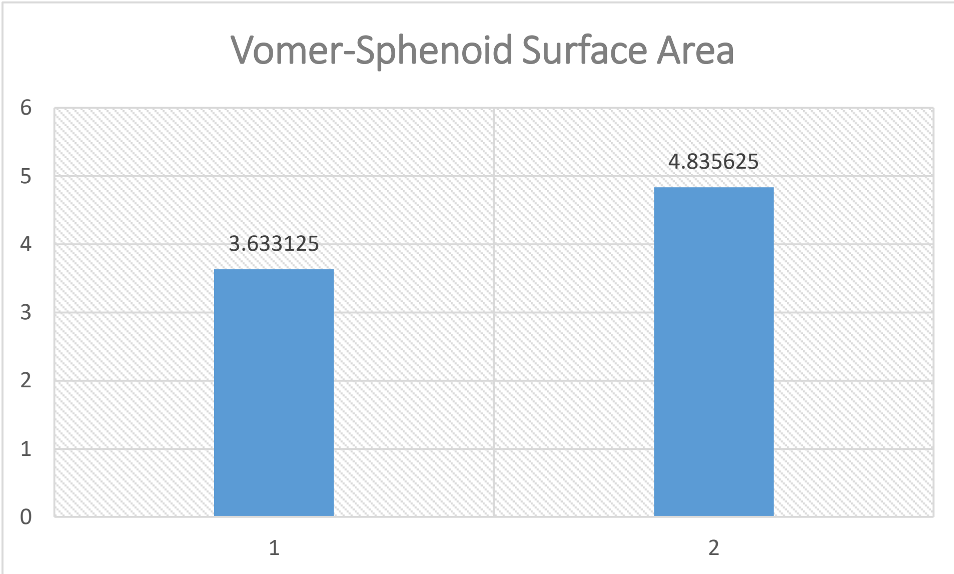


Fig 25. A 33% increase in the Vomer-Sphenoid joint T0-T1

Hyrax:

Before Hyrax treatment (T0), the surface area of the vomer-sphenoid joint was 7.98 mm^2. After the expansion (T1) the surface area of the vomer-sphenoid joint decreased in almost every patient with a mean of 7.22 mm^2 (Table 11). This indicates a difference of -0.76 mm^2 between T0 and T1. When changes between T0 and T1 were evaluated a non-statistically significant difference was found of t value equal to -1.794925, and p value equal to 0.122813. The result is not significant at $p \leq 0.05$.

Table 11:

	Vomer-sphenoid joint Surface Area T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	-0.8	-0.04	0
2	-0.31	0.45	0.21
3	0.51	1.27	1.62
4	-0.6	0.16	0.03
5	-3.04	-2.28	5.18
6	-1.05	-0.29	0.08
7	-0.06	0.7	0.5
	M: -0.76		S: 7.61

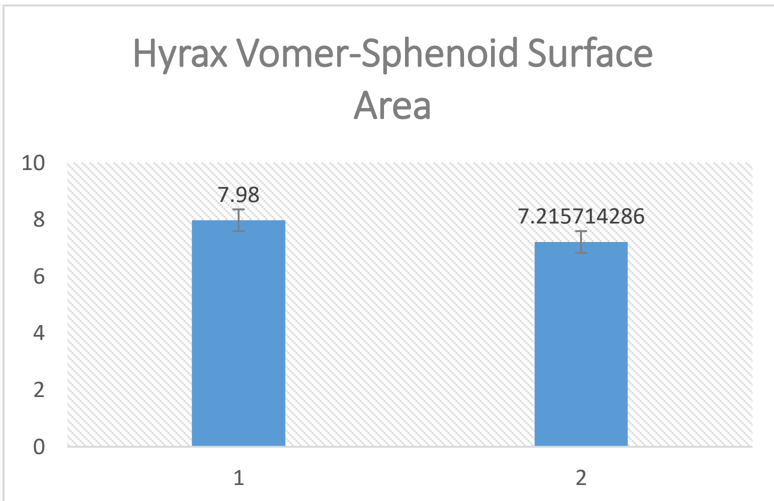


Fig 26. A very minor decrease in the vomer-sphenoid joint which result in no difference between T0-T1

Linear Measurement:

MSE:

Before MSE treatment (T0), the mean width of the vomer-sphenoid joint was 1.14 mm. After the expansion (T1) the width of the vomer-sphenoid joint increased in every patient with a mean of 1.85 mm (Table 12). This indicates a difference of 0.71 mm between T0 and T1. When changes between T0 and T1 were evaluated a statistically significant difference was found of t value equal to 3.991249, and p value equal to 0.00118. The result is significant at $p \leq 0.05$.

Table 12:

	Vomer-sphenoid joint Linear T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	1.31	0.6	0.36
2	0.73	0.02	0
3	0.52	-0.19	0.04
4	2.25	1.54	2.38
5	0.27	-0.44	0.19
6	0.13	-0.58	0.33
7	0.41	-0.3	0.09
8	2.2	1.49	2.22
9	0.27	-0.44	0.19
10	0.15	-0.56	0.31
11	0.2	-0.51	0.26
12	0.3	-0.41	0.17
13	1.1	0.39	0.15
14	1.2	0.49	0.24
15	0.1	-0.61	0.37
16	0.2	-0.51	0.26
	M: 0.71		S: 7.57

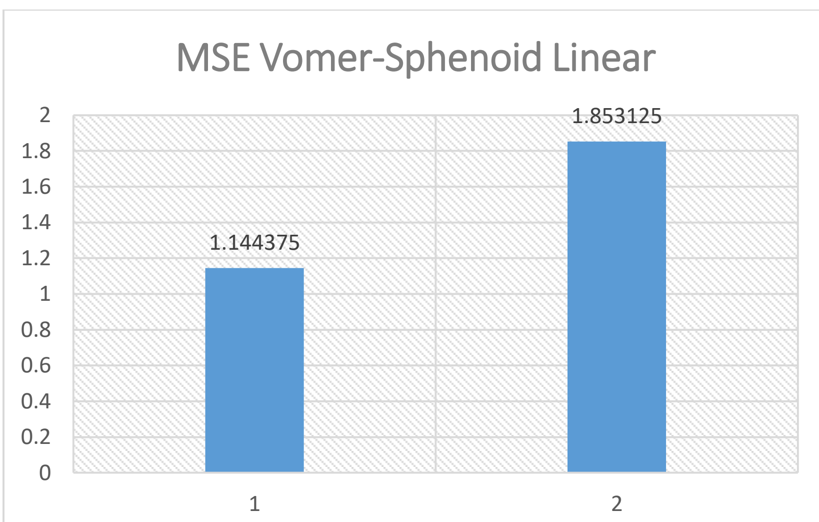


Fig 27. A 62% increase in the Vomer-Sphenoid joint T0-T1

Hyrax:

Before Hyrax treatment (T0), the width of the vomer-sphenoid joint was 1.27 mm. After the expansion (T1) the width of the vomer-sphenoid joint decreased with a mean of 1.24 mm (Table 13). This indicates a difference of - -0.02 mm between T0 and T1. When changes between T0 and T1 were evaluated a non- statistically significant difference was found of t value equal to -1.318973, and p value equal to 0.23528. The result is not significant at $p \leq 0.05$.

Table 13:

	Vomer-sphenoid joint Linear T1-T0	*Dev* (Diff - M)	*Sq. Dev*
1	-0.02	0	0
2	-0.05	-0.03	0
3	0.07	0.09	0.01
4	-0.04	-0.02	0
5	-0.06	-0.04	0
6	-0.02	0	0
7	-0.03	-0.01	0
	M: -0.02		S: 0.03

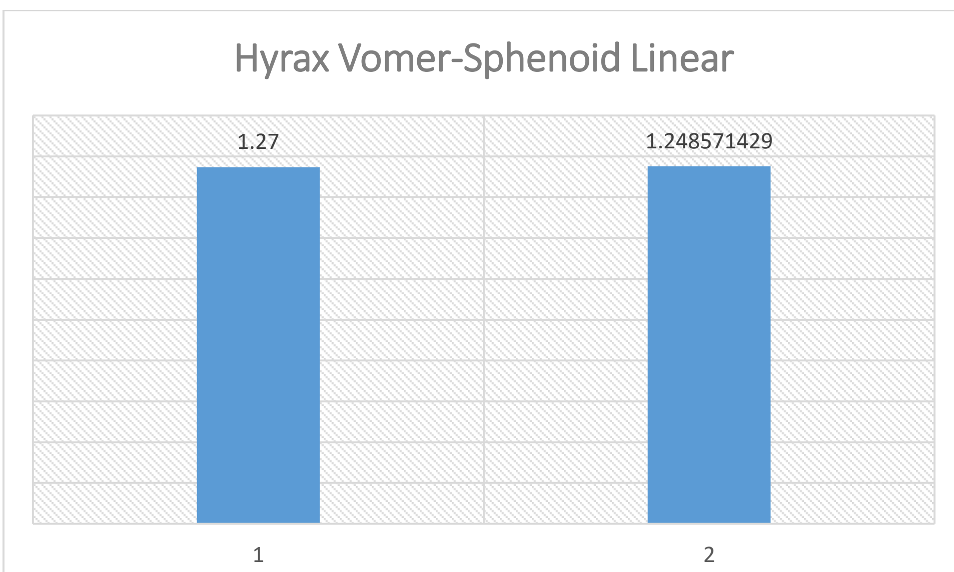


Fig 28. T0-T1 have not changed, which indicate that the vomer did not move

Difference between MSE & Hyrax:

There were highly statistically significant differences between the two treatment groups regarding the spheno-occipital synchondroses (SOS) and the vomer-sphenoid joint bone. Furthermore, analyses of the variables between the two groups were done. Those descriptive comparisons can be seen in details:

Surface Area of the sphenooccipital Synchondroses on the sagittal section MSE vs Hyrax:

Comparing between the two means of the spheno-occipital synchondroses surface area of each treatment group after the treatment (T1) to determine the difference in treatment outcome between MSE and Hyrax group. The differences between the two groups were evaluated and a statistically significant difference was found of t value equal to 4.8861, and p value equal to 0.000039. The result is highly significant at $p < 0.001$. (Table 14).

Table 14:

Treatment 1 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
1.32	-2.96	8.79
12.53	8.25	67.99
6.4	2.12	4.48
5.1	0.82	0.67
13.85	9.57	91.5
0.25	-4.03	16.28
8.01	3.73	13.88
1.26	-3.02	9.15
0.93	-3.35	11.25
1.36	-2.92	8.55

0.8	-3.48	12.14
1.33	-2.95	8.73
3.27	-1.01	1.03
2.9	-1.38	1.92
5.59	1.31	1.7
3.65	-0.63	0.4
	M: 4.28	SS: 258.45

Treatment 2 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
-1.31	5.1	26.01
-19.2	-12.79	163.58
-4.34	2.07	4.28
-1.28	5.13	26.32
-4	2.41	5.81
-6.03	0.38	0.14
-8.71	-2.3	5.29
	M: -6.41	SS: 231.44

Surface Area of the sphenooccipital synchondroses on the axial section MSE vs Hyrax:

Comparing between the two means of the spheno-occipital synchondroses surface area of each treatment group after the treatment (T1) to determine the difference in treatment outcome between MSE and Hyrax group. The differences between the two groups were evaluated and a statistically significant difference was found of t value equal to 4.88385, and p value equal to 0.000039. The result is highly significant at $p < 0.001$.

Table 15:

Treatment 1 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
2.9	-0.72	0.51
10.78	7.16	51.34
5.09	1.48	2.18
2.63	-0.98	0.97
0.37	-3.24	10.53
0.14	-3.48	12.08

13.52	9.9	98.11
0.47	-3.14	9.89
0.64	-2.98	8.85
1.26	-2.36	5.55
0.7	-2.92	8.5
1.64	-1.98	3.9
5.18	1.56	2.45
4.28	0.66	0.44
5.18	1.56	2.45
3.06	-0.56	0.31
	M: 3.62	SS: 218.04

Treatment 2 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
-3.6	1.51	2.29
-9.54	-4.43	19.6
-2.38	2.73	7.47
-3.85	1.26	1.59
-12.59	-7.48	55.91
-1.13	3.98	15.86
-2.7	2.41	5.82
	M: -5.11	SS: 108.54

Linear Measurement of the spheno-occipital synchondroses on the sagittal section MSE vs Hyrax:

Comparing between the two means of the antero-posterior width of the spheno-occipital synchondroses of each treatment group after the treatment (T1) to determine the difference in treatment outcome between MSE and Hyrax group. The differences between the two groups were evaluated and a statistically significant difference was found of t value equal to 6.10073, and p value < 0.00001. The result is highly significant at p < 0.001 (Table 16).

