Neurovascular sparing transposition of pterygopalatine fossa: Anatomical principles and techniques

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TITLE PAGE

Neurovascular sparing transposition of pterygopalatine fossa: Anatomical principles and techniques

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Running title: Neurovascular sparing transposition of PPF

Compliance with ethical standards

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ABSTRACT

Objective: Sacrifice of pterygopalatine fossa (PPF) neurovascular structures during endoscopic endonasal transpterygoid approach (EETPA) may impact on patient's comorbidity. We present anatomical and surgical techniques for maximizing PPF transposition while preserving its neurovascular through orbito-pterygo-sphenoidal (OPS) ligament release and descending palatine canal (DPC) decompression. **Methods**: The EETPA was performed on six specimens. Two measurements were obtained to assess PPF transposition: 1) inferior transposition (distance between the superior margins of the base of the pterygoid process and PPF); 2) lateral transposition, (distance from Eustachian tube lateral margin to PPF medial margin).
Results: After incising the OPS ligament, a mean gain of PPF inferior transposition of 7 mm (4-11 mm, $p = 0.03$) was observed, with a total inferior transposition of 12 mm (6-15 mm). Subsequently, the posterior half of the inferior turbinate was removed and the DPC was decompressed, with a mean gain of PPF lateral transposition of 12 mm (range 8-15 mm, $p = 0.01$).
Conclusion: The OPS ligament release offers a significant advantage for the PPF inferior transposition, allowing access to the inferolateral recess of the sphenoid sinus, cavernous sinus, and paramedian middle cranial fossa; while the DPC decompression provides a significant advantage for the PPF lateral transposition, granting access to the Eustachian tube and ITF.

KEY WORDS: Endoscopic transpterygoid approach; Orbito-pterygo-sphenoidal ligament; Pterygopalatine fossa transposition; Anatomical measurements; Innovative techniques.

LEVEL OF EVIDENCE: 1.

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INTRODUCTION

The endoscopic endonasal transpterygoid approach (EETPA) is as a versatile technique to access various intracranial and extracranial regions, enabling surgeons to address complex pathologies located in the middle cranial fossa (MCF), infratemporal fossa (ITF), cavernous sinus (CS), petrous apex, and clivus.[(1-4)] Compared to transcranial approaches, the EETPA offers significant advantages, including reduced morbidity and improved postoperative recovery.[5] However, the presence of critical neurovascular structures within the pterygopalatine fossa (PPF) poses a significant challenge, limiting the optimal surgical trajectory.[4,6-8] Specifically, the EETPA classically requires division of the vidian nerve to maximize inferolateral transposition of the PPF and, thus, the reach of the EETPA. Division of the vidian nerve, however, may lead to dry eye and, consequently, decreased quality of life (Fig. 1).[9]

In an attempt to maximize inferolateral transposition of the PPF without dividing the vidian nerve, in select cases we divided orbito-pterygo-sphenoidal (OPS) ligament – which tethers the PPF superiorly to the inferior orbital fissures – and decompressed the descending palatine canal (DPC) – which tethers the PPF medially.[10,11]

While this technique has provided us with subjectively increased mobilization of the PPF without sacrificing the vidian nerve, no study has quantified the benefits that release of the OPS and decompression of the DPC provides. Thus, we present a detailed examination of the anatomical with a step-by-step description of the surgical techniques of OPS release and DPC decompression, and quantify the benefit it provides in PPF transposition through an EETPA.

MATERIALS AND METHODS

All aspects of this study were approved by the Institutional Review Board and Biospecimens Committee (17-005898), as required by standard protocols. Twelve sides of 6 head specimens were dissected in the anatomy laboratory of our institution. All specimens were formalin-fixed and latex-injected using six-vessel technique previously described.[12-16] All dissections and measurements were performed with a 0-degree, 30-degree, and 45-degree endoscope (4 mm, 18 cm, Hopkins II, Karl Storz, Tüttlingen, Germany) attached to a high-definition camera and a digital video

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recorder system. Each dissection was performed until the expected quality level was achieved, so that each critical anatomical landmark was clearly documentable and measurable.

Step-by-step dissections for PPF exposure and landmarks identification

The specimen was placed supine on the dissection table in neutral position. First, a careful endoscopic inspection of the nasal cavities was performed. Then the middle turbinate was gently medialized to expose the middle meatus. An incision was performed along the anterior border of the uncinate process with a Cottle dissector to enter the ethmoid infundibulum. The uncinate process was gently medialized before transection of its superior and inferior attachments with endoscopic scissors. The removal of the uncinate process allowed great visualization of the natural ostium of the maxillary sinus and ethmoidal bulla. A bullectomy was then performed. The natural ostium of the maxillary sinus was entered with Thru-cut forceps and the posterior fontanelle of the maxillary sinus was removed. A large maxillary sinus antrostomy was carried out up to the nasolacrimal duct anteriorly, the posterior wall of the maxillary sinus posteriorly, the orbital floor superiorly, and the attachment of the inferior turbinate inferiorly. The tail of the middle turbinate was then removed.

