An anatomic classification of the ethmoidal bulla

REUBEN C. SETLIFF, III, MD, PETER J. CATALANO, MD, FACS, LISA A. CATALANO, MPH, and **CHAD FRANCIS, BA,**

Sioux Falls, South Dakota, and Burlington, Massachusetts

OBJECTIVE: **The ethmoid bone is arguably the most complex and varied osseous structure in the human body. The partitions within form a unique labyrinth of lamellae and spaces from specimen to specimen or, as in this study, from patient to patient. The surgical anatomy of the ethmoid bone, and the ethmoidal bulla in particular, is ill-defined and heretofore largely unclassified. In an attempt to better understand the ethmoid labyrinth, a prospective anatomic study of 107 patients undergoing primary intranasal endoscopic ethmoidectomy was undertaken.**

STUDY DESIGN: **Two hundred fourteen ethmoidal bullae were dissected intraoperatively with videodocumentation obtained in over 90% of cases. Based on these dissections, the compartments or cells formed by the partitioning within the ethmoidal bulla and the respective communication with adjacent spaces were the parameters used to develop the classification system.**

SETTING: **Private midwestern rhinologic referral practice.**

RESULTS: **Three main categories of ethmoidal development were identified: simple, compound, and complex. Forty-seven percent of bullae were of the simple type, 26% were compound, and 27% complex. Sixty-eight percent of ethmoidal bullae had a single opening into the hiatus semilunaris superior; 6 (2.8%) ethmoidal bullae had a single anterior opening to the ethmoidal infundibulum. The remaining 28.7% had multiple cells with multiple openings, at least 1 of which opened into the hiatus semilunaris superior 98.4% of the time. There was a cell in the complex bulla opening anteriorly to the ethmoidal infundibulum in 46.5%. In 58% of cases, there was symmetry from side to side.**

CONCLUSION: **A novel anatomic classification for the ethmoidal bulla is presented, with examples of the 3 types of sinus development encountered. We believe that understanding ethmoid sinus anatomy and potential drainage pathways is a core principle to functional sinus surgery.** (Otolaryngol Head Neck Surg 2001;125:598-602.)

The advent of high-resolution computerized tomography in the 1970s allowed otolaryngologists further insights into the ethmoid labyrinth, confirming its anatomic complexity, variability, and relationship to adjacent structures. Diseases of the nose and paranasal sinuses have been studied, well documented, and even classified from the radiologic perspective.[1-4] However, it was not until the introduction of endoscopy in the 1980s that otolaryngologists were able to better visualize the anatomy of the nasal cavity and more fully appreciate the relationships of the nasal cavity, the paranasal sinuses, and sinus ostia.[5,6] The technological advances in computerized tomography and nasal endoscopy, coupled with improved surgical concepts of endoscopic sinus surgery have advanced our understanding of the functional and surgical anatomy of the paranasal sinuses.

This study will demonstrate that the advent of minimally invasive sinus techniques (MIST),[8] using powered instruments with real-time suction,[9] combined with a more conservative surgical approach and advanced photodocumentation has further enhanced the knowledge base of the surgical anatomy of the paranasal sinuses in general, and the ethmoid sinuses in particular. Even though the ethmoidal bulla is expendable in both the Wigand and Messerklinger approaches, its location lends itself to an anatomical study. Because the anatomy of the sinus and its ostia are minimally altered, MIST enhances the potential of such a study of the ethmoidal bulla, usually the major component of the anterior ethmoidal labyrinth.

The ethmoid sinuses have classically been described as being divided into anterior and posterior compartments, separated by the vertical portion of the basal lamella.[10,11] The posterior ethmoid cells are presumed to have a separate medial drainage pathway via the superior meatus, whereas drainage from the anterior cells is classically described as via the hiatus semilu-

From the Setliff Clinic, Sioux Falls, SD, and the Lahey Clinic (Dr Catalano), Burlington, MA

Reprint requests: Peter J. Catalano, MD, Department of Otolaryngology, Lahey Clinic, 41 Mall Road, Burlington, MA 01805; e-mail, peter.j.catalano@lahey.org

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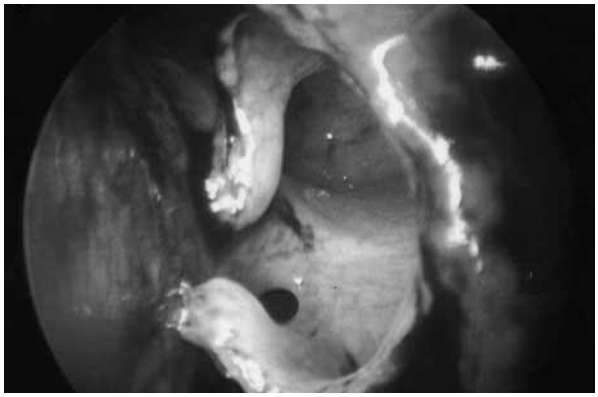

Fig 1. Intraoperative endoscopic view of left simple bulla. Note single medial communication with the HSS.