Table 16:

Treatment 1 (X)	*Diff* (X - M)	*Sq. Diff* $(X - M)^2$
0.42	-0.24	0.06
0.61	-0.05	0
0.95	0.29	0.09
0.63	-0.03	0
0.35	-0.31	0.09
0.12	-0.54	0.29
0.33	-0.33	0.11
0.06	-0.6	0.36
0.34	-0.32	0.1
0.7	0.04	0
0.3	-0.36	0.13
0.2	-0.46	0.21
2.1	1.44	2.08
0.9	0.24	0.06
1.2	0.54	0.29
1.3	0.64	0.41
	M: 0.66	SS: 4.28

Treatment 2 (X)	*Diff* (X - M)	*Sq. Diff* $(X - M)^2$
-0.6	0.26	0.07
-0.86	0	0
-0.03	0.83	0.68
-1.05	-0.19	0.04
-1.66	-0.8	0.64
-1.44	-0.58	0.34
-0.36	0.5	0.25
	M: -0.86	SS: 2.02

Linear Measurement of the spheno-occipital Synchndroses on the axial section MSE vs Hyrax:

Comparing between the two means of the anteroposterior width of the spheno-occipital synchondrosis of each treatment group after the treatment (T1) to determine the difference in treatment outcome between MSE and Hyrax group. The differences between the two groups were evaluated and a statistically significant difference was found of t value equal to 9.40479, and p-value is < .00001. The result is highly significant at p < 0.001 (Table 17).

Table 17:

Treatment 1 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* (X - M)^2
0.18	-0.3	0.09
1	0.52	0.28
0.7	0.22	0.05
0.6	0.12	0.02
0.45	-0.02	0
0.2	-0.28	0.08
0.3	-0.18	0.03
0.37	-0.1	0.01
0.2	-0.28	0.08
0.6	0.12	0.02
0.3	-0.18	0.03
0.2	-0.28	0.08
0.5	0.02	0
0.8	0.32	0.11
0.4	-0.08	0.01
0.8	0.32	0.11
	M: 0.48	SS: 0.96

Treatment 2 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* (X - M)^2
-0.48	0.09	0.01
-0.8	-0.23	0.05
-0.3	0.27	0.07
-0.57	0	0
-0.85	-0.28	0.08

-0.68	-0.11	0.01
-0.3	0.27	0.07
	M: -0.57	SS: 0.30

Comparing between the surface are of the vomer between MSE vs Hyrax:

Comparing between the two means of the surface area of the vomer-sphenoid joint of each treatment group after the treatment (T1) to determine the difference in treatment outcome between MSE and Hyrax group. The differences between the two groups were evaluated and a statistically significant difference was found of t value equal to 4.00365, and p-value equal to 0.000322. The result is highly significant at $p < 0.001$ (Table 18).

Table 18:

Treatment 1 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
0.68	-0.52	0.27
0.59	-0.61	0.38
2.64	1.44	2.07
3.36	2.16	4.65
0.88	-0.32	0.1
0.44	-0.76	0.58
0.55	-0.65	0.43
1.5	0.3	0.09
0.91	-0.29	0.09
0.47	-0.73	0.54
0.5	-0.7	0.49
1.11	-0.09	0.01

0.61	-0.59	0.35
3.57	2.37	5.61
0.03	-1.17	1.37
1.4	0.2	0.04
	M: 1.20	SS: 17.06

Treatment 2 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
-0.8	-0.04	0
-0.31	0.45	0.21
0.51	1.27	1.62
-0.6	0.16	0.03
-3.04	-2.28	5.18
-1.05	-0.29	0.08
-0.06	0.7	0.5
	M: -0.76	SS: 7.61

Comparing between the linear widths of the vomer-sphenoid joint between MSE vs Hyrax:

Comparing between the two means of the linear measurements of the width of the vomer-sphenoid joint of each treatment group after the treatment (T1), in order to determine the difference of treatment outcome between MSE and Hyrax group. The differences between the two groups were evaluated and a statistically significant difference was found of t value equal to 2.68211, and p value equal to 0.006976. The result is significant at $p < 0.05$ (Table 19).

Table 19:

Treatment 1 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
1.31	0.6	0.36
0.73	0.02	0
0.52	-0.19	0.04
2.25	1.54	2.38
0.27	-0.44	0.19

0.13	-0.58	0.33
0.41	-0.3	0.09
2.2	1.49	2.22
0.27	-0.44	0.19
0.15	-0.56	0.31
0.2	-0.51	0.26
0.3	-0.41	0.17
1.1	0.39	0.15
1.2	0.49	0.24
0.1	-0.61	0.37
0.2	-0.51	0.26
	M: 0.71	SS: 7.57

Treatment 2 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* $(X - M)^2$
-0.02	0	0
-0.05	-0.03	0
0.07	0.09	0.01
-0.04	-0.02	0
-0.06	-0.04	0
-0.02	0	0
-0.03	-0.01	0
	M: -0.02	SS: 0.01

Discussion:

3D Measurements

Cephalometric super-impositions traditionally were the best and nearly the only way to quantitatively evaluate dental and skeletal changes in orthodontics. Structures that are stable are used as an orientation and registration landmarks. Furthermore, in cephalometric analysis the location of different bone structures can be described relative to those stable landmarks (13). Recently with the introduction of cone beam computed tomography (CBCT) and the development of new software in the orthodontic field. All these advancements enable us to reach an optimal alignment and therefore superimpose 3D CBCT pre and post scans. Moreover, we can obtain different sets of radiographic images at selected time points with sub-voxel accuracy after identifying the cranial base. The investigation of changes in treatment, aging, growth and relapse after treatment are now possible by using this technology. In this study, the superimposition method used is fully automated with voxel wise rigid registration of the entire surface of the cranial base structure for adults as well as the anterior cranial fossae for growing children. However, in order to avoid observer technique dependent error based on the overlap of anatomical landmark, the superimposition is automated. This method compares the grey level of intensity of each voxel in the cranial base structure to superimpose the post-treatment CBCT over the pre-treatment CBCT and which allows procedures of image analysis to be mainly independent of observer errors. In this study, we used OnDemad3D software by Cybermed Inc. which allows quantitative and visual assessment of the magnitude and location of changes over time by calculations and graphic overlays of the distances and surface areas between multiple time points. The superimposition of OnDemand3D have been validated in 2015 by Weissheimer.

References Planes:

In the present study we used three reference planes plus a novel methodology have been presented. This methodology have been developed with regard to establish a process to be able to analyze the movement of different skeleton structures affected by the palatal expansion therapy. Landmarks were tested for inter-rater reliability with interclass correlation coefficient (ICC), ICC has been at least 97.5% and higher for linear parameters and at least 95.4% and higher for the surface area, showing high reliability.

Sphenooccipital synchondroses (SOS) ossification:

The spheno-occipital synchondroses is quite important, because of its late ossification at adulthood, unlike the other synchondroses ossification where they ossify at prenatal. The growth of the cranial base cartilage is controlled by cycles of mitosis and apoptosis. The spheno-occipital synchondroses closure has been studied histologically, morphologically and radiographically (14, 17, 18, 20). Some of these findings show that there is no spheno-occipital synchondroses open in any patient after the age of 13. Also, other studies demonstrated that the spheno-occipital synchondroses is involved during the rapid maxillary expansion therapy (RPE) but the findings in these studies can't be applied to adults and only can be applied to young growing patients (4, 19).

The involvement of the SOS during expansion therapy has an important research and clinical implication which can explain the useful treatment effect of RME in favor of patients with class III malocclusion patients. The opening of the SOS could account for the forward and downward movement of the midface during RME, suggesting that the SOS can undergo bone remolding.

Stress on the synchondroses can trigger biomolecular events, which could lead to enhanced endochondral ossification. Recent studies showed the tensile stress increased growth at SOS. Thus, improvement of growth at the synchondroses appears to be expected following the application of mechanical force (4, 12, 19). Growth modification therapy may be possible in older patients as we have demonstrated in our study. Combining MSE with face mask therapy could be in favor especially with patients with class III malocclusion.

<u>The impact of age on skeleton effects after expansion therapy:</u>

The impact of RME on adult patents and the magnitude of skeleton changes after the treatment is an interesting topic in clinical orthodontics. In the previous studies, the age range of the sample only investigated skeletal changes in young patients (4, 19). However, in our study, we investigated the MSE effect on adult patients and we have seen some dimensional high statistical significant changes after the therapy $p \leq 0.001$. Growth modification therapy may be possible in older patients as we have demonstrated in our study. Combining MSE with face mask therapy could be in favor with patients with class III malocclusion.

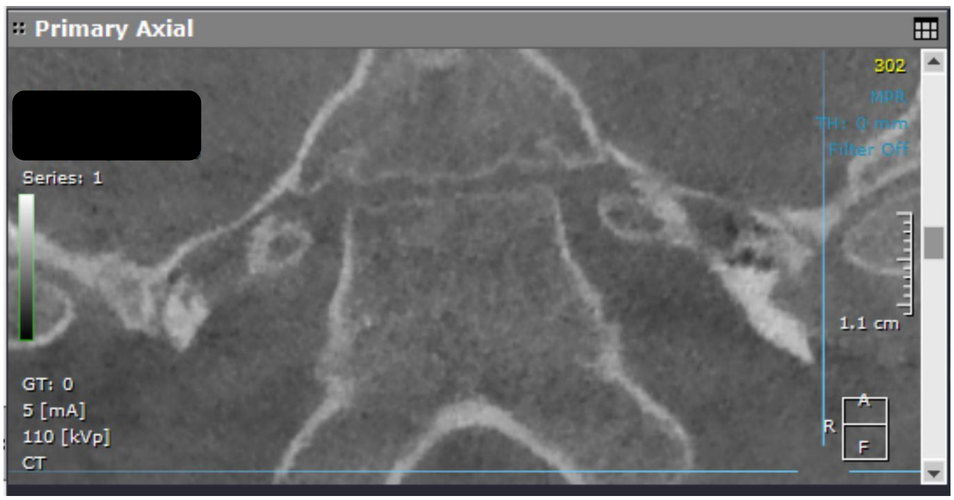
Relationship between the Sphenooccipital synchondroses and the craniofacial development:

Cranial base synchondroses is important growth center of the craniofacial skeleton, especially the synchondroses between the sphenoid and occipital bones. The reason for its importance stems from it's the contribution to the post-natal cranial base development compared to other midline chondral structures (15). Furthermore, the spheno-occipital synchondroses (SOS) is also an important growth center for the craniofacial skeleton. The (SOS) plays a significant role as a link between the development of the facial skeleton and the cranial vault. The abnormalities of the synchondroses can lead to several developmental and growth conditions including craniofacial development (15). Fortunately, in orthodontic mechanical forces are applied to the cranial base for growth modification therapy for such conditions. However, Limited studies have been conducted on the effect of the palatal expansion therapy and treatment outcome on cranial base. Therefore, further molecular biology, genetics and radiographic investigations on the spheno-occipital synchondroses are needed to understand the factors effect on the craniofacial development.

MSE vs Hyrax:

When comparing the two different treatment modalities as seen in this study, both MSE and Hyrax had dissimilar results in their effect on the spheno-occipital synchondroses and the vomer-sphenoid joint. This dissimilarity could be due to the two different treatment concepts, on one hand in MSE its bone to bone relationship where on the other hand in Hyrax its tooth to bone relationship, which can lead to the difference in the tensile forces transmitted to further structure far from the maxillary bone. Also, the widening of the SOS in MSE group can be result of the palatal expansion which lead to the downward and forward of the midface which can causes bone strain in the cranial base near the SOS. The difference between the MSE and Hyrax appliance and the effect on the SOS and vomer-sphenoid joint can be seen for both groups in the next figures (Fig 29 - 48).

