Morphological Changes of the Ethmoid and Maxillary Cavities after Endoscopic Sinus Surgery, A Quantitative Digital Analysis

Thesis

Submitted for fulfillment of M.D. degree in Otorhinolaryngology

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Abstract

Objectives:
To determine changes in ethmoid, maxillary sinus and orbital volume following endoscopic sinus surgery.

Methods:
45 patients were subjected to endoscopic sinus surgery for chronic sinusitis with or without nasal polypi.
C.T scans done preoperative and 3 months postoperative.
Five ethmoidal measures (3 axial, 2 coronal) IOD 1-5.
Two maxillary measures (left and right).
Orbital measure (POE)

Results
Postoperative C.T scans demonstrate decrease in mean ethmoid cavity mainly at IOD 2 (mean decrease = -1.89)
Decrease in maxillary measures (mean decrease = -1.89)
Increase in POE by .37

Key Words:
Endoscopic Sinus Surgery - Ethmoid and Maxillary Cavities.
First of all, I should thank god the greatest and most merciful not only for helping me through this work, but also for helping me all through my life.

I would like to thank my supervisors, Prof. Dr. Kamal Labib Samy, Prof. Dr. Hazem Mohamed Moharam, and Asst prof. Dr. Ahmed Mohamed Atef For their constant guidance, support, and encouragement that allowed me to accomplish this work.

Finally, there is no word that can express my deepest and sincere gratitude to my lovely family that was and will always be beside me.
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Introduction

Plasticity of the bony walls of the paranasal sinuses allows for normal alterations in sinus dimensions associated with facial growth and development. Pneumatization of the paranasal sinuses begins in utero and continues through the teenage years (Spaeth et al., 1997).

Alteration in the bony architecture of the sinuses has also been seen in pathological disease processes. Expansile changes of the sinuses are commonly observed in patients with allergic fungal sinusitis, massive sinononal polyposis, mucocele formation, and benign neoplasms. Contractile changes of the sinus cavities are associated with cystic fibrosis and silent sinus syndrome, where ostial obstruction leads to atelectasis of the maxillary sinus. Endoscopic sinus surgery is often performed in the setting of bony changes in an effort to halt expansion or contraction of the sinus cavities, and prevent complications within adjacent regions such as the orbit or intracranial cavity (Kim et al., 1997).

The effect of surgical manipulation of the paranasal sinuses on the bony architecture has been studied in the pediatric population. Endoscopic sinus surgery has been shown to not affect facial growth in pediatric patients with chronic sinusitis or cystic fibrosis. In the adult population, alteration of the bony architecture after endoscopic sinus surgery has not been studied (Cunnane et al., 2009).

Plasticity of the ethmoid sinus after endoscopic sinus surgery is a newly described entity (Cunnane et al., 2009).
Review of literature
Paranasal Sinus Development

The embryological development of the paranasal sinus is a very complex process, and its description varies among different authors. The growth pattern of the paranasal sinus is totally unpredictable and extremely variable from one individual to another or even from side to side in the same person (Ritter and Fritsch, 1992).

The initial development of the nasosinus cavities takes place early in fetal life, occurring at the same time as the growth of the palate below, facial structures anteriorly, and the cerebral cranium above. The paranasal sinuses, with the exception of the sphenoid sinus, arise as evaginations from the lateral nasal wall. At the beginning, the lateral nasal wall is a smooth, undifferentiated structure, but during the seventh gestational week it starts to develop (Clement, 2005).

Maxillary Sinus Development

The maxillary sinus is the first to develop during human fetal life, roughly during the 10th week. The maxillary sinus begins to form from an outpouching of the lateral wall of the ethmoid area of the nasal capsule within the infundibulum and immediately posterior to the developing uncinate process (Donald et al., 1995).

This outgrowth enlarges slowly throughout fetal life due to the constriction by the perichondrium of the nasal capsule, limiting extension into the maxillary process (maxilla). Thus, the maxillary sinus appears as a slit, caught between the developing ethmoid cells, the inferior turbinate, and the bone of the maxilla. Only as the nasal capsule is resorbed during its ossification does the maxillary sinus have an opportunity to enter the developing maxillary process. As the maxillary sinus expands into the maxilla, it is restricted by dental development.
Figure (1): Developmental pattern of the maxillary sinus (Clement, 2005).

Further growth of the maxillary sinus into the maxilla follows the development of the maxilla and the descent of the teeth (Clement, 2005).

In the neonate, the largest sinus is represented by a small cavity whose lower border lies above that of the nasal floor and is encroached upon by the upper dentition. However, as the development of the mid-third of the face progresses and eruption of the permanent dentition occurs, the floor of the sinus migrates to a lower level than that of the nasal cavity (0.5–10 mm). (McGowan et al., 1993)
Table 1 Measurements of the Maxillary Sinus through Different Ages.

