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Frontal sinus and its outflow tract: A comprehensive anatomical and surgical review

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Abstract --- Introduction: The frontal sinus and its outflow tract attracts special concern for the budding otorhinolaryngologists because of its complex location, variation in anatomy and disease processes altering its pathophysiology. The surgical management is challenging and a surgeon must be well aware of its anatomical variation, radiological finding to anticipate the best surgical outcome. Objectives:-To review the frontal sinus and its drainage pathway with respect to anatomy radiology and different surgical methods. Data Analysis:-The FS presents a variety of anatomical variation and multiple pathological situations can direct multiple surgical approaches to deal with them. FR is the area of "surgical bottleneck" with maximum narrowing endoscopically and beginners must know the boundaries of safe work to have an optimal outcome. Chronic rhinosinusitis, frontoethmoidal mucocele and Osteomas are common disease process affecting frontal sinus and there are vast variant of malignant tumors that can affect the area posing special challenge to surgeon, Conclusion:- Different surgical pathologies affect frontal sinuses and its outflow tract which can be managed successfully if surgeon has good knowledge of its relevent anatomy and by use of appropriate surgical tools and individualized approach.

Keywords---frontal sinus, frontal recess (FR), agar nasi cell (ANC), frontal sinus outflow tract (FSOT), draf classification.

Introduction

Surgery of frontal sinus is considered the most challenging part of sinus surgery because of its close proximity to skullbase and orbit. This may lead the surgeon to inadequately clear the disease or inadvertently injure the normal anatomy to invite complications. Proper surgical planning like an preoperative radiography to

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identify the disease process and relevant frontal sinus anatomy is essential before the patient enters the operating room.Our study provides a comprehensive view of the relevant concept and techniques of frontal surgery.

Anatomy and Radiology

FS is an air space bounded between two cortical bone in the anterior cranial vault.It radiologically becomes visible by 4 years of age and craniofacial growth is synchronous with the frontal sinus and its peak growth occurs at age of 18 years. As with any surgery the success of any surgery is dependent on the anatomical details of the region. Frontal sinus lies close to orbit and skullbase, hence special care must be taken to avoid any injury to the critical structure uring endoscopic sinus surgery. Previously frontal sinus was considered to be a ethmoidal cell because of the close anatomical proximity and common embryological origin.^{1,2} Embrological origin suggests that FS develops as a direct expansion of the infundibulum or as a epithelial migration of ethmoidal cells into frontal bone usually during 16 week.

The FS has enourmous anatomical and dimensional variation which can expand to zygomatic parietal and supraorbital recesses. Unilateral and bilateral FS aplasia occurs in 3-5% individuals.³ The FSOT is an three dimensional space in which the frontal sinus opens through the ostium to the FR inferiorly. The FR is an inverted cone like bony space which is narrowed superiorly at the internel frontal opening. The lower limit is wider and opens into the ethmoidal infundibulum.The FR is limited anteriorly by bony beak and agar nasi cell(ANC) posteriorly by ethmoidal bulla ,medially by middle turbinate and laterally by lamina papyracea^{4,5}. Variation in the lower third of FSOT are main source of obstruction and diseases.

The ANC is the anterior most ethmoid cell marking the anterior limit and is used as a landmark to identify FR. The extent of pneumatisation is the chief determinant of the endoscopic accessibility of the FS.The joining of medial wall of ANC with Uncinate forming the "vertical Bar" is a major referral point for correct identification of FR and FS. As the ANC is separate from ethmoidal bulla and the middle turbinate, the FSOT lies posteromedial to ANC. When ANC pneumatises in mediolateral direction displacing the bony bar, the FSDP is narrowed and lies behind the ANC.When ANC is poorly pneumatised FSOT lies medial to it as there is sufficient space between vertical bar and middl turbinate. The attachment of uncinate and the ethmoidal cell pneumatisation also greatly influence the FSOT's shape and width. Different anatomical attachments of superior uncinate are also used as landmark to identify the FR as described by Stammberger⁶.if this insertion occurs to the lamina papyraceae the FR drains into middle meatus and when uncinate attaches to skullbase or middle turbinate the FR directly drains into ethmoidal infundibulum. The anterior wall of ethmoidal bulla attaches to the skullbase capping the posteriorly placed Anterior ethmoidal artery which lies 2-3mm behind the FR. Preserving the bulla(Intact bulla technique) sometimes provide a good landmark for posterior limit of dissection.