Fig 29: MSE



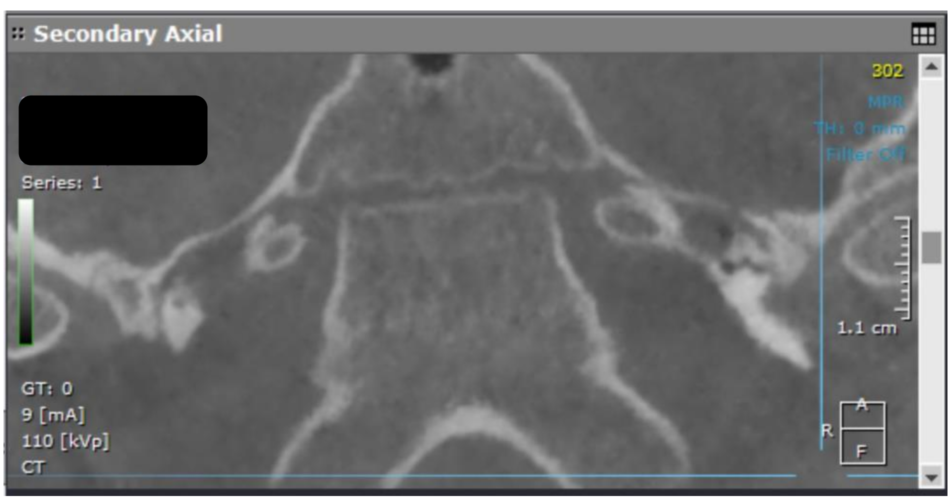
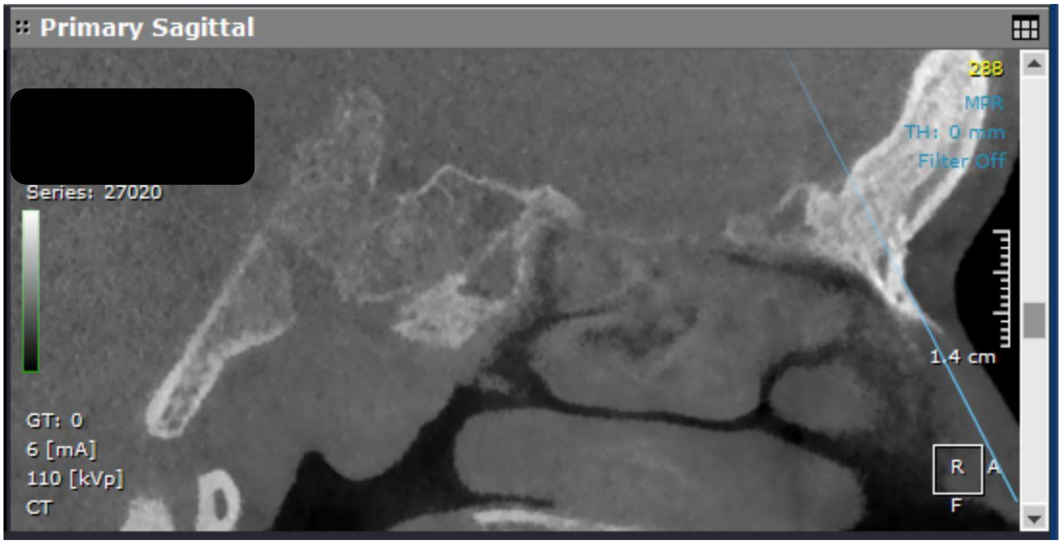


Fig 30: MSE


Primary Sagittal
[redacted]
303
MPR
TH: 0 mm
Filter Off
1.2 cm
Secondary Sagittal
[redacted]
Series: 1
303
MPR
TH: 0 mm
Filter Off
1.2 cm

Fig 31: MSE


Primary Sagittal
[redacted]
Series: 27020
288
MPR
TH: 0 mm
Filter Off
1.4 cm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F

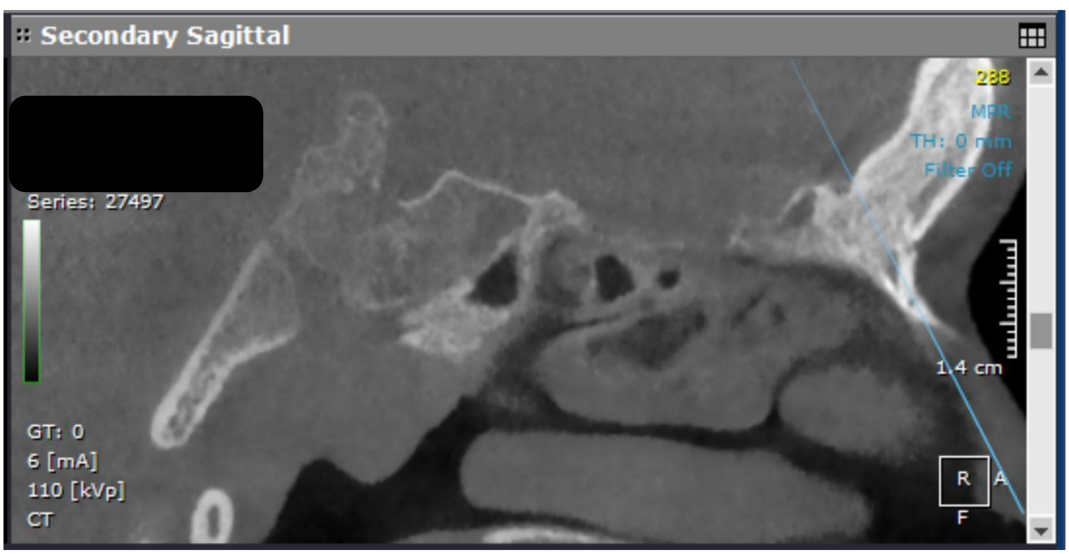

Secondary Sagittal
[redacted]
Series: 27497
288
MPR
TH: 0 mm
Filter Off
1.4 cm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F

Fig 32: MSE

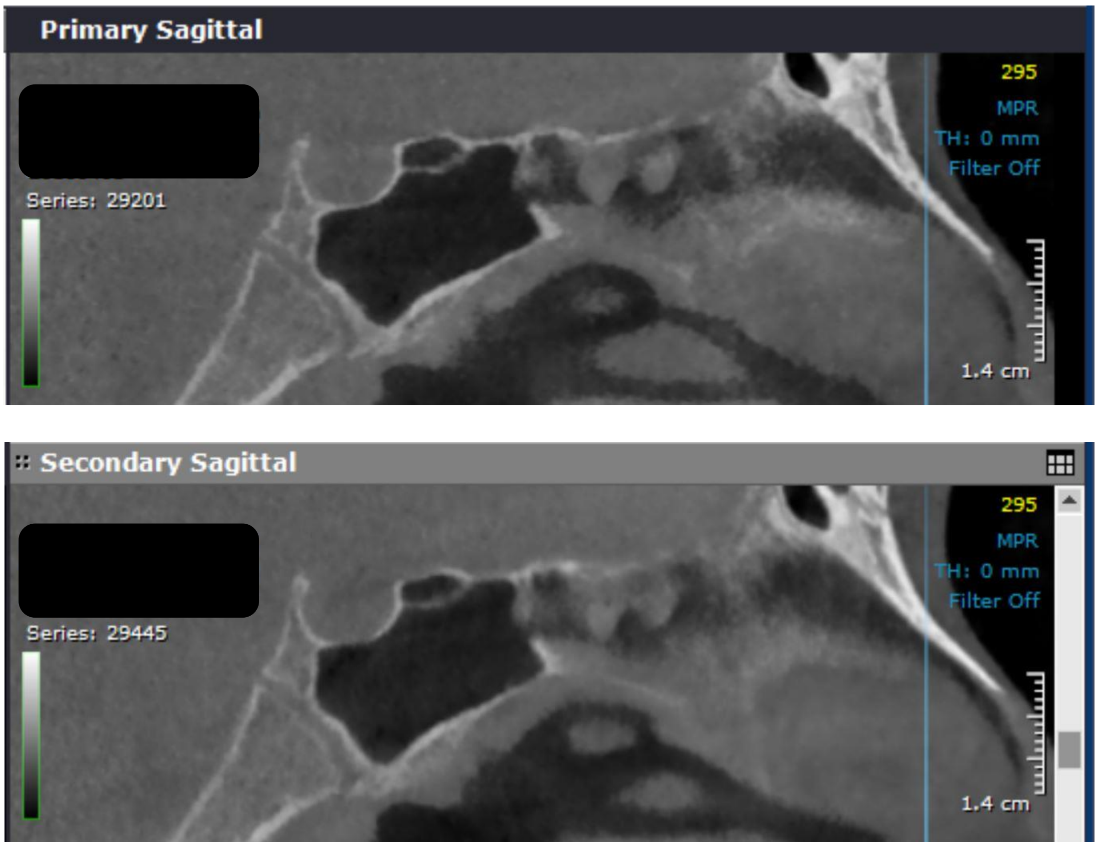
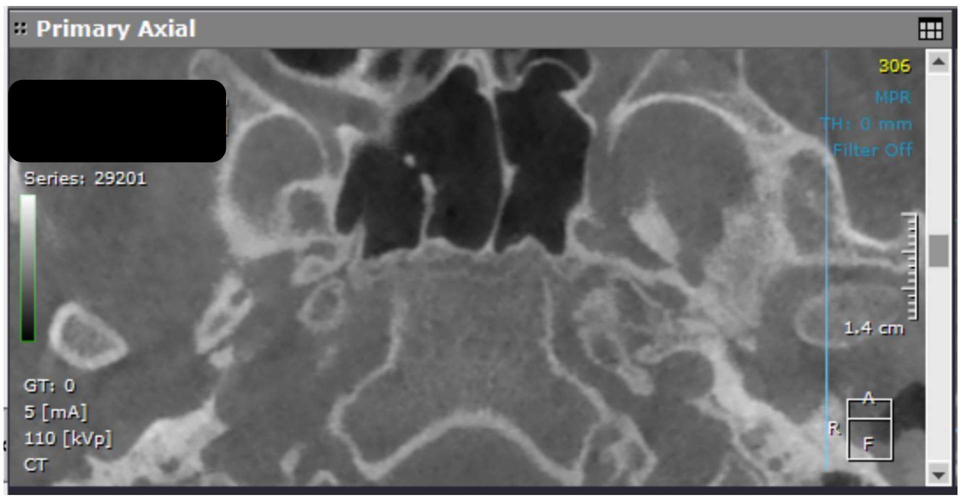
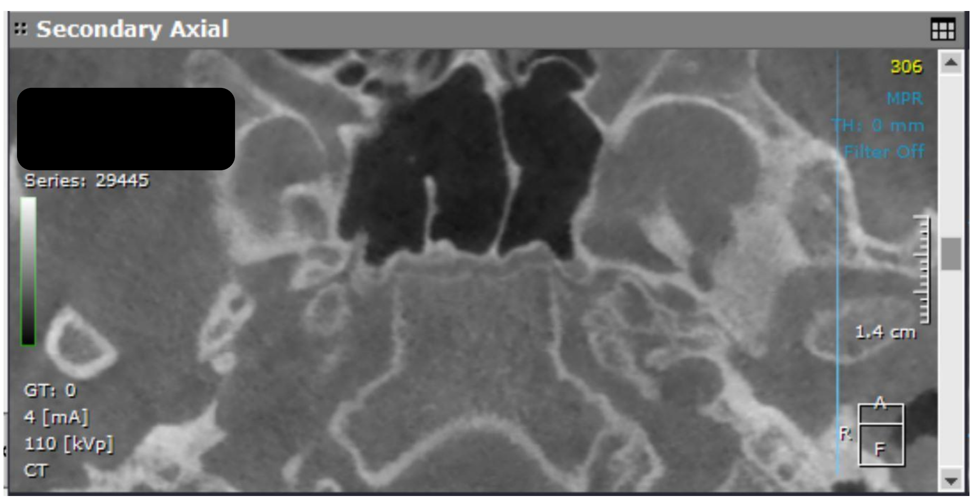