<table>
<thead>
<tr>
<th>Age</th>
<th>Ventreodosal (length) (mm)</th>
<th>Cophalocaudal (height) (mm)</th>
<th>Mediolateral (width) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>7.0–8.0</td>
<td>4.0–6.0</td>
<td>3.0–4.0</td>
</tr>
<tr>
<td>6 months</td>
<td>10.0–10.5</td>
<td>4.0–5.0</td>
<td>4.0–4.5</td>
</tr>
<tr>
<td>9 months</td>
<td>11.0–14.0</td>
<td>5.0–5.0</td>
<td>5.0–5.5</td>
</tr>
<tr>
<td>1 year</td>
<td>14.0–16.0</td>
<td>6.0–6.5</td>
<td>5.0–5.5</td>
</tr>
<tr>
<td>1.5 years</td>
<td>20.0–20.5</td>
<td>8.0–9.0</td>
<td>5.0–6.0</td>
</tr>
<tr>
<td>2 years</td>
<td>21.0–22.0</td>
<td>10.0–11.0</td>
<td>6.0–6.5</td>
</tr>
<tr>
<td>3 years</td>
<td>22.0–23.0</td>
<td>11.0–12.0</td>
<td>8.0–9.0</td>
</tr>
<tr>
<td>6 years</td>
<td>27.0–28.0</td>
<td>16.0–17.0</td>
<td>9.0–10.0</td>
</tr>
<tr>
<td>8 years</td>
<td>28.0–29.0</td>
<td>17.0–17.5</td>
<td>17.0–18.0</td>
</tr>
<tr>
<td>10 years</td>
<td>30.0–31.0</td>
<td>17.5–18.0</td>
<td>19.0–20.0</td>
</tr>
<tr>
<td>12 years</td>
<td>31.0–32.0</td>
<td>18.0–20.0</td>
<td>19.0–20.0</td>
</tr>
<tr>
<td>15 years</td>
<td>31.0–32.0</td>
<td>18.0–20.0</td>
<td>19.0–20.0</td>
</tr>
</tbody>
</table>

(Raphael et al., 2006)

Ethmoid Sinus Development

The earliest signs of development of the ethmoid sinus are seen during the fourth fetal month (Moore, 1988). The ethmoid sinus has a multicentric origin. A great majority of the cells begin at the middle meatus as anterior ethmoid cells, and a minority develop from the superior and supreme meatus as posterior ethmoid cells. The anterior ethmoid cells appear as evaginations in the lateral nasal wall of the middle meatus. Somewhat later, the posterior cells evaginate the nasal mucosa in the superior meatus. All of these cells enlarge gradually throughout fetal life (Clement, 2005).
Other primitive structures called ethmoturbinals (middle, superior, and supreme), the uncinate process, the agger nasi, and the ethmoid bulla are medial extensions of the lateral wall of the nasal capsule. The attachments of these structures to the lateral nasal wall of the nasal capsule are the lamellae. There exist five lamellae with the following nomenclature.

| First basal lamella                  | Lateral extension of uncinate process |
| Second basal lamella                | Lateral extension of ethmoid bulla   |
| Third basal lamella                 | Attachment of middle turbinate       |
| Fourth basal lamella                | Attachment of superior turbinate     |
| Fifth basal lamella                 | Attachment of supreme turbinate      |

**TABLE 2** Classifications of Lamellae. (Clement, 2005).

The sinus cells during their development may stretch the lamellae but do not break through them, thereby retaining the integrity of each of the compartments.
During primary pneumatization, the rudiments of the ethmoid sinus consist of dimple-like depressions of the nasal mucosa into the nasal capsule. These depressions may originate from any of the mucosal furrows in the middle meatus or along the mucosa of the superior meatus, which is, itself, no more than a furrow at this time. The depressions gradually deepen and become globular air cells. As development progresses and these cells reach maximum growth and encroach on adjacent bony cells, they become flattened (Clement, 2005).

The ethmoid sinus is well developed at birth. During the second year after birth the air cells may grow beyond the confines of the ethmoid bone into the surrounding bones: maxilla, frontal, lacrimal, and sphenoid. The growth pattern of the ethmoid sinus is completely unpredictable, and development will continue until the ethmoid has reached almost adult size by the age of 12 years. Some further enlargements may take place in early adulthood. (Clement, 2005).