The FR has variable dimension in antero-posterior and medio-lateral direction depending on the level of pneumatisation of ethmoidal cell. Supra orbital cell

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pneumatises above ethmoid and behind FR above the orbit whears suprabullar cell pneumatises into skullbase. Sometimes intersinus septal cell pneumatises causing narrowing and lateral displacement of FR⁷ Other cell types exist in the vicinity of anterior wall best described by Bent and Kuhn classification.Type 1 is single cell above ANC; type 2 cell when there are more than multiple cells above ANC; type 3 cell when a cell pneumatises into frontal sinus wall and type 4 when a single isolated cell exists in frontal sinus⁸

Multiplanner reconstructed computed Tomography is mandatory now a days before proceeding for any surgery of the frontal sinus given the complex anatomy of the region . The anteroposterior dimension is best evaluated in the saggital plane whereas the mediolateral space is best seen in coronal planes. The measurements will detect the easy of doing surgery in the region while assessing the potential difficulty that the surgeon is likely to face. Narrow FR space needs extra care so as not to damage the sinus mucosa as it scarring may occur in the post operative period posing failure. Magnetic resonance imaging is necessary when there is intraorbital or intracranial extension or there is suspected malignancy⁹

Clinical and surgical consideration

The disease process guides the preoperative imaging and operative planning. The goal of surgery in most benign condition is to enlarge the FR space . Malignancy on the otherhand may require extensive bony work along with mucosal resection.

Imaging

A through preoperative radiological analysis of the FS and FSOT helps in successful operative procedure. A CT scan and MRI if needed should be available to the surgeon all the time during surgery. Key anatomical factors that needs to be seen and reviewed prior to surgery includes:

- Nasal cavity-vestibular patency, synechia
- Inferior turbinate
- Middle turbinate-anatomical variation, attachments, concha bullosa. Lateralization
- Uncinate process-attachments.proximity to orbit, previous surgery
- Maxillary sinus- haller cell, accessory ostium, pneumatisation orbit relation
- Frontal sinus/FR/Ethmoid cells-pneumatisation, FSOT beak thickness,lamina papyrace,Anterior ethmoidal artery
- Posterior ethmoid/sphenoid sinus-pneumatisation onodi cell optic and carotid location, bony dehiscence
- brain/orbit /skullbase- foveal depth and symmetry

Equipments

Most pathological situations are handled using endoscopic sinus surgery. The angled endoscopes viz, 30° , 45° , 75° and the angled instruments form the core of any sinus surgeon's instrument basket. Endoscopes provide a wide angle view and a high definitional image. Frontal set consists of giraffe sinus forcep, the

horseman forcep and the angled kerrison rongeur angled cucurerres frontal sinus seeker. Powered instruments in the form of microdebrider removes tissue by oscillating or rotating knives in an interior cannula.it helps in continuous suction of blood and secretion thereby maintaining a clear bloodless field for good visualization which is important while working in this region.4m 360° rotable $12,^{\circ}$ 40° , 60° angled debrider blades are most frequently used in our set up. Continuous and attentive visualization of the tip is critical so as to avoid artery injury and orbital and intracranial injury. For bony work in case of an extended resection we use curved burrs mainly coarse diamond 4mm 15° 40° angled burrs apart from 40° and 60° diamond burrs which are used top drill bones at critical sites.

Navigation is a recent advancement in the basket of sinus surgeon which provides more accurate orientation of critical structure in sinus surgery. As the operating cost is high, it is reserved for selected cases like revision surgery where the anatomy is severly distorted by the previous surgery or the disease process itself. But the technology is an adjunct and not a replacement to good anatomical knowledge and surgeon"s expertise.

Operative preparation

Anaesthesia

Total intravenous anaesthesia with propofol and ramifentanilis preferred in our set up . Heart rate is maintained close to 60/minute which helps lessen capillary bleed¹⁰.