Primary Sagittal
[redacted]
Series: 29201
295
MPR
TH: 0 mm
Filter Off
1.4 cm
Secondary Sagittal
[redacted]
Series: 29445
295
MPR
TH: 0 mm
Filter Off
1.4 cm

Fig 33: MSE


Primary Axial
[redacted]
Series: 29201
GT: 0
5 [mA]
110 [kVp]
CT
306
MPR
TH: 0 mm
Filter Off
1.4 cm
A
R
F


Secondary Axial
[redacted]
Series: 29445
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4 [mA]
110 [kVp]
CT
306
MPR
TH: 0 mm
Filter Off
1.4 cm
A
R
F

Fig 34: MSE

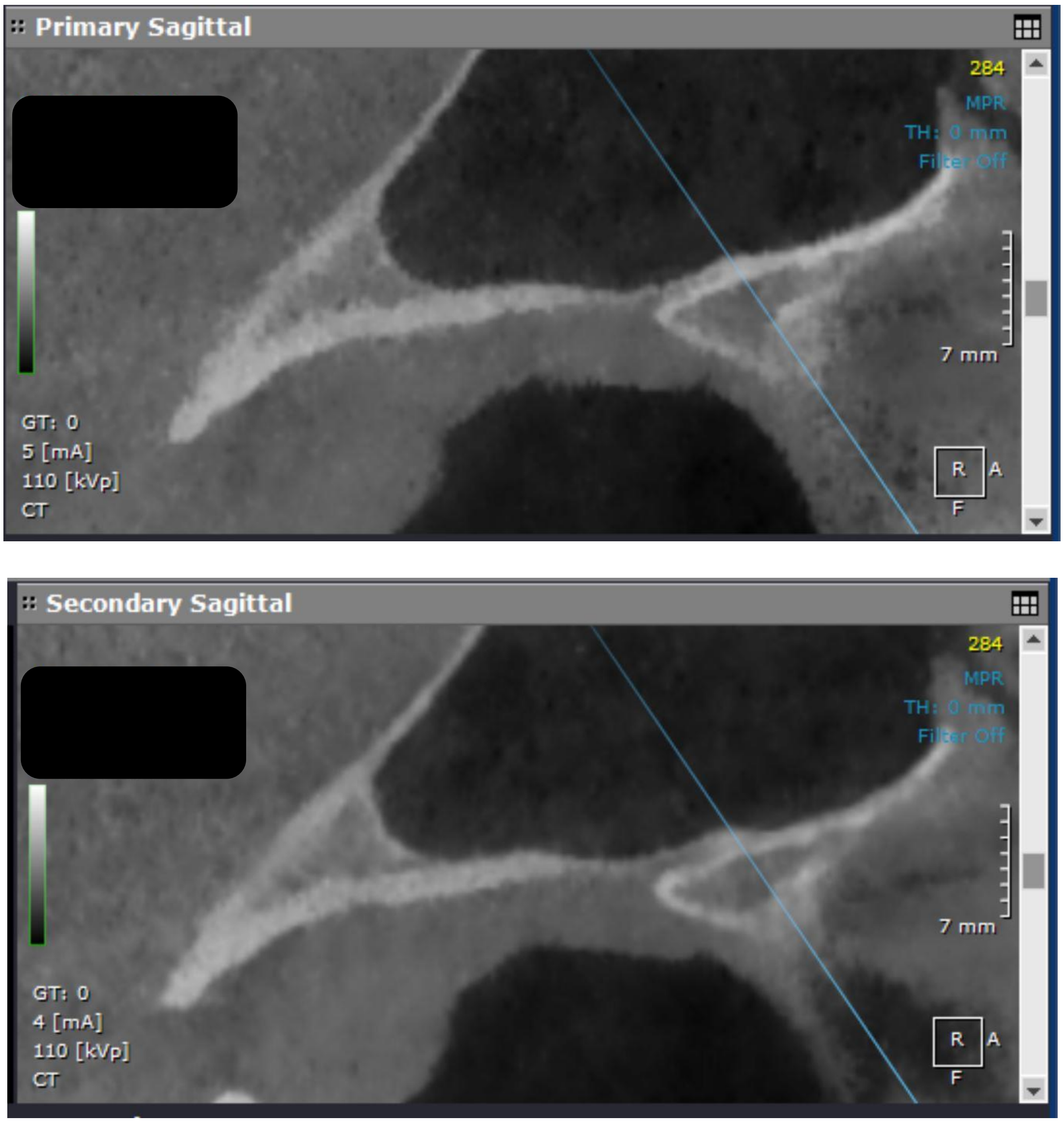

Primary Sagittal
284
MPR
TH: 0 mm
Filter Off
7 mm
GT: 0
5 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
284
MPR
TH: 0 mm
Filter Off
7 mm
GT: 0
4 [mA]
110 [kVp]
CT
R
A
F

Fig 35: MSE

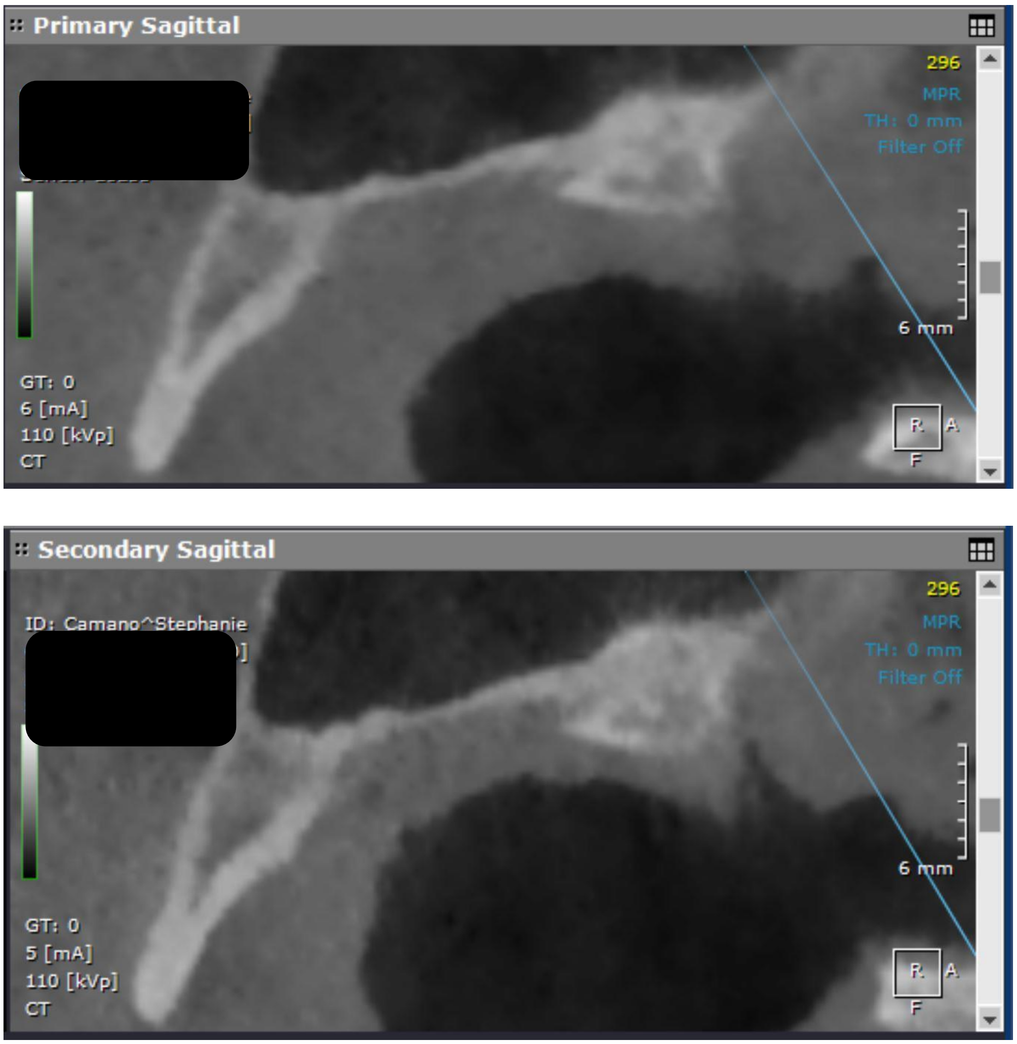

Primary Sagittal
[redacted]
296
MPR
TH: 0 mm
Filter Off
6 mm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
ID: Camano^Stephanie
[redacted]
296
MPR
TH: 0 mm
Filter Off
6 mm
GT: 0
5 [mA]
110 [kVp]
CT
R
A
F