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Group</th>
<th>Cephalocaudal (mm) (height)</th>
<th>Mediolateral (mm) (width)</th>
<th>Ventrodorsal (mm)(length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>Anterior</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>Anterior</td>
<td>2–8</td>
<td>1.5–6</td>
<td>2–7</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>2–8</td>
<td>1.5–7</td>
<td>2–9</td>
</tr>
<tr>
<td>2</td>
<td>Anterior</td>
<td>3–9</td>
<td>2–6</td>
<td>2–6</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>5–8</td>
<td>3–4</td>
<td>4–6</td>
</tr>
<tr>
<td>5</td>
<td>Anterior</td>
<td>7–8</td>
<td>5–7</td>
<td>5–6</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>7–8</td>
<td>7–10</td>
<td>6–7</td>
</tr>
<tr>
<td>8</td>
<td>Anterior</td>
<td>8–11</td>
<td>7–10</td>
<td>6–7</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>8–11</td>
<td>7–10</td>
<td>9–16</td>
</tr>
<tr>
<td>10</td>
<td>Anterior</td>
<td>9–12</td>
<td>8–12</td>
<td>8–10</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>9–14</td>
<td>8–12</td>
<td>9–17</td>
</tr>
<tr>
<td>14</td>
<td>Anterior</td>
<td>9–16</td>
<td>10</td>
<td>5–23</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td>9–15</td>
<td>14</td>
<td>8–20</td>
</tr>
</tbody>
</table>

(Raphael et al., 2006)
Paranasal Sinus Anatomy

Ethmoid sinus:

Of all the paranasal sinuses, the ethmoid sinus is the most complex and is aptly referred to as a labyrinth. The anterior cells of this sinus first appear in the third fetal month as pits of the lateral nasal wall adjacent to the middle meatus (Kasper, 1936).

At birth, the anterior ethmoid measures 2 _ 2 _ 5 mm, and the posterior ethmoid measures 2 _ 4 _ 5 mm; they are difficult to view with routine radiography. The ethmoids attain adult size by the twelfth year, expanding into adjacent areas beyond its capsule (Van Alyea, 1951).

In the adult, the ethmoids are pyramidal in shape, with the base located posteriorly. They measure 4 cm to 5 cm anterior to posterior, 2.5 cm in height, 0.5 cm wide anteriorly, and 1.5 cm wide posteriorly. The roof of the sinus, the fovea ethmoidalis, usually extends 2 to 3 mm above the more medial cribiform plate (Mosher, 1929).

The entire ethmoid bone is a paired scaffolding held together by two lamina cribrosa. Each lamina cribrosa is separated in the midline by an upward projection, the crista galli. The perpendicular plate of ethmoid lies inferior and opposite the crista galli. The ethmoid labyrinth forms the greater portion of the ethmoid bone (Polavaram et al., 2004).

Laterally, the lamina papyracea forms the bony division from the orbit. Any dehiscence of this lamina forms a potential pathway for spread of sinus infections into the orbit. Medially, it is bounded by the middle, superior, and (if present) supreme turbinates. Posteriorly and inferiorly, the ethmoid clefts open into the corresponding nasal passages and finally into the choanae. The anterior roof is bounded by the downward extension of the frontal bone (Polavaram et al., 2004).
The complex ethmoid labyrinth is divided into a series of lamellae, which are relatively constant and can help guide the surgeon during the surgery. These lamellae are the uncinate process, the bulla ethmoidalis, the ground lamella of the middle turbinate, and the lamella of the superior turbinate. Rarely, there is a fifth lamella known as the supreme turbinate. The ground lamella of the middle turbinate is a constant and well-developed lamella. It divides the ethmoid into anterior and posterior portions. The anterior cells are smaller and more numerous than the posterior cells (Polavaram et al., 2004).

**Anterior ethmoid:**

Most sinus disease involves the anterior ethmoids. Several important anatomic landmarks are associated with this structure.

**Figure (3):** Coronal illustration of ethmoid sinus anatomy at the level of the maxillary sinus ostia (Kennedy et al., 2001)
Uncinate process

The uncinate process is a thin and almost sagitally oriented bone. It runs in a sickle-shaped curve from anterosuperior to posteroinferior. Its anatomy is better appreciated by medializing the middle turbinate. It is approximately 3 to 4 mm wide and 1.5 to 2 cm in length. Its posterior margin is sharp and concave. It is anterior and parallel to the anterior surface of the ethmoid bulla (Stammberger, 1991).

The hiatus semilunaris occupies the space between the posterior aspect of the uncinate and the anterior surface of the ethmoid bulla. The lateral surface of the uncinate forms the medial surface of the infundibulum. Posteriorly and inferiorly, the uncinate attaches to the ethmoidal process of the inferior turbinate bone. The posterior-superior attachment is to the lamina perpendicularis of the palatine bone. The ascending anterior convex margin contacts the lateral nasal wall, which may extend up to the lacrimal bone. (Stammberger, 1991).