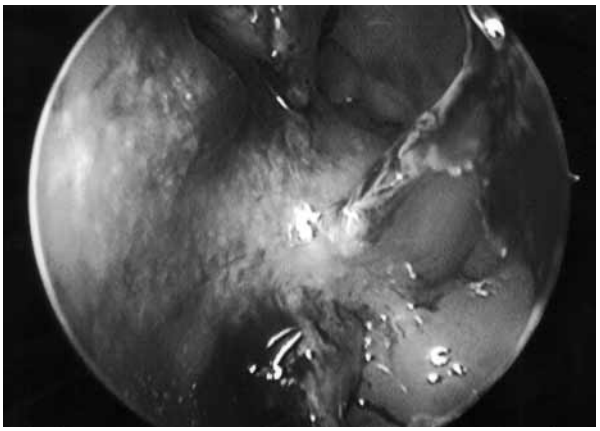

Fig 3. Intraoperative endoscopic view of left compound bulla. Note multiple medial communications with the HSS.

Fig 2. Intraoperative endoscopic view of communication through anterior face of left simple bulla. HSS is to the extreme left.

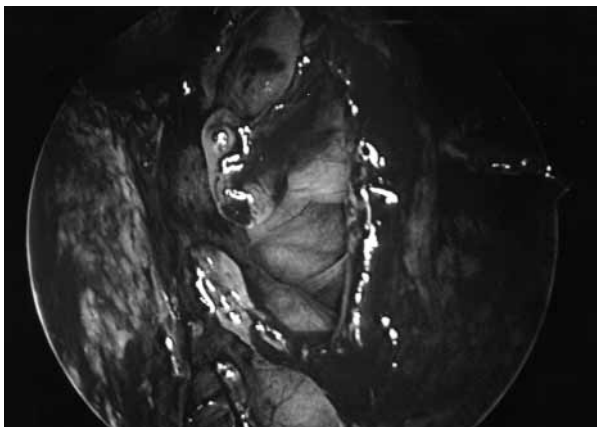

Fig 4. Intraoperative endoscopic view of left compound bulla shows multiple medial communications with the HSS.

naris superior into the middle meatus.[12] Our dissections suggest both verification of the former, but, by contrast, variations of the latter that have not heretofore been described. In addition, to our knowledge, there is no previous report, commentary, or discussion regarding the presence or absence of surgical anatomical symmetry between right and left ethmoidal bullae within the same person. Most anatomical studies are reported from cadaveric material that may not have correlation with in vivo endoscopic surgical dissection. We herein report the first in vivo anatomic study to evaluate each of these factors and present a classification system for the surgical anatomy of the ethmoidal bulla on the basis of its internal partitioning, resultant configuration, and the respective communication patterns from its compartment(s) to adjacent spaces.

MATERIALS AND METHODS

A total of 107 consecutive patients undergoing primary MIST were enrolled in the study. Exclusions included those patients with massive polyposis, a nasal mass, or any other process causing bone destruction or remodeling on preoperative imaging. Dissections were performed by the senior authors in ambulatory surgical centers. Video-documentation was obtained in over 90% of cases, serving as a data file and allowing case review when necessary.

The same surgical approach to the ethmoidal bulla was used in all cases.[8,13] After a complete uncinectomy performed via a retrograde approach, the face of the ethmoidal bulla was inspected for the presence of an anterior opening. The hiatus semilunaris superior (HSS) was first identified, and only the medial wall of the ethmoidal bulla was removed (ie, a controlled ethmoidotomy) using a micro-debrider, microforceps,

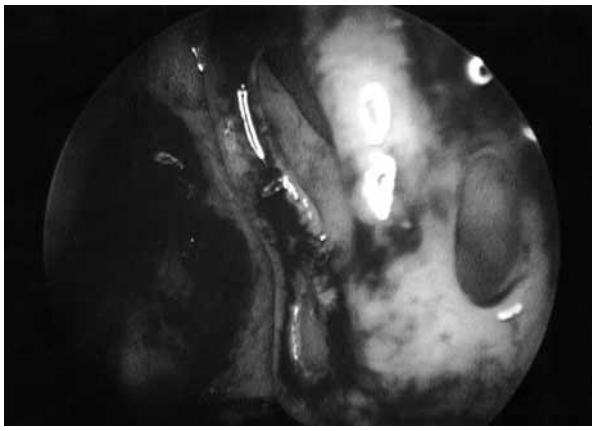

Fig 5. Intraoperative endoscopic view of left complex bulla. Note multiple anterior and medial communications from bulla to HSS (each drained a separate compartment).