Fig 36: MSE

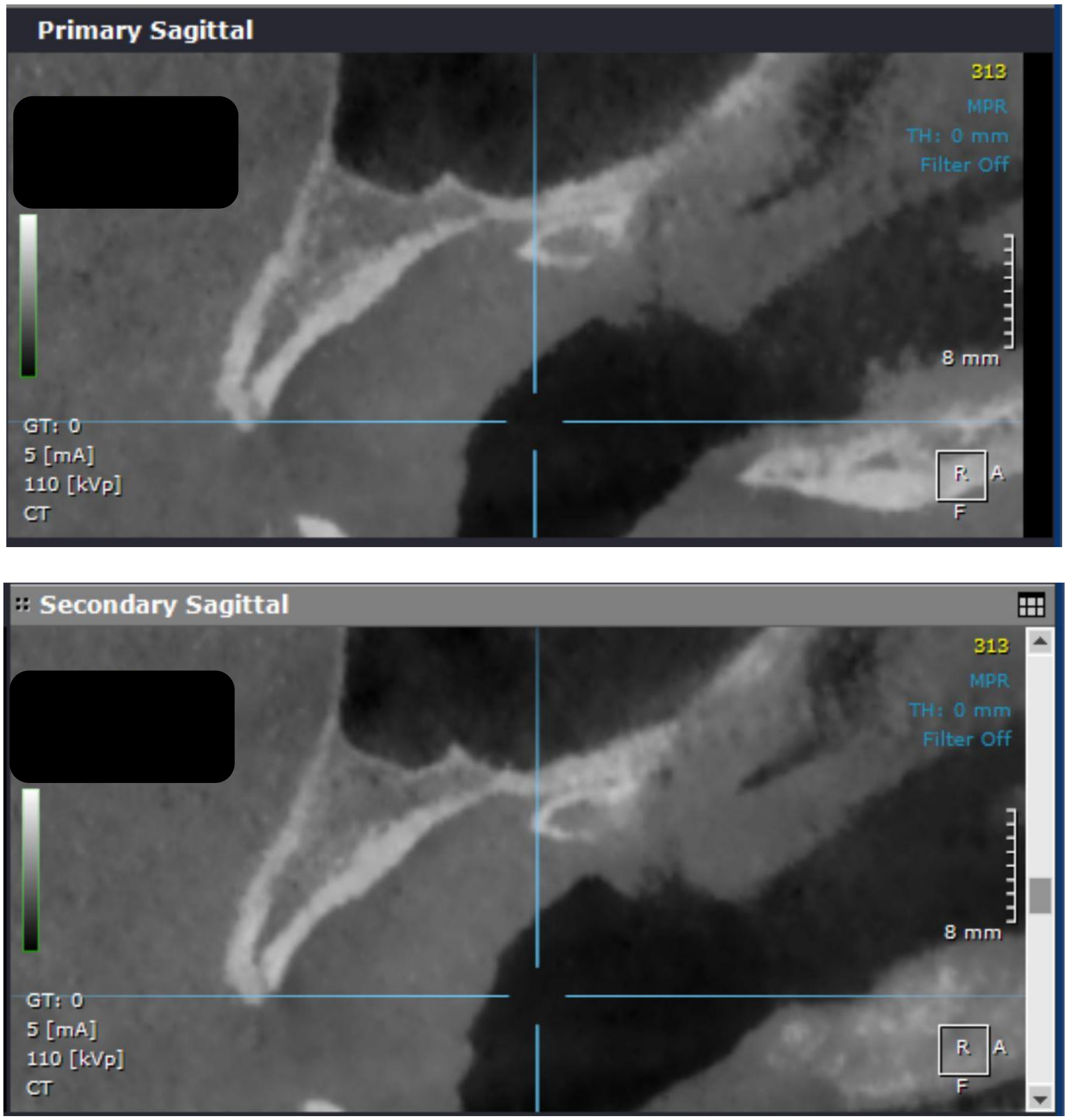
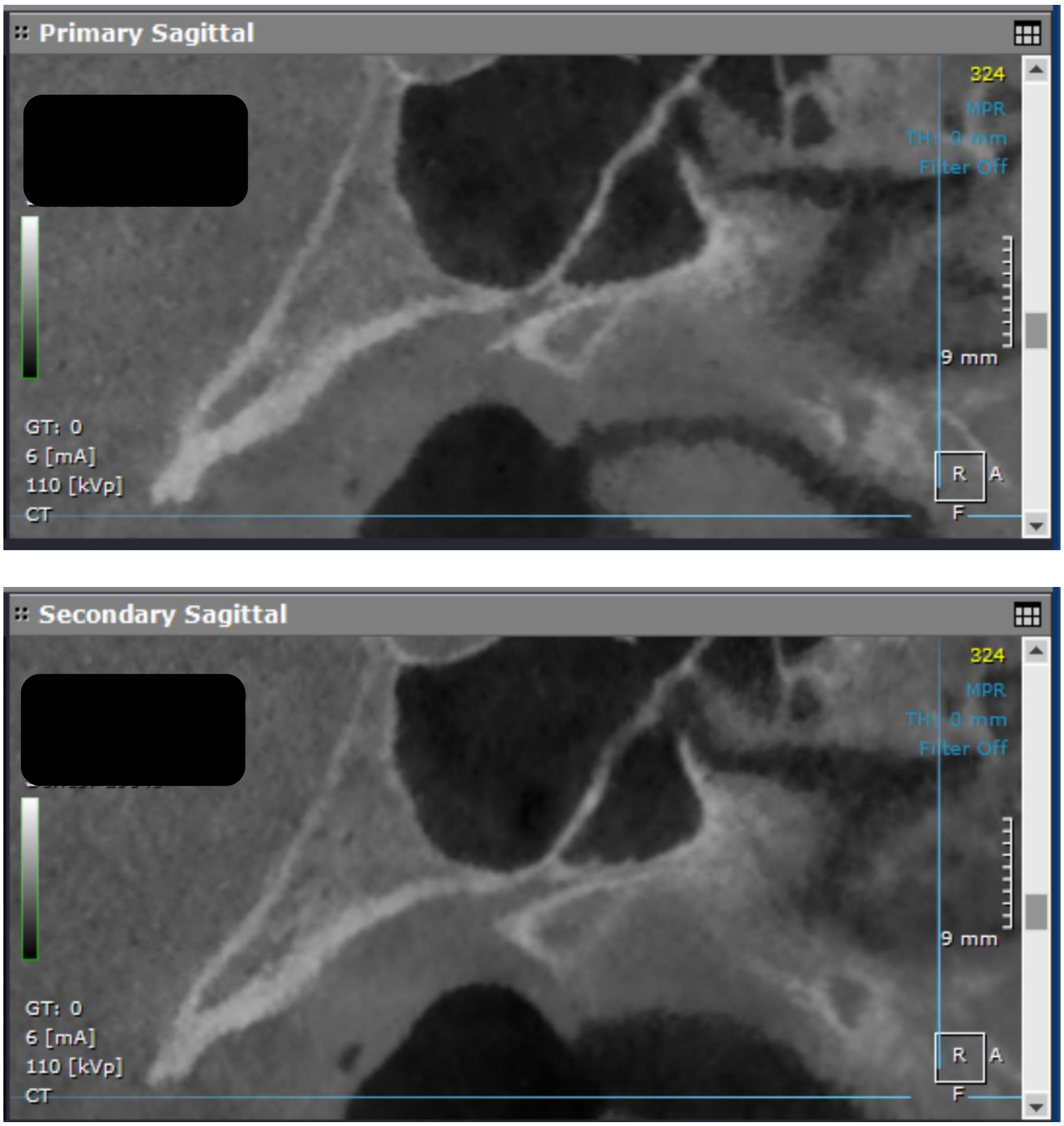

Primary Sagittal
[redacted]
313
MPR
TH: 0 mm
Filter Off
8 mm
GT: 0
5 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
[redacted]
313
MPR
TH: 0 mm
Filter Off
8 mm
GT: 0
5 [mA]
110 [kVp]
CT
R
A
F

Fig 37: MSE

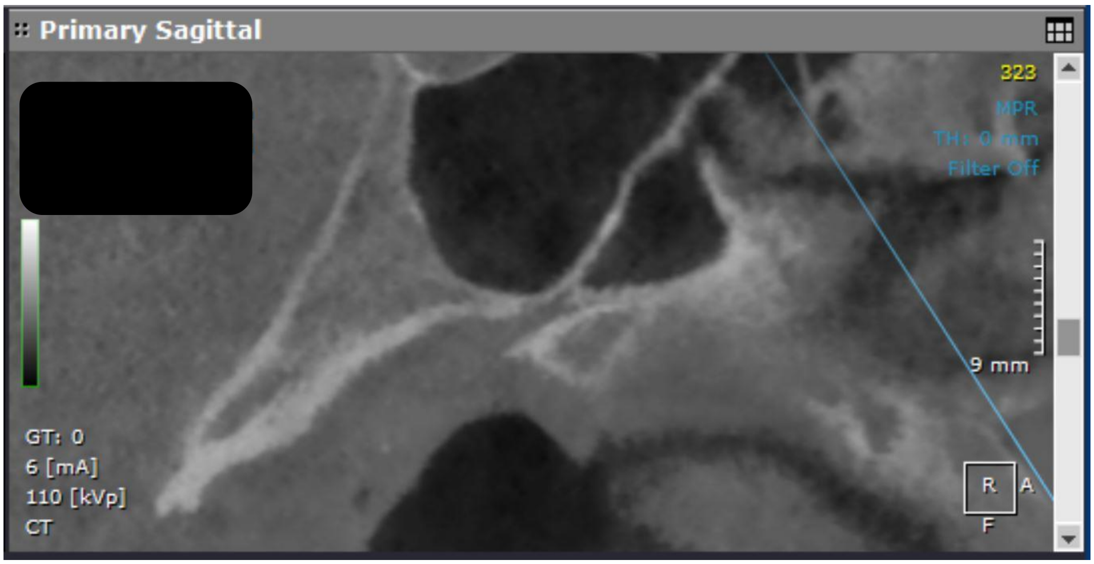

Primary Sagittal
288
MPR
TH: 0 mm
Filter Off
8 mm
GT: 0
3 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
288
MPR
TH: 0 mm
Filter Off
8 mm
GT: 0
4 [mA]
110 [kVp]
CT
R
A
F

Fig 38: MSE



Primary Sagittal
324
MPR
TH: 0 mm
Filter Off
[redacted]
9 mm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
324
MPR
TH: 0 mm
Filter Off
[redacted]
9 mm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F

Fig 39: MSE


Primary Sagittal
[redacted]
323
MPR
TH: 0 mm
Filter Off
9 mm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F

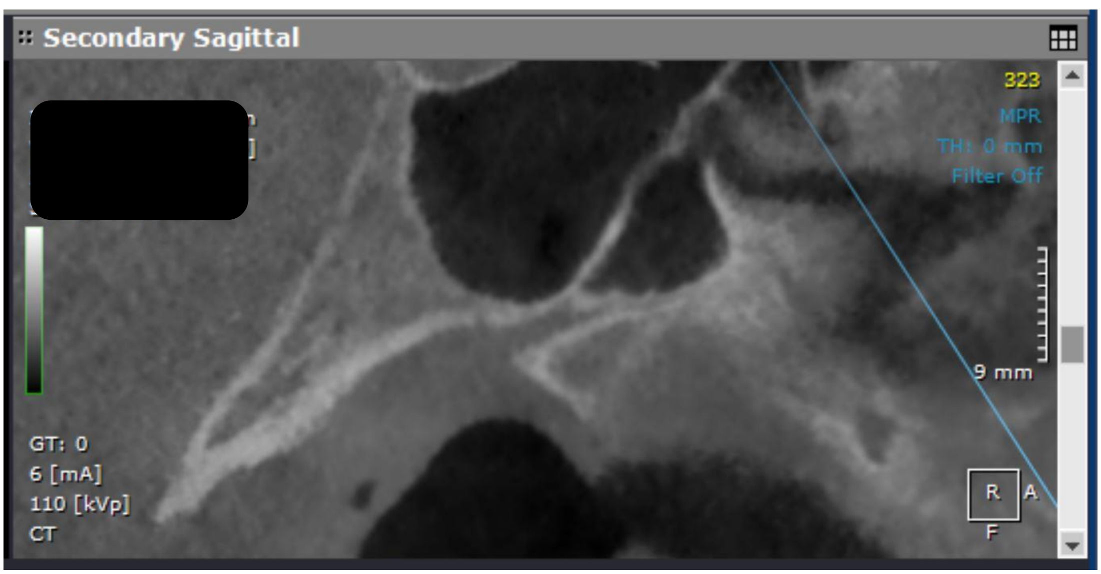

Secondary Sagittal
[redacted]
323
MPR
TH: 0 mm
Filter Off
9 mm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F

Fig 40: MSE

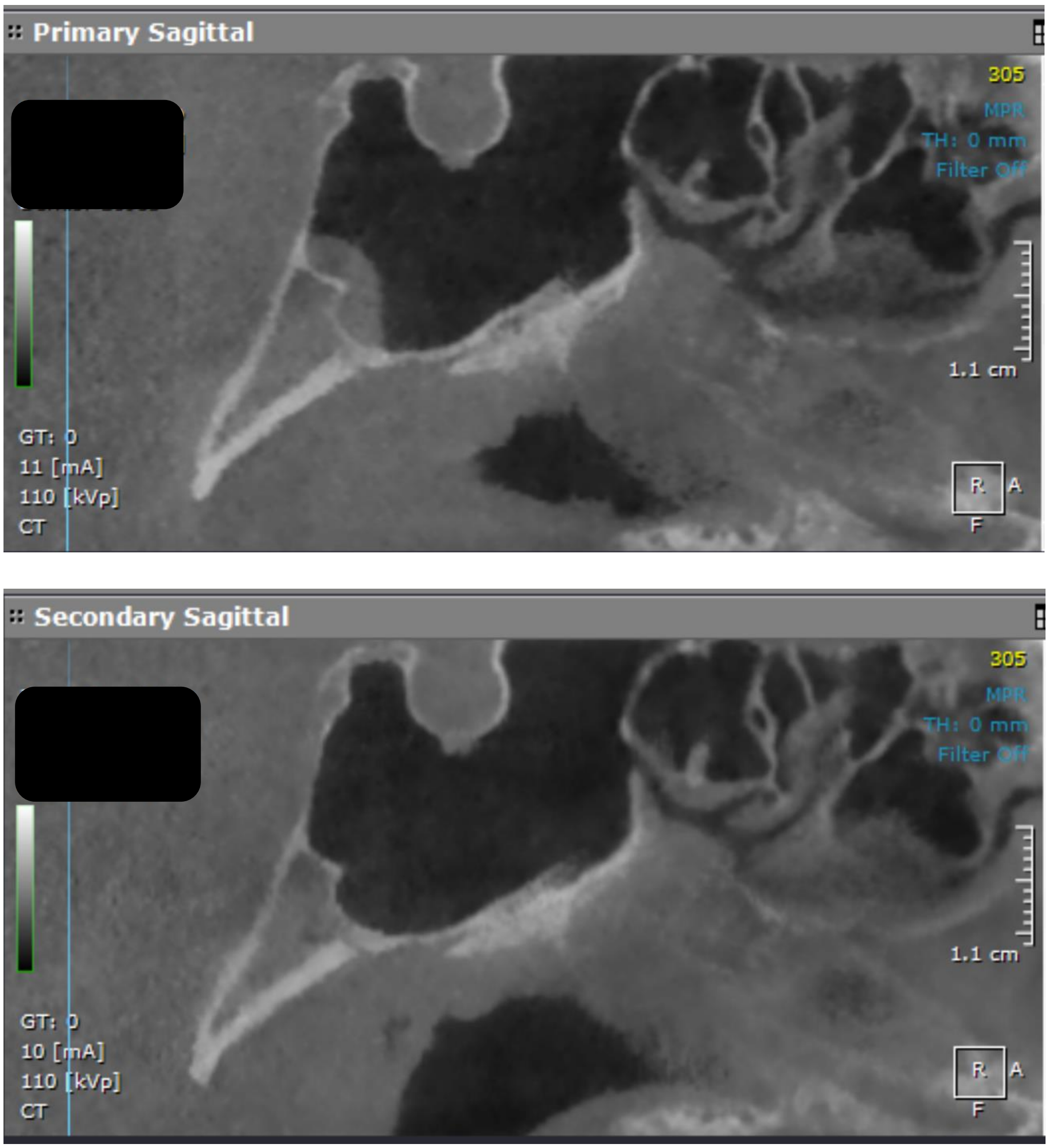

Primary Sagittal
[redacted]
305
MPR
TH: 0 mm
Filter Off
1.1 cm
GT: 0
11 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
[redacted]
305
MPR
TH: 0 mm
Filter Off
1.1 cm
GT: 0
10 [mA]
110 [kVp]
CT
R
A
F