Positioning

The patient is poisoned 30° in anti trendelenberg position with head slightly extended and turned to face the surgeon. It improves surgical field and reduces bleeding¹¹

Prophylactic antibiotics

we prefer to give antibiotics perioperatively usually 1 hour prior to the procedure. a broad spectrum antibiotics is preferred although it can be individualized. We give Amoxicillin and clavulanate(60-90mg/kg/24 hours) as it is broad spectrum and is cost effective.

Topical preparation

We always prefer to give topical preparation in the form of saline adrenaline(1 in 1 lakh) soaked in cotton neuropatties before sinus surgery. Infiltration is avoided to avoid systemic side effect.

Surgical procedure

The type of surgery is individualized based on patient's symptoms, radiological finding and associated comorbidities. A septoplasty should be performed

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whenever necessary to expose the field and avoid blocking the FSDP postoperatively. A fullview of the axillary region of middle turbinate is necessary before doing work in frontal sinus¹² Draf systematized frontal surgery into four types with successive increase in the complexities of the procedure(Draf 1, 2a, 2b,3 or modified Lothrop)

Draf 1

A Draf 1 is a procedure of ethmoidectomy that aims to improve the FR aeration.it concludes with uncinectomy, removal of the anterior face of Bulla and resection of the parts of the medial lamella of the ANC. Further extension of the resection is avoided to prevent scarring which can be detrimental to the FSOT. The procedure is done when there is minimal disease like acute complicated frontal sinusitis failed to medical management. The initial steps sre done with 0^o endoscope.the Middle Turbinate is medialised using a elevator and uncinectomy is done completely by removing its attachments to lateral wall and its horizontal and vertical parts are also removed widening the maxillary ostium^{13.} Anterior ethmoidectomy is done with resection of anterior ethmoidal cells that surround FR without manipulating frontoethmoidal cell.¹⁴

Draf 2a

This procedure involves the clearance of above mentioned ethmoidal cell along with complete ethmoidectomy and removal of all cells related to FR and FS between lamina papyraceae and middle turbinate. It is indicated for procedures like refractory chronic rhinosinusitis, nasal polyposis mucocele and benign tumor limited to frontal sinus. We prefer to procede with an intact Bulla technique for Draf 2 dissection. The anterior bulla should be preserved as long as it is possible as per Rudert.^{15,16} Initially using 0^o endoscopy uncinectomy is performed with complete exposure of wide maxillary ostium.

An 30° scope and microdebrider are then used to expose the anterior wall of terminal recess. Dissection is continued superiorly till the lacrimal bone lateral to anterior wall of terminal recess with middle turbinate and medial to lamina papyracea. Anterior wall of ANC is partially debrided and then using sinus seeker FR is identified. The medial wall of ANC is then debrided . The posterior limit of resection is intact anterior wall of bulla. The intact bulla technique preserves the anterior ethmoidal artery. the o° endoscope is again used to to clear the bulla and the remaining frontoethmoidal cell till the internal frontal sinus ostium is vidualised with no bony chips around it. Any further sinus surgery is then continued depending upon the disease extention.

Draf 2b

The procedure begins with dissection of anterior part of middle turbinate and axilla. The frontal sinus floor is then drilled out between septum and lamina opapyracea. The frontal beak is drilled to widen the anterior face of sinusotomy. The indications are mostly unilateral benign diseases like mucocele and benign tumor. In our experience draf2b procedure is less frequently indicated for inflammatory pathology. The neoosteogenesis that follows the drilling posed more

harm than the inflammatory disease process itself. So we resort to a draf3 when there is a need to drill the frontal floor in case of CRS

Draf 3

The procedure begins with joining of the two sides of frontal sinuses through complete removal of anterior ethmoid cells, anterior part of middle turbinates FS floor bilaterally and intersinus septum along with adjacent nasal septum. The indications for the procedure are massive sinonasal polyposis any disease causing massive frontal osteitis CSF leak in Frontal sinus encephalocele and big frontal mucocele.for most inflammatory pathology Draf3 is done when well performed Draf2 procedure and medical therapy fail to control disease. Draf 3 can be accomplished by a "inside out" or an "outside in" approach. Inside out technique is our procedure of choice for a routine Draf3. The anterior limit of maximal dissection is periosteum of frontal process, medial limit is medial wall of orbit and posterior limit is first olfactory neuron(Filum)on both sides¹⁷.