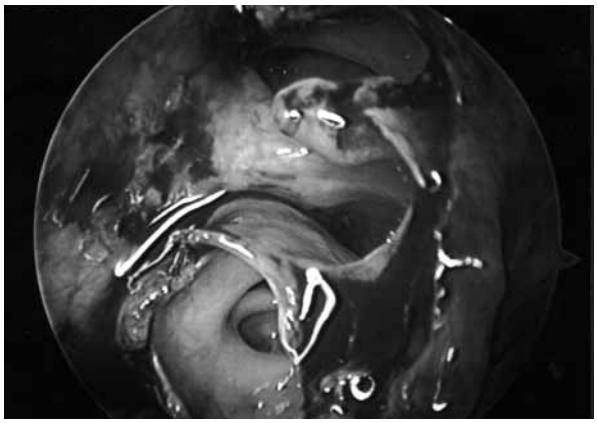

Fig 6. Intraoperative endoscopic view of left complex bulla. Inferior compartment communicates with posterior ethmoid cells.

and microscissors. Neither the partitions within the bulla nor its anterior face was disturbed. With the use of a 30 and/or a 70 degree endoscope, compartments within the ethmoidal bulla could be identified and their respective communication with adjacent spaces visualized. Through this exposure, a frontal or angled seeker could be used to confirm the visual observation, if necessary. Sinus components were assigned to a particular opening only if it could be visually confirmed as the only egress from the space. If a posterior communication was suspected, the superior meatus was directly visualized while the posterior exiting opening from bulla was irrigated. The presence of irrigation fluid in the superior meatus and behind the basal lamella validated the visual observation. No dye studies were done.

Partitioning and the resulting compartmentalization of the ethmoid bulla was noted, charted, and video-documented. Based on the configuration of the bulla, 3 classes of ethmoidal bullae development were noted. The simple bulla is a single, usually large, cavity with 1 medial opening anterior to the basal lamella and communicating to the HSS or, less often, anteriorly via a discrete opening in the face of the bulla to the ethmoidal infundibulum (EI) (Figs 1 and 2). The compound ethmoidal bulla usually has 2, but occasionally 3, separate compartments, each of which opens medially anterior to the basal lamella and communicates to the HSS (Fig 3), but there is no communication between the compartments. The complex bulla has 2 or 3 compartments, one of which commonly communicates with the HSS. The other components of the complex bulla will communicate anteriorly to the EI, and/or posteriorly to the superior meatus (Figs 4 and 5). As in the compound bulla, no communication with each other was found.

RESULTS

This study included 107 patients who underwent dissection of 214 ethmoidal bullae. There were 54 males and 53 females, with ages ranging from 20 to 89 years (mean, 49 years). Of these, 107 (47%) ethmoidal bullae were found to be a single cell and thus classified as simple. A single opening medially to the HSS was identified in 102 patients or anteriorly to the EI in 5. The simple bulla was located on the left in 60 patients and on the right in 47; 35 of these patients had a simple pattern bilaterally. A compound bulla, ie, 2 or more partitioned components, both communicating medially to the HSS but not with each other, was identified in 49 patients. Twenty-three sinuses of the compound type were present on the left and 26 on the right. The complex bulla, ie, multiple cells, mixed patterns of communication, was present in 58 patients (27%), 26 on the left and 32 on the right. Its many variations were symmetrical in 17 patients. All bullae in the complex group were found to have multiple (2 or 3) compartments with a variable communication to adjacent spaces, but no communication with each other. Both anterior (EI) and medial (HSS) openings were identified in 23 patients (10 left/13 right). Posterior and medial openings were identified in 32 (16 left/16 right). Anterior and posterior openings without a medial opening was found only in 1 (right).

Combined, 208 ethmoidal bullae (97.2%) had at least one opening to the HSS; 33 (15.4%) had at least 1 communication to the superior meatus; and 31 (15%) had at least 1 anterior opening to the EI. In 6 patients (2.8%), no ostium communicated with the HSS. Of these, 5 had

a single anterior opening to the EI, and 1 had posterior and anterior openings. Therefore, direct communication between a simple ethmoidal bulla and the EI was usually present when an opening was not identified in the HSS. It is important to note that the shape or appearance of the face of the bulla on nasal endoscopy was neither predictive of its internal configuration nor the pattern of communication with adjacent spaces.

Overall, the simple bulla was the most common type identified; compound and complex configurations were approximately equal. The HSS was the most common communicating space, whereas anterior and posterior communications occurred with equal frequency. Bilaterally symmetric ethmoid anatomy was present in 62 (58%) patients and most commonly seen with simple bulla (35%). Bilateral anatomic symmetry among complex and compound bullae was 29% and 25%, respectively.