Fig 41: MSE

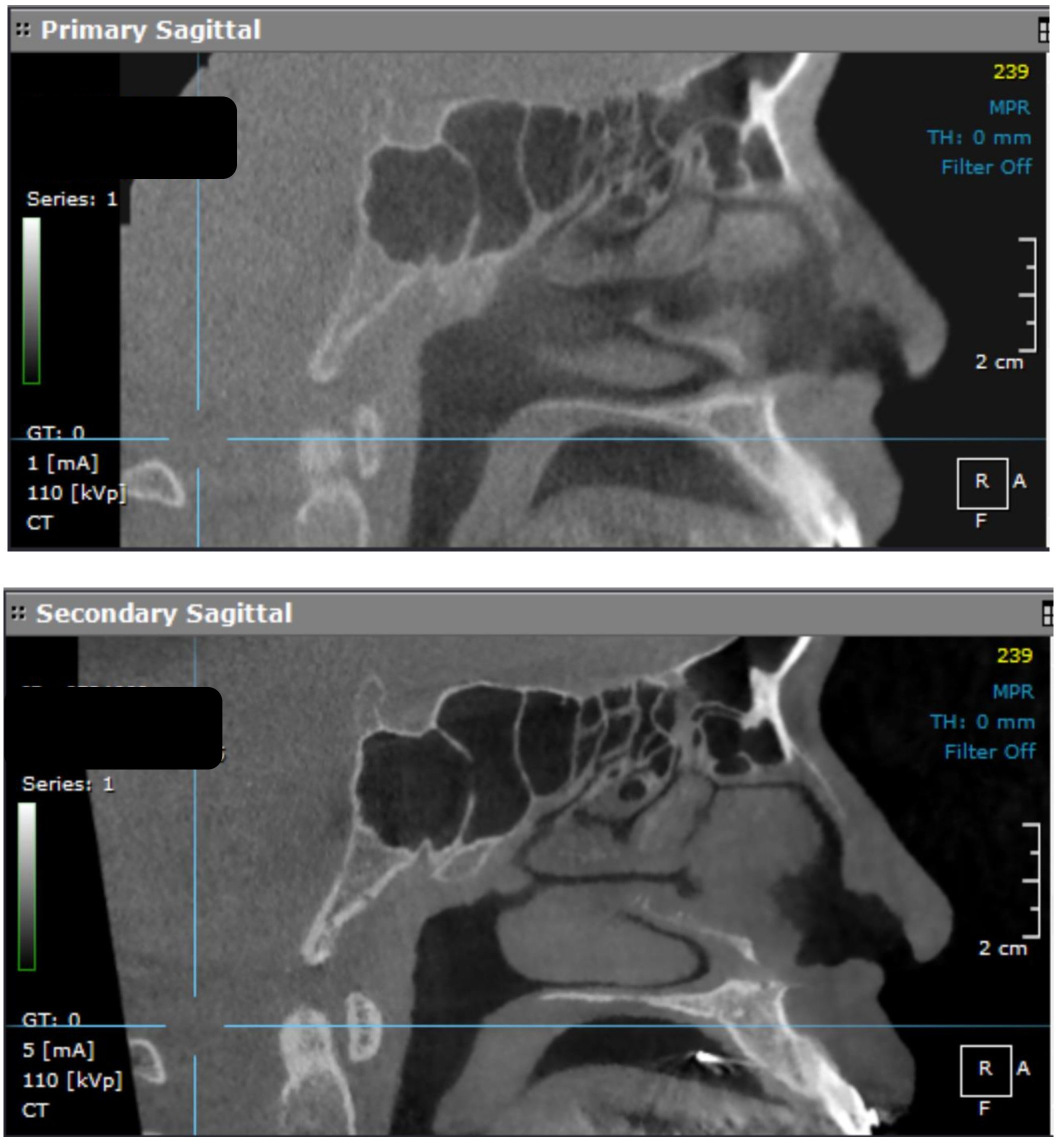
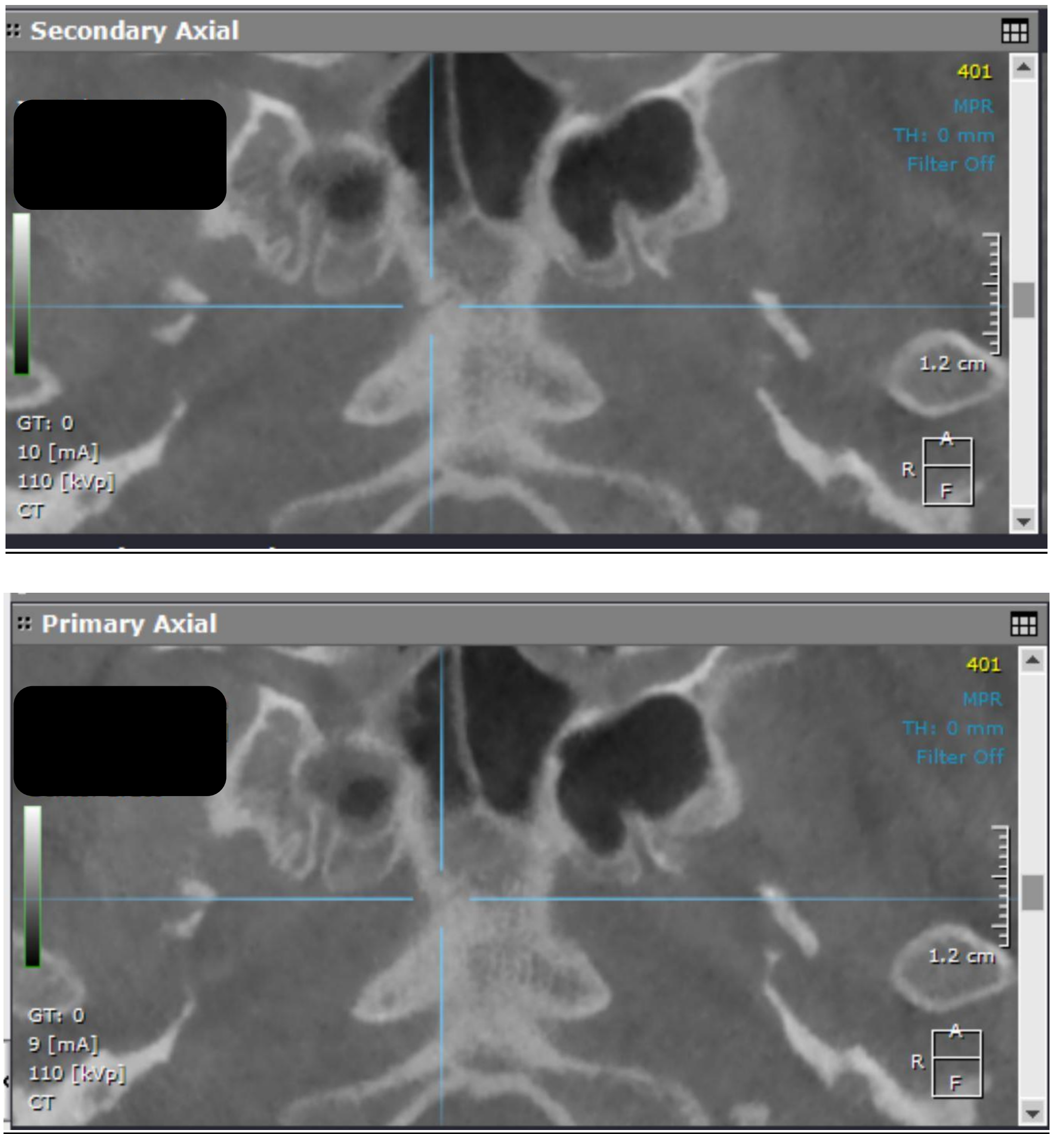

Primary Sagittal
[redacted]
Series: 1
GT: 0
1 [mA]
110 [kVp]
CT
239
MPR
TH: 0 mm
Filter Off
2 cm
R
A
F
Secondary Sagittal
[redacted]
Series: 1
GT: 0
5 [mA]
110 [kVp]
CT
239
MPR
TH: 0 mm
Filter Off
2 cm
R
A
F

Fig 42: Hyrax



Secondary Axial
401
MPR
TH: 0 mm
Filter Off
[redacted]
1.2 cm
GT: 0
10 [mA]
110 [kVp]
CT
A
R
F
Primary Axial
401
MPR
TH: 0 mm
Filter Off
[redacted]
1.2 cm
GT: 0
9 [mA]
110 [kVp]
CT
A
R
F

