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3D Airway changes using CBCT in patients following mandibular advancement surgery with and without constriction

INTRODUCTION

Malocclusion caused by skeletal or dental factors is widespread with ethnicity being one factor in the type of malocclusion observed. Class II malocclusion is higher in Caucasians of Northern European descent[1 2], whereas the prevalence of Class III malocclusions are more commonly found in the Hispanic and Asian population which suggests a genetic component.[3] According to the National Health and Nutrition Examination Survey (NHANES II) the prevalence of Class II malocclusion in adults in the United States approximates 13.4%.[4]

Class II can result from dentoalveolar abnormalities, skeletal malpositioning, or both. In Class II dental malocclusions, the lower molar is distally positioned relative to the upper molar but the skeletal bases are appropriately positioned. For skeletal Class II malocclusion, the maxilla may be prognathic, the mandible retrognathic, or a combination of both.[5, 6] The majority of Class II patients can be treated conventionally, however when the deformity is severe, surgical intervention maybe indicated [7]. Severe Class II malocclusion can, in some cases, also lead to medical comorbidities such as obstructive sleep apnea[8] which affects approximately 13% of males and 6% females in the general population.[9]

Orthognathic surgery for Class II may include single jaw or double jaw approaches. [10, 11] When planning surgical mandibular advancement, one must also consider the transverse dimension .[12] Following advancement, a wider portion of the mandible articulates with a narrower portion of the maxilla. A common treatment is widening of the maxilla through orthopedic rapid maxillary expansion (RME) in younger patients or surgically assisted RME in adults.[13 14] An alternate approach is mandibular advancement with simultaneous constriction.[12, 15]

With the increased awareness of obstructive sleep apnea, attention has focused on airway changes resulting from orthodontics and orthognathic surgery. Previous investigations have demonstrated that mandibular advancement is associated with an increase in the pharyngeal airway space (PAS).[16, 17] Many of these studies have employed lateral cephalograms,[18, 19],[20]. To overcome two dimensional limitations, cone beam computed tomography (CBCT) has been used[21 20 22] to obtain a three dimensional (3D) understanding of the resulting changes and quantification of the airway volume. While recent studies have demonstrated airway changes resulting from mandibular advancement alone, the possible impact of simultaneous mandibular advancement with constriction has not been evaluated. The specific aim of this retrospective study is to comprehensively evaluate the three dimensional airway changes from CBCT scans in adult patients undergoing surgical mandibular advancement with and without simultaneous constriction.

MATERIALS AND METHODS

Institutional review board exemption (HUM00108933) was granted for this retrospective study. Inclusion criteria included adult patients with preoperative (T1) and postoperative (T2) CBCT scans who underwent mandibular advancement surgery with or without constriction for the correction of Class II skeletal malocclusion. To control for variability in head position, only patients with consistent head posture (<5°) as assessed by measuring the craniocervical angle (N-S-Ba) were included. A total of 42 patients met the inclusion criteria, 17 underwent mandibular advancement surgery with constriction (11 female and 6 male) and 25 patients underwent advancement only (16 female and 9 male). Patients with syndromes, maxillary surgery, or obstructive sleep apnea (OSA) were excluded.

All scans were obtained with an EWOO Master 3DS™ CBCT scanner (EWOO Technology USA Inc. Houston, Texas). The scan parameters were 90.0kV, 3.3mA, 20x19cm field of view, 15s exposure time, normal quality mode, 0.2mm slice thickness, isotropic voxel size of 0.40mm. All CBCT scans were de-identified, labeled saved in DICOM format.

Pre- and post-surgical cephalograms were extracted from the CBCT for every patient. The cephalograms were digitally traced (Figure 1) and analyzed using the cephalometrics for orthognathic surgery (COGS) analysis (Dolphin Imaging ™ Version 11.7).

THREE-DIMENSIONAL ANALYSIS

Prior to analysis, all scans were reoriented for consistency (Figure 2). In the coronal plane (Figure 2A), the right and left inferior orbital borders were aligned horizontally. Sagittally, (Figure 2B) the best fit of the zygomatic arch was aligned horizontally. Axially, the lateral walls of the orbits were placed tangent to each other.