DISCUSSION

Based on in vivo dissection of the ethmoidal bulla using MIST, this anatomic study confirms that the most common developmental pattern of the ethmoidal bulla is that of 1 simple cavity with a single opening in a medial location communicating with the HSS anterior to the basal lamella. However, the expected variations in both partitioning and the respective communication to adjacent spaces, are also confirmed, giving rise to additional patterns that lend themselves to classification. The classification system proposed is based on the dominant partitioning patterns with the ethmoidal bullae, ie, simple, compound, and complex. The compound bulla is usually composed of 2, infrequently more, partitioned spaces, each of which communicates medially to the HSS, but not to each other. The complex bulla, accounting for 28% of the bullae in our study, is characterized by multiple (2 or 3) components, anterior and/or posterior communications, usually in conjunction with 1 cell that opens to the HSS, but without a communication or opening from cell to cell. A posterior draining cell was always in an inferior position relative to other components of the bulla. At this time, it is uncertain whether this posterior communication represents an anterior extension of the posterior ethmoid or a posterior extension of the anterior ethmoid. A similarity in pneumatization is seen with respect to concha bulla of the middle turbinate.

Cadaveric dissections of the paranasal sinuses performed by renowned rhinologists of the 19th and early 20th centuries[10-12] emphasized the complexity and variability of the ethmoid bone, but failed to detail the communicating patterns of the anterior labyrinth. It is well known that limitations in visualization and instrumentation were associated with a high morbidity and mortality in ethmoid surgery through the 1980s.[14] Intranasal ethmoid surgery was considered high risk and therefore performed infrequently by a select few, hardly a setting for precise studies in surgical anatomy.[11]

Until the introduction of sinus endoscopy in the mid-1980s, external surgical approaches to the ethmoid complex were considered the standard of care by most otolaryngologists, the skull base and lamina papyracea being the major anatomical considerations. The advent of endoscopes and associated improved lighting enhanced visualization, but relatively crude instrumentation and the absence of real-time suction largely precluded appreciation of subtle variations in the surgical anatomy of the ethmoid complex, particularly with respect to the ethmoidal bulla, frequently destroyed in the surgical dissection.

Minimally invasive techniques (MIST) for sinus surgery, products of real-time suction, and precision instrumentation dictate an effort to identify and, when possible, preserve the integrity of sinus outflow tracts. A medial approach to the ethmoidal bullae offers a controlled entry with preservation of the basal lamella, face of the bulla, and any partitioning inside. This is in direct distinction to the traditional approach through the face of the bulla with a jay curette or forceps. This "controlled entry," beginning at the HSS, is a medial to lateral entry into the bulla and addresses what we previously believed to be the only drainage from the anterior ethmoid. Entering the bulla at this position made evaluation of partitioning within the rest of the bulla more reliable and prevented inadvertent damage to existing anatomy. Thus, this approach further makes possible detailed observations of surgical anatomy. Using this standardized approach has revealed both consistencies and variations in the ethmoidal bulla previously undocumented. Cadaveric dissections were not performed in this study, because it was designed for the express purpose of defining the endoscopic surgical anatomy of the ethmoidal bulla. The dissection technique described herein provided excellent visualization of all spaces within the ethmoidal bulla, thereby minimizing the chance of inaccurately describing the anatomy, missing incomplete septations within the bulla, or not being able to classify what was seen.

Although the clinical significance of the above findings is uncertain at present, the study demonstrates that the anterior ethmoidal labyrinth has order and can be dissected with precision. We hope to generate new interest in the possible relationships between ethmoidal anatomy, physiology, and pathophysiology. The anatomic repetition and consistency of our findings, coupled with an unexpectedly high incidence of

anatomic symmetry (ranging from 25% to 35% for the 3 bulla types identified) in a structure often referred to as a "labyrinth," appears more than coincidental and, not surprisingly, strongly suggests the same genetic influence known to be operative in other developmental processes. However, unlike the ethmoidal sinuses, the dependent sinuses appear to have more consistent outflow tracts. Variability in outflow from the frontal, maxillary, and sphenoid sinuses is partially influenced by variations in the ethmoidal bone, and perhaps partially by local clinical factors and/or genetics.

SUMMARY

This endoscopic surgical study reports the recurrent, although variable, patterns of ethmoidal bullae anatomy, with particular attention to the number of compartments and their respective communication with adjacent spaces. It is an anatomic study that invites speculation and further investigation in the areas of the embryologic, physiology, as well as the pathophysiology of sinus disorders. An anatomic classification system for the ethmoidal bulla into simple, compound, and complex offers the possibility of correlating developmental patterns and the occurrence of disease within the ethmoidal bulla. More importantly, the study further enhances realization of the elusive goal of a precise, systematic surgical approach to the ethmoid labyrinth based on detailed anatomic observations.

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