Fig 43: Hyrax

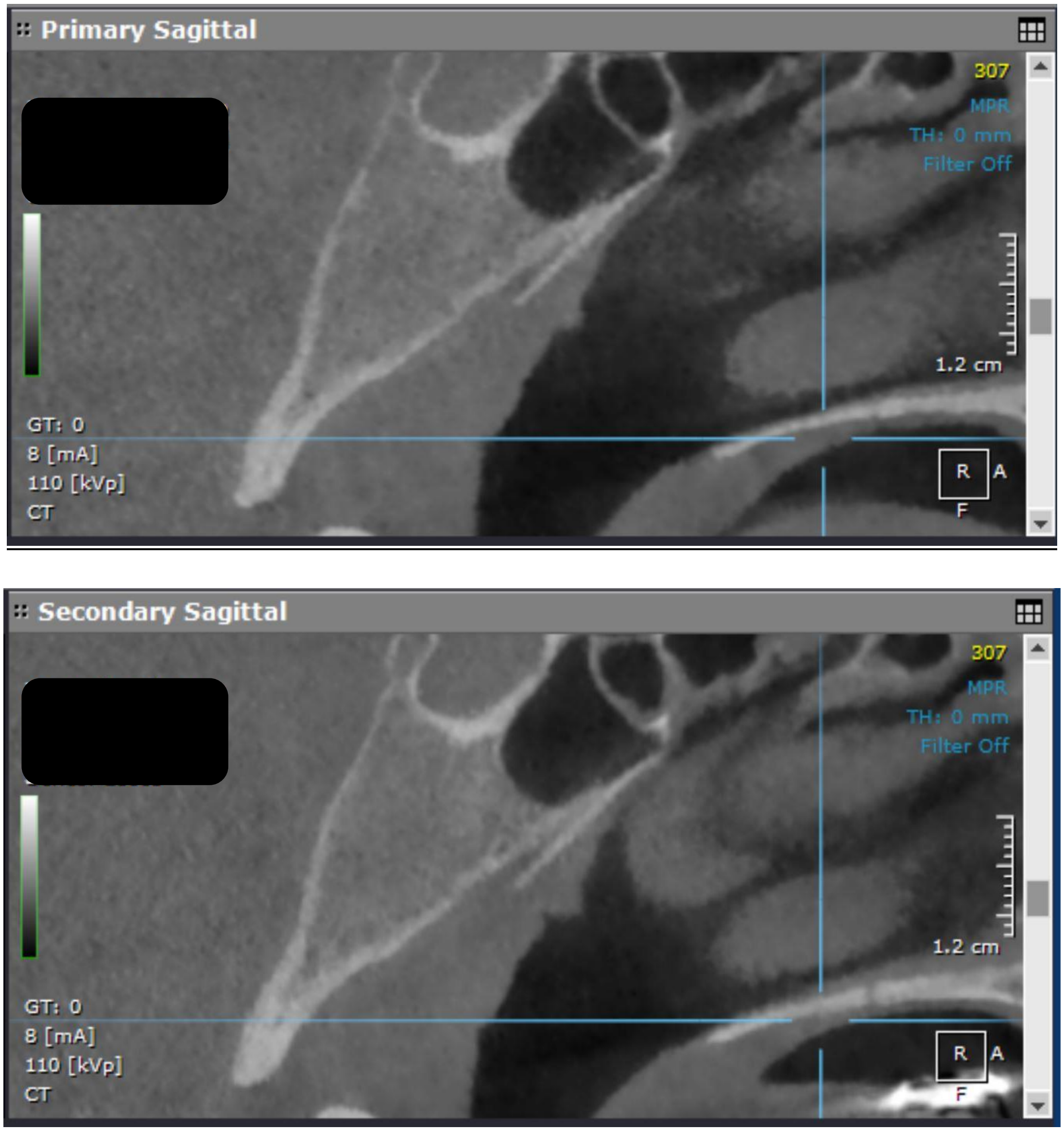
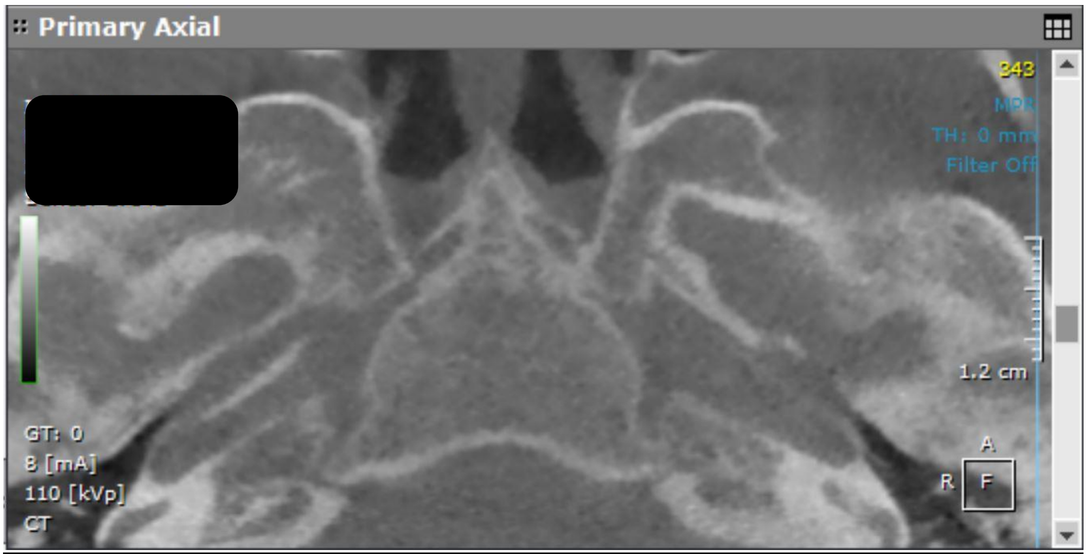

Primary Sagittal
[redacted]
307
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
8 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
[redacted]
307
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
8 [mA]
110 [kVp]
CT
R
A
F

Fig 44: Hyrax


Primary Axial
[redacted]
343
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
8 [mA]
110 [kVp]
CT
A
R
F

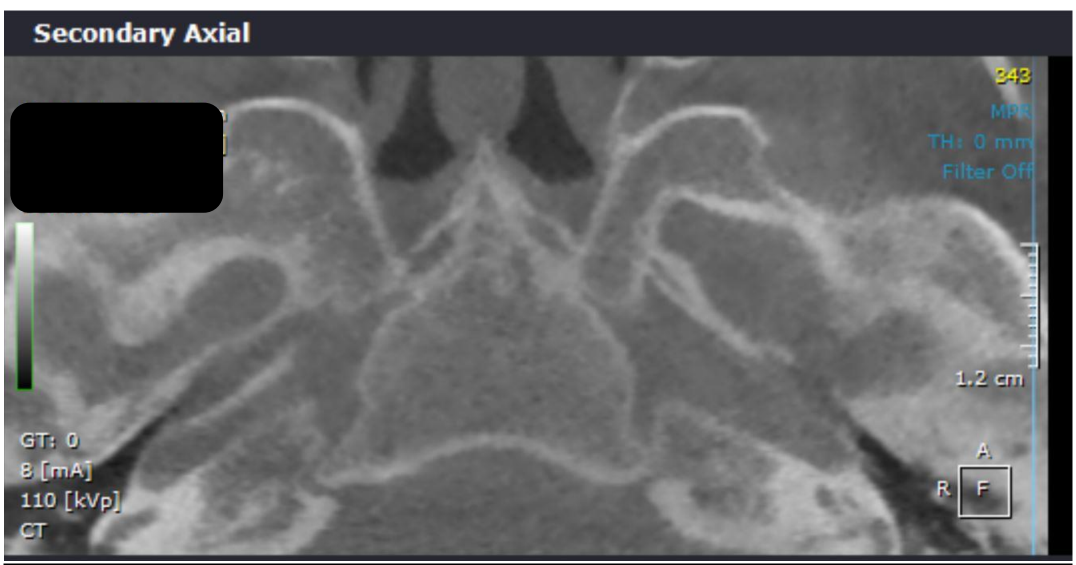

Secondary Axial
[redacted]
343
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
8 [mA]
110 [kVp]
CT
A
R
F

Fig 45: Hyrax

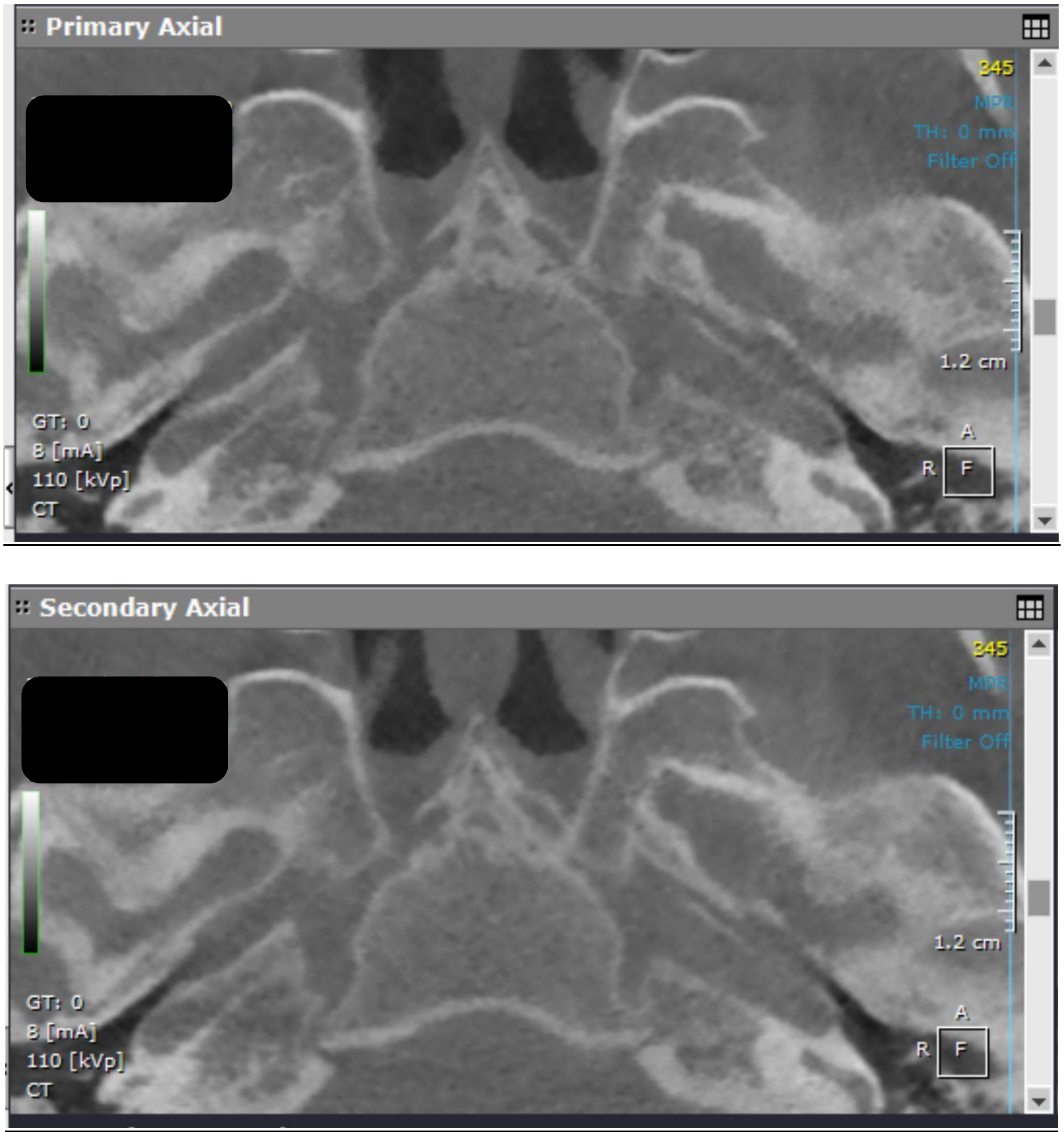

Primary Axial
[redacted]
345
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
8 [mA]
110 [kVp]
CT
A
R
F
Secondary Axial
[redacted]
345
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
8 [mA]
110 [kVp]
CT
A
R
F