The airway volume (Figure 3A) was bounded superiorly by the line extending from posterior nasal spine (PNS) to the posterior pharyngeal wall and inferiorly by a parallel line from the anterior-inferior border of C3 to the base of the tongue. The posterior limit was the posterior pharyngeal wall and the anterior boundary was created by the soft palate and base of the tongue. Seed points were placed in the region of interest and airway sensitivity was set to 73. Each scan was assessed to confirm the volume remained within anatomic airway boundaries.

Minimum axial airway was determined for entire airway as well as the retropalatal (Figure 3B: anterior-inferior border of C1) and retroglossal (Figure 3C anterior-inferior of C2) regions.

The amount of constriction was assessed using the millimetric distance between the right and left gonial angles, the mesial lingual cusps of the mandibular first molars and cusps of the mandibular canines pre- and post-operatively.

STATISTICAL ANALYSIS

ANOVA was performed to confirm similar start forms between presurgical groups. Paired t-tests performed for 2d and 3d comparison of preoperative to postoperative changes within groups. Welch's unpaired t-test was used to compare the changes pre and post surgically between the BSSO with constriction group and the BSSO only group. Statistical significance was set a $p<0.05$.

For intra- and inter-examiner reliability, a random number generator was used to select 10 scans from both groups. The measurements were repeated 2 months after the initial measurements. Both intra and inter-examiner reliability tests exhibited high correlation ranging from 0.912 to 0.982 for all measures.

RESULTS

CEPHALOMETRIC RESULTS

ANOVA revealed no significant differences between the mandibular advancement alone and the mandibular advancement with constriction groups presurgically (T1). (Table 1) Mean mandibular advancement (T2-T1) was 5.8mm in the constriction group and 5.5mm in the non-constriction group with no difference between groups. The mandibular plane exhibited a statistically significant decrease (1.2°, $p<0.05$) in the advancement only group and no difference in the mandibular advancement alone group. Post-surgically (T2), there was no difference in mandibular plane between groups. Post-surgically, soft tissue changes were observed with decreases in the angle of facial convexity, (N-A-Pg), upper lip protrusion (UL-SnPg'), lower lip protrusion (LL-SnPg') and interlabial gap reduction in both groups. Mandibular projection (G-Pg') increased in both groups. Dentally, the lower incisor intruded in both groups (2.0mm vs 1.3mm) however; there was no difference between groups. Transversely, the mandibular advancement with constriction patients exhibited an average of 2.1mm of constriction at the first molar and 0.8mm at the canine.

3-DIMENSIONAL ANALYSIS RESULTS

The mandibular advancement with constriction patients exhibited wider intermolar (38.5mm vs 35mm) and intercanine dimensions (27.8mm vs 26.1mm) at the start of treatment (Table 2). At the conclusion, mandibular advancement with constriction patients exhibited similar intermolar distances as the mandibular advancement without constriction patients (36.3mm vs 33.8mm) and intercanine distances (26.9mm vs 24.9mm).

Airway volume (8.68mm^3, 4.29mm^3) and cross sectional airway measures increased at multiple sites within both the mandibular advancement with constriction (6 sites) and the mandibular advancement alone groups (11 sites). Between groups, a single statistically significant difference was observed for the minimum cross sectional area in the region between C2 and C3 (Table 3).

DISCUSSION

To compare two different techniques, patients with similar presurgical cephalometric measures were selected. In addition, the amount of advancement was similar. An expected difference between treatment groups was the intermolar and intercanine widths. At the start, mandibular advancement with constriction patients exhibited wider intermolar (38.3mm vs 33.7mm) and intercanine dimensions (27.8mm vs 25.9mm). At the conclusion of treatment mandibular advancement with constriction patients exhibited similar intermolar distances as the mandibular advancement without constriction patients (36.2mm vs 33.6mm) and intercanine distances (26.5mm vs 25.9mm).