The uppermost segment of the uncinate process runs a variable course. It is hidden by the insertion of the middle turbinate. It can extend to the base of the skull or turn laterally to insert into the lamina papyracea and may turn frontally and fuse with the insertion of the middle turbinate (Stammberger, 1991).

There are almost always defects between the uncinate and the inferior turbinate. These defects are covered with dense connective tissue and nasal mucosa and are known as the anterior and posterior fontanelles. Accessory maxillary ostia are often observed in the posterior fontanelle region (Van Alyea, 1939).
Figure (4) the superior portion of the uncinate most commonly attaches laterally to the orbit (A) however, it can attach centrally (B) or medially (C) to the skull base (Daniel Simmen and Nick Jones, 2005)

The uncinate is usually oriented at 140 degree to the lateral nasal wall and the lamina papyracea, but the orientation can vary significantly. Extensive nasal polyps within the infundibulum can displace the uncinate medially. It can be displaced laterally, as seen in maxillary sinus hypoplasia (Kennedy and Zinreich, 1988). Rarely, the uncinate can be pneumatized (Bolger et al., 1990). Orbital injury can occur if lateral displacement of the uncinate (with accompanying atelectasis of the infundibulum) is not appreciated during the infundibulotomy (Bolger and Kennedy, 1992).

Medially bent uncinate: A medially bent uncinate is the most common variation and may involve the entire uncinate. Sometimes the uncinate can protrude anterior-inferior to the middle turbinate, giving the impression of two middle turbinates. Superiorly, the uncinate may bend laterally and insert onto the lamina papyracea. It attaches to the skull base in this fashion. It can also twist medially and fuse with the middle turbinate.

Laterally bent uncinate: Lateral protrusion of the uncinate can also narrow the ethmoid infundibulum.
Elongated and enlarged uncinate process; An elongated and enlarged uncinate process may come in close contact with the ethmoid bulla, significantly narrowing the hiatus semilunaris. When concomitant mucosal derangements are present, this narrowing may lead to obstruction (Stammberger and Hawke, 1993).

Ethmoid bulla

The ethmoid bulla is one of the largest and most consistent anterior ethmoid air cells. It is created by the pneumatization of the bulla lamella. Occasionally, the ethmoid bulla is poorly developed or absent. It is located in the middle meatus, directly behind the uncinate process, and in front of the ground lamella of the middle turbinate. Superiorly, the anterior wall of the ethmoid bulla can extend to the skull base to form the posterior limit of the frontal recess. If this division is absent, there is direct communication between the frontal recess and the sinus lateralis, normally located above the bulla. Posteriorly, the bulla can fuse with the ground lamella (Stammberger and Hawke, 1993).

Variations include a highly pneumatized bulla lying in the lower aspect of the middle meatus. In this position, the ethmoid bulla can narrow the infundibulum. If the ethmoid bulla is not pneumatized, a bony projection known as the torus lateralis forms from the lamina papyracea (Mosher, 1929).

Enlarged ethmoid bulla; Bulla pneumatization can vary. A greatly pneumatized bulla may extend anteriorly to contact the uncinate process, resulting in a narrow hiatus semilunaris. The bulla may extend anteriorly to protrude between the uncinate and the middle turbinate (Polavaram et al., 2004).

Hiatus semilunaris

The hiatus semilunaris is a sagittal cleft between the posterior border of the uncinate process and the anterior surface of the ethmoid bulla.
The middle meatus communicates with the infundibulum through this area, designated as the hiatus semilunaris inferior. The hiatus semilunaris superior is the cleft formed between the posterior wall of the ethmoid bulla and the ground lamellae of the middle turbinate (Stammberger, 1991).

![Diagram of ethmoid sinus](image)

**Figure (5):** ethmoid sinus (Clement, 2005).

**Ethmoid infundibulum**

The ethmoid infundibulum (often simply called the infundibulum) is a funnel-shaped, three-dimensional space located in the anterior ethmoidal region. It is bounded medially by the uncinate and laterally by the lamina papyracea. The frontal process of the maxilla and lacrimal bone forms its anterior-superior boundary (Stammberger et al., 1995).

The lumen of the infundibulum appears as a V-shaped structure in axial CT. The posterior border of the infundibulum is bounded by a portion of the anterior ethmoid bulla and tapers in this direction. The ethmoid infundibulum can measure 4 cm in length and 5 mm to 12 mm in depth. The ethmoidal infundibulum communicates with the middle meatus through the hiatus semilunaris.