Fig 46: Hyrax

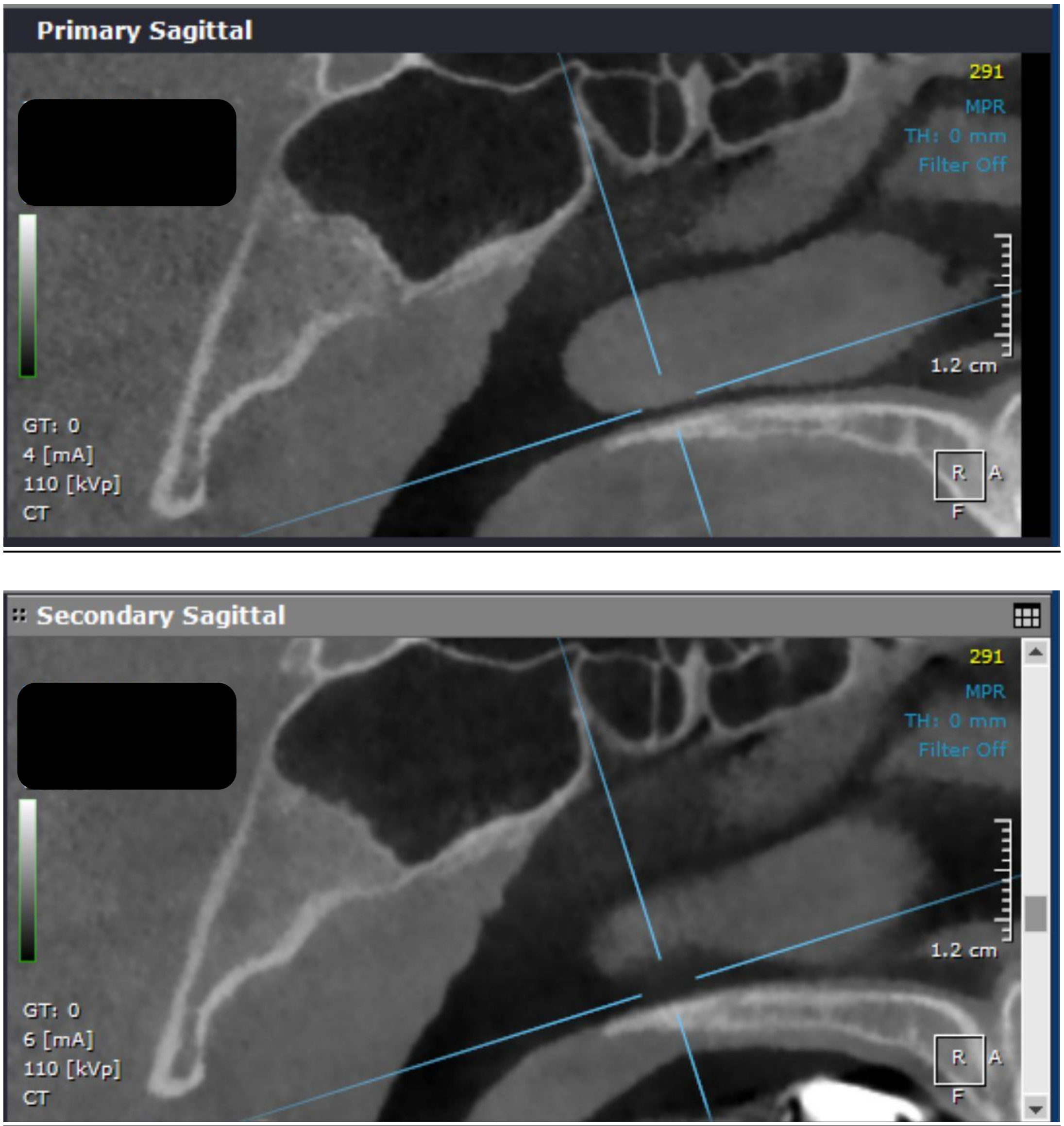
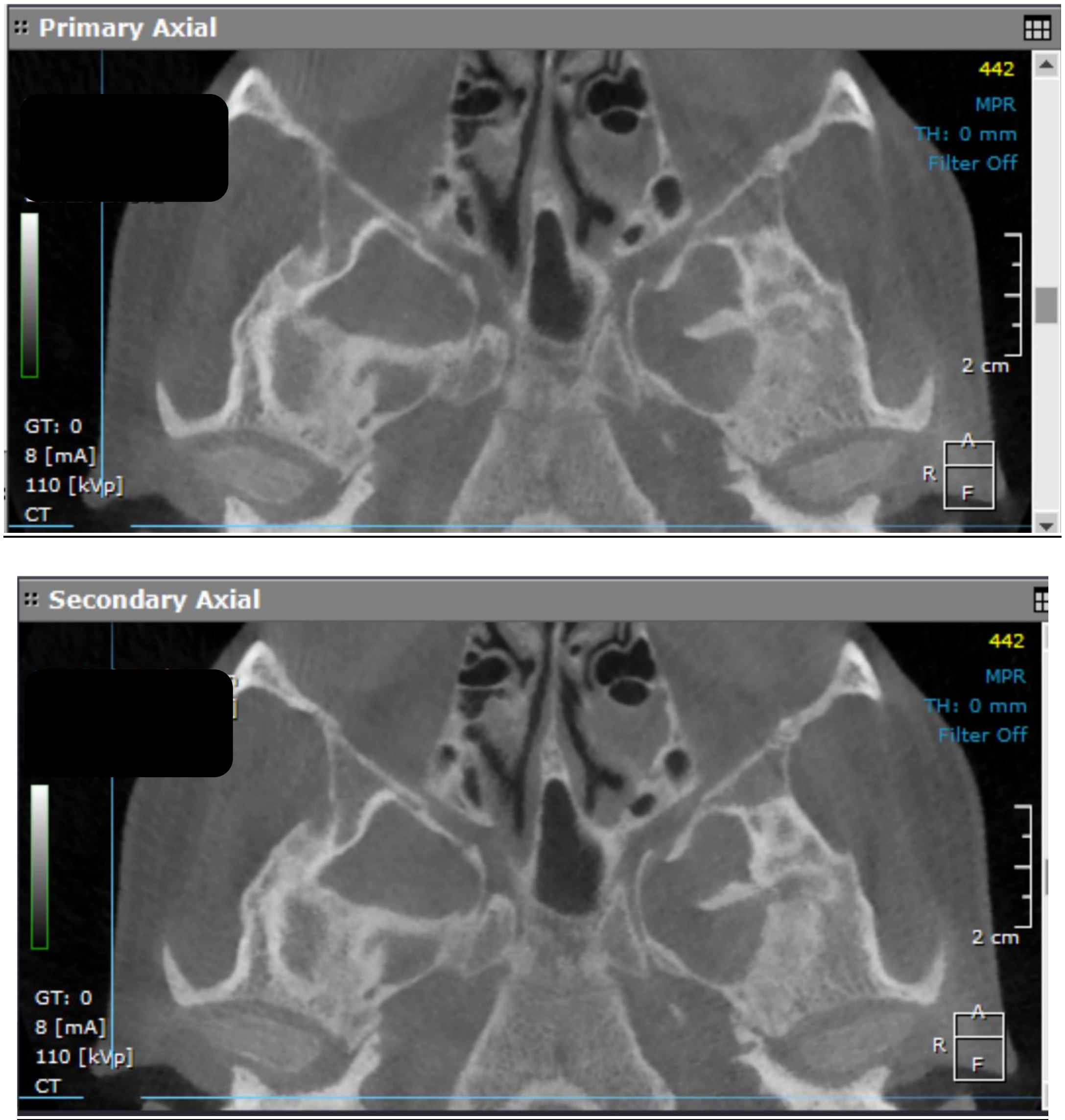
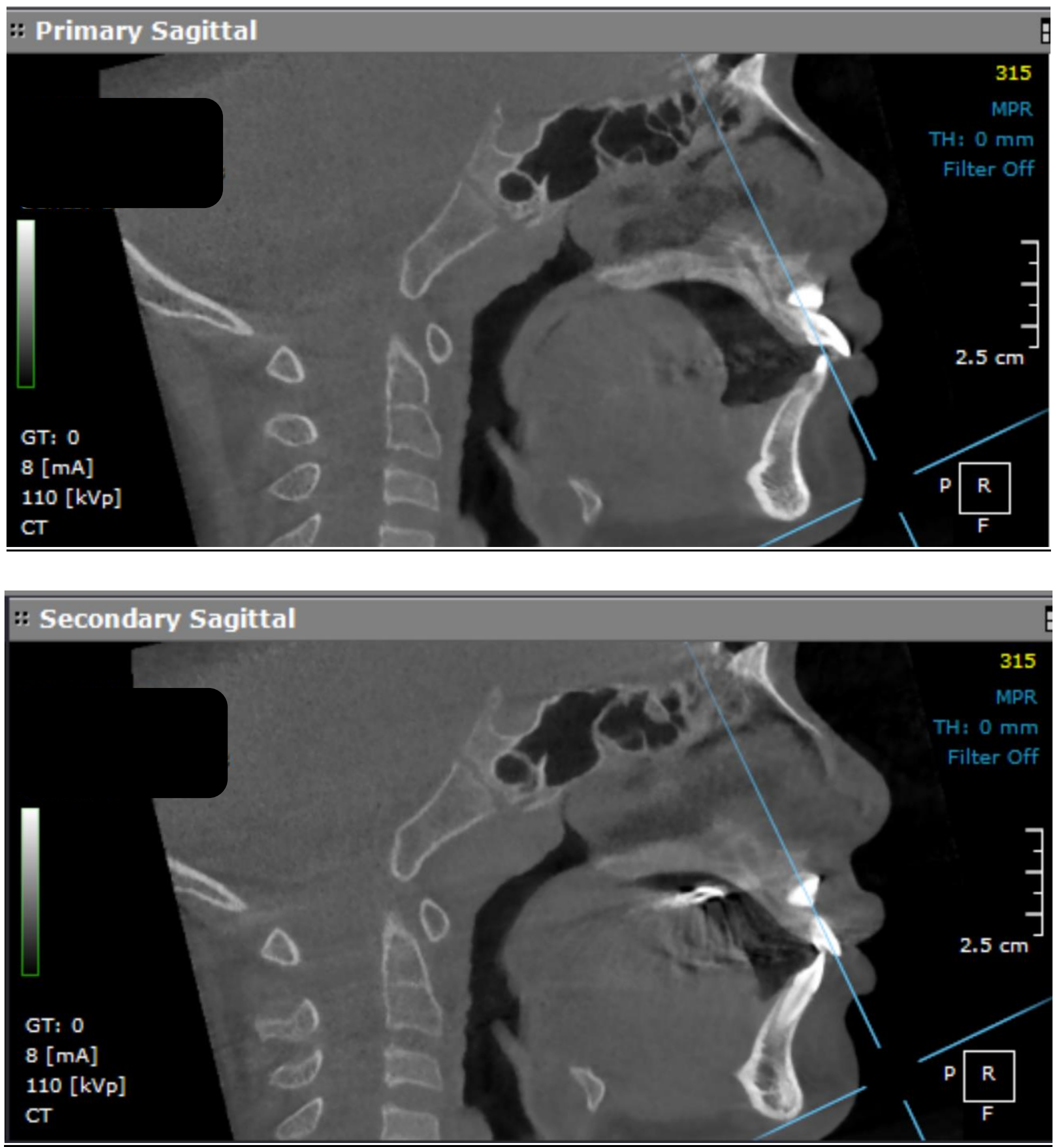

Primary Sagittal
[redacted]
291
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
4 [mA]
110 [kVp]
CT
R
A
F
Secondary Sagittal
[redacted]
291
MPR
TH: 0 mm
Filter Off
1.2 cm
GT: 0
6 [mA]
110 [kVp]
CT
R
A
F

Fig 47: Hyrax



Primary Axial
442
MPR
TH: 0 mm
Filter Off
2 cm
GT: 0
8 [mA]
110 [kVp]
CT
A
R
F
Secondary Axial
442
MPR
TH: 0 mm
Filter Off
2 cm
GT: 0
8 [mA]
110 [kVp]
CT
A
R
F

Fig 48: Hyrax


Primary Sagittal
[redacted]
315
MPR
TH: 0 mm
Filter Off
2.5 cm
GT: 0
8 [mA]
110 [kVp]
CT
P
R
F
Secondary Sagittal
[redacted]
315
MPR
TH: 0 mm
Filter Off
2.5 cm
GT: 0
8 [mA]
110 [kVp]
CT
P
R
F

Maxillary expansion and its impact on the vomer-sphenoid joint bone:

The vomer bone is a thin, small and plow shaped that occupies and splits that nasal cavity in the midline. The vomer forms the posterior - inferior section of the nasal septum, which splits the nasal cavity.

A significant increase in the width of the nasal cavity was found in multiple different studies, showing that these areas are affected by the forces generated by maxillary expansion therapy (3, 4). In our study, we found that the maxillary skeletal expansion (MSE) affected the vomer-sphenoid joint bone and it shows that the vomer moves inferiorly. The MSE produced a significant increase in the width of the vomer bone-sphenoid joint over the hyrax $p \leq 0.05$. The increase in the width of the vomer bone-sphenoid joint supports that the vomer follows the maxilla.

Conclusion:

- The novel methodology allowed to quantify the changes regarding the spheno-occipital synchondrosis and the vomer-sphenoid joint bone.
- Spheno-occipital synchondrosis (SOS) opens in older patients.
- MSE expansion leads to widening of the spheno-occipital synchondrosis.
- No widening of the SOS in the Hyrax group.
- MSE produces significant dimensional changes in the width of the vomer-sphenoid joint bone which effect the nasal cavity.
- The vomer bone moves inferior during the MSE treatment.
- The vomer doesn’t move in the Hyrax group.
- The comparative analysis provides evidence that there are statistical significant changes between the two treatment groups regarding the spheno-occipital synchondrosis (SOS) and vomer.
- With Maxillary Skeleton Expansion (MSE) the midface moves downward and forward and causes bone strain in the cranial base near SOS which can explain the widening of the SOS.
- CBCT imaging proved to be a useful 3D tool for the evaluation and assessment of treatment effects.

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