Both groups experienced significant skeletal mandibular advancement. The amount of advancement was nearly identical with only 0.3mm more advancement ($p>0.05$) in the constriction group yielding a homogenous group of patients for direct comparison of the impact on two different surgical protocols.

Difficulties in measuring changes in airway space due to differences in head position have been reported previously.[23, 24] Craniocervical angle change was used in the present study to assure consistent head position during their CBCT scan. By controlling head position via the craniocervical angle ($p>0.05$), the observed differences can only be the result of surgery.

To date, there is no consensus regarding airway measurement on CBCTs. Many different approaches, different computer programs, different regions of interest, and/or different segmentations are reported. Current consensus is that airway should be measured in 3D rather than in 2D to obtain not only the transverse measures, but also airway volumes. Many previous publications recommend creating a region of interest by extending and connecting lines from palatal plane (anterior nasal spine to posterior nasal spine), the posterior pharyngeal wall, and a line tangent to hyoid that is parallel to palatal plane, and finally back superiorly to posterior nasal spine. To account for differences in oral volume, patients are instructed to place the tongue in a consistent position without swallowing. In this investigation, hyoid was not visible in all patients so the inferior boundary was modified to be a line parallel to palatal plane that was tangent to the anterior inferior border of the third cervical vertebra (C3).[21, 25, 26] The airway was further subdivided to assess possible changes in retropalatal (palatal plane to C1), retroglossal (C1 to C2), and hypoglossal (C2 to C3) regions since constriction might have a variable effect in each region.

As anticipated from previous investigations, the airway volume and cross sectional areas increased at many levels in both groups. The advancement alone group experienced more sites of enlargement (11 sites) than the advancement with constriction group (6 sites). The amount of volume increase in the mandibular advancement alone group was nearly twice that of the mandibular advancement with constriction group (8.68 versus 4.29 cm^3). However, post-surgically, both groups demonstrated similar airway volumes (25.6 versus 22.3 cm^3).

The change in minimum cross sectional areas (mCSA) in the retropalatal and retroglossal regions were equivalent. The change in location of the minimum cross sectional area was also consistent between groups.

Within the hypoglossal region a difference was observed with the constriction group demonstrating a small decrease (1.6mm^2) and the advancement only group showing an increase (137.2 mm^2) in the minimum cross sectional area. As the mandible constricts, laxity can be created within the mylohyoid and associated posterior mandibular muscle groups. This observation was observed again in the cross sectional area at the anterior-inferior aspect of C3. Among mandibular advancement only patients, an increase of 107mm^2 was observed while among the constriction group, a decrease of 39.2mm^2 was observed.

Unfortunately, gonial angle changes have not been described in the literature extensively since mandibular advancement with constriction is less common. The information that is available comes from posterior anterior cephalograms that are prone to interpretation errors due to patient positioning and overlapping structures. Angle et al reported an intergonial angle width increase of 6.5mm and changes in the angulation of the proximal segments of 3.2 degrees post operatively.[27] Becktor et al reported a 5.6mm increase in the gonial angle region when evaluating posterior-anterior cephalograms[28]. In the current investigation, the gonial angle distance increased 4.7mm in the advancement only group and 2.2mm in the advancement with constriction group. The smaller expansion is expected because the proximal segment does not have to rotate as much.

Conclusions:

The investigation suggests that mandibular advancement with constriction is not only effective in correcting the malocclusion but also does not negatively affect airway volume. Specific findings were:

1. Both Class II mandibular advancement alone and mandibular advancement with constriction patients show statistically significant increases in airway volume following surgery.
2. Mandibular advancement alone patients gained nearly twice as much airway space as mandibular advancement with constriction patients.
3. Mandibular advancement alone patients showed statistically significantly larger increases in minimum axial area of the PAS when measured to between palatal plane and C3 with the largest difference observed between C2 and C3.

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Figure Legends:

Figure 1: A representative lateral cephalometric tracing with landmarks from the Cephalometrics for Orthognathic Surgery (COGS) Analysis labled.