The surgery starts with bilateral frontal sinusotomy as described above. Septal window is created around 2 cm in the caudal area of FS floor which extends till the septal attachment to FS floor dorsally and lower limit being the axilla and the anterior limit is nasal bone. This window allows visibility of axilla of middle turbinate from either sides. Monopolar with low coagulation setting can be used to mark the limits. Mucosal graft from septectomy can be harvested which can be used at the end of the surgery to cover exposed bone.

The anterior middle turbinate is trimmed and mucosa on axilla cut and cauterized. Nasoseptal angulation identified and mucosal flap is elevated by a freer's elevator posteriorly till the nasal branch of anterior ethmoidal artery just anterior to first olfactory fibre with which it is commonly mistaken¹⁸ is identified. A 4mm 15° coarse diamond burr along with suction irrigation is introduced through one nostril and a 45^o endoscope is introduced from other nostril to allow for more work space. Drilling starts from the FS floor in an antero-medial direction and whole floor rontal beak, and junction of bony septum to sinus floor is drilled out . Finally frontal process of maxilla is thinned until periosteum is visible. The intersinus septum is then meticulously drilled till the frontal roof. Sufficient irrigation is done at the end of the procedure to flush out bone dust and chips. The surgical site can be covered with mucosal flaps after achieving hemostais. At the end "soframycin" soaked formal gauze can be placed to pack the cavity which provides a sterile humid mileu reducing granulation and causing early mucosalisation. Literature shows upto 95% patency rate at 28.5 months after draf 3¹⁹ Although long term patency rates vary, but large FS aperature following Draf3 is critical for long term high patency rate.

Surgical complications

CSF Leak

CSF Leak encountered during surgery should be repaired at the same sitting. Variations like a low and deep fovea ethmoidalis is more prone to be associated with iatrogenic CSF Leak. A late repair may predispose patients to recurrent bouts of meningitis. An early repair carries success rate upto 905 in primary setting and 97% in rvision cases²⁰. A precise localization is key to successful repair using standard technique. The choice of procedure again depends on site of leak and size of defect.

Orbital complication

The commonly encounterd compilcations are fat prolapsed and medial rectus disruption and orbital hematoma. Minor fat prolapsed can be addressed by bipolarization and loose nasal pack at the end of surgery. Powered shaver should be used cautiously at a breached lamina papyracea. Lack of periorbita identification might land up the surgeon in injuring optic nerve and medial rectus. Anterior ethmoidal artery injury in most cases can be cauterized or a tight pack can be considered. An accidental transcection may lead to intraorbital hematoma which is a surgical emergency. A lateral cathotomy along with upper and lower eye lid cantholysis must be done to ensure relief or intraocular pressure.. Subacute orbital hematoma which appears hours after surgery usually is a result of slow venous bleeding due to breach in lamina. It can cause orbital swelling pain vision loss. Ipsilateral nasal pack has to be immediately loosened or removed in such situation.

Synechia and scarring

Middle turbinate lateralization can lead to middle meatus synechia formation and failure of FS surgery which might require revision surgery²¹. Measures taken reduce such incidences are preserving horizontal part of basal lamella and "Bolgerisation", a willful creation of synechia between Middle turbinate and adjacent septum by targeted injury.

Mucocele

When mucus is confined to bony spaces, they form mucocele and cause obstruction of FSOT. The symptoms can be proptosis,opthalmoplegia diplopia etc. In FS surgery mucosa preservation and maintaining patency of FSOT helps prevent mucocele formation²². The standard of care is endoscopic marsupialisation.

Conclusion

Frontal sinus has complex anatomy beyond doubt. The diseases affecting FS and FR can be safely dealt with great confidence if the surgeon has reasonable understanding of the anatomical variation, precise use of technique and use of appropriate instrumentation including image guides surgery. FS surgery still remains a huge challenge and if surgical principles are not considered and followed damage to critical structure can happen inviting unwanted and dreaded complication.

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