Figure 2: A representative Cone Beam Computed Tomography (CBCT) scan used for orientation.

A: In the frontal plane, the orbits are leveled with respect to horizontal reference grid.

B: In the sagittal plane, the zygomatic arch is leveled with respect to the horizontal reference grid.

Figure 3: A representative CBCT airway segmentation.

A: Mid-sagittal slice from CBCT depicting the “seed” points (yellow dots), airway region of interest (yellow box) and airway volume (purple area).

B. Retroplalatal airway (tangent to anterior-inferior aspect of C1)

C: Retroglossal airway (tangent to anterior-inferior aspect of C2)

Table 1:

	T1	**T2**

Measure	BSSO(-)	BSSO(+)	p	BSSO(-)	BSSO(+)	p
Ar-PTM (//HP) (mm)	33.4 ± 3.7	30.5 ± 4.8	0.0804	33.3 ± 3.8	30.7 ± 3.7	0.07
PTM-N (//HP) (mm)	58.1 ± 3.7	58.4 ± 4.5	0.4370	58.0 ± 3.7	58.7 ± 4.0	0.62
N-A-Pg (//)	11.4 ± 9.6	14.3 ± 6.7	0.2945	5.8 ± 7.7	6.0 ± 6.2	0.92
N-A (//HP) (mm)	-1.9 ± 5.0	-3.2 ± 7.4	0.5423	-1.8 ± 5.0	-4.9 ± 4.9	0.09
N-B (//HP) (mm)	-15.9 ± 9.9	-20.3 ± 11.9	0.2630	-10.3 ± 8.2	-14.6 ± 9.6	0.19
N-Pg (//HP) (mm)	-15.3 ± 11.9	-20.2 ± 12.8	0.2708	-9.3 ± 9.8	-14.6 ± 10.7	0.16
N-ANS (⊥HP) (mm)	55.9 ± 3.8	57.6 ± 3.2	0.1135	56.0 ± 3.8	57.3 ± 3.4	0.29
ANS-Gn (⊥HP) (mm)	69.3 ± 7.1	67.4 ± 6.1	0.9650	69.7 ± 7.6	68.3 ± 5.9	0.56
PNS-N (⊥HP) (mm)	56.1 ± 4.0	56.8 ± 4.4	0.4327	56.3 ± 4.3	55.2 ± 3.4	0.42
Mand Plane - HP (°)	29.6 ± 7.2	33.8 ± 8.3	0.1140	28.4 ± 6.6	33.2 ± 8.3	0.09
U1 - NF (⊥HP) (mm)	30.3 ± 4.1	30.7 ± 3.4	0.3627	30.3 ± 4.1	30.6 ± 3.4	0.81
U6 - NF (⊥HP) (mm)	24.0 ± 3.4	24.0 ± 2.1	0.5024	24.2 ± 3.4	23.9 ± 2.1	0.72
L6 - MP (⊥HP) (mm)	31.5 ± 5.1	30.5 ± 2.9	0.7505	30.7 ± 4.9	29.7 ± 2.4	0.44
L1 - MP (⊥HP) (mm)	40.3 ± 4.6	39.1 ± 3.9	0.9374	38.9 ± 5.1	37.1 ± 3.6	0.25
PNS-ANS (HP) (mm)	56.6 ± 5.2	56.8 ± 4.1	0.7825	56.5 ± 5.0	56.3 ± 3.9	0.88
Ar-Go (mm)	53.1 ± 6.8	51.0 ± 8.6	0.5506	52.0 ± 6.2	50.2 ± 5.9	0.41
Go - Pg (mm)	69.2 ± 6.6	67.3 ± 7.4	0.6214	74.7 ± 6.0	73.1 ± 6.8	0.51
B-Pg (MP) (mm)	6.9 ± 2.4	7.3 ± 2.70	0.4443	6.5 ± 2.7	5.8 ± 2.2	0.37
Ar-Go-Gn (°)	122.3 ± 3.5	124.5 ± 6.4	0.2429	123.8 ± 5.1	125.0 ± 6.2	0.57
OP-HP (°)	9.2 ± 4.9	12.0 ± 6.8	0.2295	8.5 ± 4.8	13.7 ± 5.2	0.11
U1 - NF (°)	114.9 ± 7.1	114.1 ± 9.2	0.2888	115.2 ± 7.5	113.3 ± 9.0	0.54
L1/Go-Me (°)	99.5 ± 7.3	96.6 ± 8.5	0.1524	98.9 ± 8.1	97.5 ± 7.4	0.63
A-B (//OP) (mm)	-6.8 ± 5.1	-8.0 ± 3.4	0.3371	-2.0 ± 3.2	0.4 ± 3.3	0.06

Cephalometric pre-operative mean pre-operative start forms for advancement only (BSSO-) and advancement with constriction (BSSO+). *p < 0.05

Table 2:

	BSSO-			BSSO+		
Measure	**T1**	**T2**	**p**	**T1**	**T2**	**p**
Volume PP-C3 (cm^3)	13.59 ± 4.70	22.28 ± 8.03	*	21.3 ± 10.9	25.6 ± 8.6	*

Volume PP-C2 (cm^3)	11.15 ± 4.04	18.12 ± 7.03	*	17.5 ± 7.3	21.6 ± 7.2	*
mCSA PP-C3 (mm^2)	123.44 ± 62.14	242.96 ± 108.34	*	198.2 ±125	217.8 ±140.2	NS
mCSA PP-C2 (mm^2)	140.73 ± 65.19	291.38 ± 112.15	*	234.1 ± 145.4	388.0 ± 203.7	*
mCSA PP-C1 (mm^2)	283.48 ± 118.72	396.56 ± 115.03	*	397.6 ± 207.7	496.4 ±135.7	*
mCSA C1-C2 (mm^2)	136.61 ± 67.04	281.26 ± 126.09	*	237.4 ± 149.3	351.3 ±166.5	*
mCSA C2-C3 (mm^2)	140.06 ± 65.76	277.24 ± 124.66	*	296.1 ± 214.7	294.5 ± 198.5	NS
mCSA S-I C3 (mm)	22.6 ± 12.40	13.86 ± 11.81	*	15.1 ±16.2	7.5 ±14.5	NS
mCSA S-I C2 (mm)	12.52 ± 12.53	14.42 ± 14.51	*	8.4 ± 10.9	5.9 ±13.5	NS
CSA @ AI C1 (mm^2)	274.30 ± 114.35	401.33 ± 146.86	*	391.1 ± 220.0	471.5 ± 172.2	NS
CSA @ AI C2 (mm^2)	175.61 ± 77.21	349.65 ± 147.71	NS	296.0 ± 164.6	429.9 ± 180.6	*
CSA @ AI C3 (mm^2)	187.43 ± 93.64	294.55 ± 154.27	*	232.2 ±110.6	193 ± 107	NS
Craniocervical Angle (°)	108.53 ± 7.50	107.69 ± 6.96	NS	119.6 ± 8.1	118.1 ± 7.2	NS
R-L Gonial Angle Distance (mm)	85.51 ± 7.49	90.27 ± 7.09	*	84.9 ± 6.64	87.1 ±7.92	*
R-L Lower Molar Distance(mm)	33.7 ± 2.35	33.56 ± 2.23	NS	38.3 ± 3.25	36.2 ± 3.6	*
R-L Lower Canine Distance(mm)	25.9 ± 2.37	25.94 ± 2.54	NS	27.8 ± 2.46	26.5 ± 2.64	NS

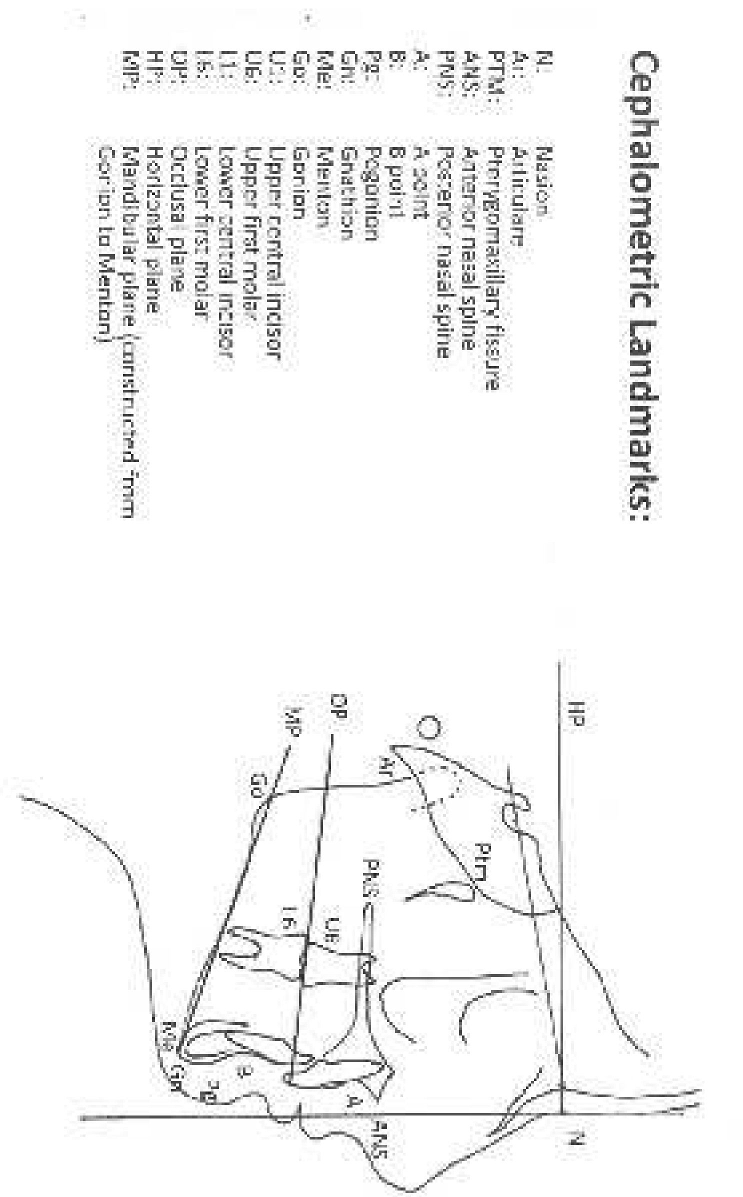
Pre-operative and post-operative airway volume, minimum cross sectional areas (mCSA), and transverse changes for the mandibular advancement alone (BSSO-) and mandibular advancement with constriction (BSSO+) groups. Statistical significance (T1-T2) within groups noted as $*p<0.05$, $**p<0.01$, and $***P<0.001$.

Table 3:

Measure	BSSO(-)	BSSO(+)	p
Advancement (mm)	5.5	5.8	NS
Volume PP-C3 (cm^3)	8.68	4.29	NS
Volume PP-C2 (cm^3)	6.79	4.11	NS
mCSA PP-C3 (mm^2)	119.52	19.65	0.0047**

mCSA PP-C2 (mm^2)	150.65	153.88	NS
mCSA PP-C1 (mm^2)	126.70	98.81	NS
mCSA C1-C2 (mm^2)	144.65	113.97	NS
mCSA C2-C3 (mm^2)	137.17	-1.6	0.0229*
mCSA S-I C3 (mm)	-8.73	-7.62	NS
mCSA S-I C2 (mm)	1.894	-2.46	NS
CSA @ AI C1 (mm^2)	127.03	80.4	NS
CSA @ AI C2 (mm^2)	174.04	133.9	NS
CSA @ AI C3 (mm^2)	107.12	-39.25	NS
Craniocervical Angle (°)	-0.83	-1.31	NS
R-L Gonial Angle Distance (mm)	4.76	2.21	NS
R-L Lower Molar Distance(mm)	-0.13	-2.11	NS
R-L Lower Canine Distance(mm)	0.04	-1.33	NS

Change in pre-operative and post-operative airway volume, minimum cross sectional areas (mCSA), and transverse changes between the mandibular advancement alone (BSSO-) and mandibular advancement with constriction (BSSO+) groups. Statistical significance (Welches unpaired t test between groups) noted as *$p<0.05$, **$p<0.01$, and ***$P<0.001$. Welches unpaired t test was performed.



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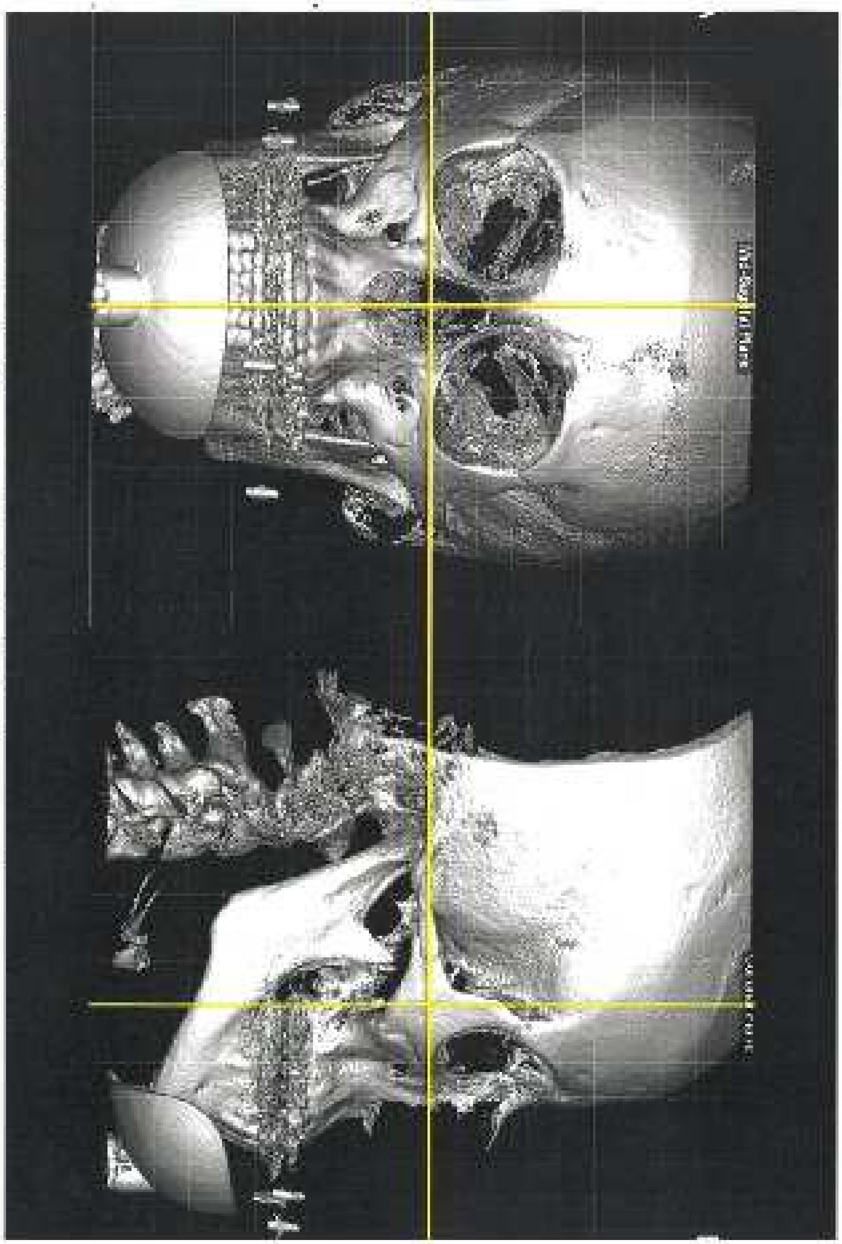
A: Orbits leveled with respect to horizontal reference plane
B: Zygomatic arch leveled with respect to horizontal reference plane.



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