The posterior ethmoid cells and superior turbinate were removed flush to the anterior skull base superiorly and lamina papyracea laterally. The ostium of the sphenoid sinus was identified and enlarged superiorly towards the skull base, laterally towards the orbit, and inferiorly towards the sphenoid floor.

After mucosal removal, the posterior wall of the maxillary sinus, the perpendicular plate of the palatine bone and its orbital and sphenoidal processes were identified. The anterior attachment of the Eustachian tube was identified posteromedial to the medial pterygoid plate. The sphenopalatine artery, exiting the sphenopalatine foramen, was divided. The mucosa posterior to the perpendicular plate of the palatine bone was elevated in a subperiosteal plane towards the anterior margin of the torus tubarius of the Eustachian tube. The perpendicular plate of the palatine bone was removed, unveiling the periosteum of the PPF. The orbital process of the palatine bone was removed and the medial portion of the infraorbital fissure and OPS ligament were exposed. The sphenoidal process of the palatine bone and the anterior limit of the sphenoid floor were drilled out from medial to lateral. In this way, the pharyngeal artery was identified within the palatovaginal – or palatosphenoidal – canal running

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from the PPF to the roof of the nasopharynx. The vidian nerve was identified and the superomedial limit of the PPF was progressively exposed (Fig. 2).[5,17]

Measurements

Two measurements were obtained to assess PPF transposition: 1) inferior transposition, defined as the distance from the superior margin of the base of the pterygoid process (BPP) to the superior margin of the PPF, recorded before and after maximal inferior retraction following OPS ligament release; 2) lateral transposition, defined as the distance from the medial aspect of the torus tubarius of Eustachian tube to the medial margin of the PPF, documented before and after DPC decompression and maximal lateral retraction (Fig. 3). A 1-cm flexible, graduated ruler was placed parallel to each measurement without covering any anatomical landmarks, and an endoscopic picture was taken. These pictures were then uploaded to a digital measurement tool (ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA) to calculate each distance. Student's T-test was utilized to assess for significant differences in the inferior and lateral retraction before and after OPS ligament release and DPC decompression, respectively.

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RESULTS

OPS ligament release and PPF inferior transposition

While maintaining the integrity of the OPS ligament, an average inferior displacement of the PPF by 5 mm (range 2-7 mm) was recorded. After incising the OPS ligament, an average gain of inferior transposition distance of 7 mm (range 4-11 mm) was observed ($p = 0.03$), with a total inferior transposition of 12 mm (range 6-15 mm). Upon achieving maximal inferior transposition, the superolateral portion of the BPP was drilled, providing access to the inferolateral recess of the sphenoid sinus (ILRS) and the CS (Fig. 4).

DPC decompression and PPF lateral transposition

Before DPC decompression, the PPF was laterally mobilized as much as possible, with a mean lateral transposition of 9 mm (range 6-15 mm). Subsequently, the posterior half of the inferior turbinate was removed, the DPC was decompressed preserving only its posterior wall, and the proximal portion of the descending palatine bundle (DPB) was exposed. This maneuver allowed for a mean lateral transposition of

19 mm (13-24 mm), with a mean gain in lateral transposition of 12 mm (range 8-15 mm) ($p = 0.01$), better exposing the inferomedial portion of the BPP and medial pterygoid plate. These portions of the pterygoid process were then drilled out, providing access to Eustachian tube and ITF (Fig. 5 and 6).

At the end, a 360° skeletonization of the distal portion of the vidian nerve, pharyngeal artery, and DPC was achieved. In all dissections the vidian nerve, DPB, IOF neurovascular structures, and the periosteal sac enclosing the PPF neurovascular content were preserved.

DISCUSSION

The transpterygoid approach provides surgical access to several extra- and intracranial regions, including Eustachian tube, ITF, CS, Meckel's cave and paramedian MCF, and petrous apex. Often, this approach requires division of the vidian nerve as it enters the PPF. In our study, we show that transposition of the pterygopalatine fossa can be greatly enhanced by OPS ligament release and DPC decompression.

Preservation of neurovascular structures during surgery is paramount to minimizing patient morbidity.[9,18-20] Damage to the vidian nerve can result in dry eye syndrome and reduced nasal secretion, adversely affecting the patient's quality of life. Similarly, injury to the greater palatine nerve and artery can lead to sensory deficits in the roof of the ipsilateral hard palate.[3,11,21] ~~While~~ Even if we demonstrate that anatomical preservation of the vidian nerve and the DPB is possible while maximizing the reach of the EETPA, further clinical studies are required to demonstrate that functional preservation of these structures is also possible.

Another important issue of this approach is the management of the inferior turbinate. While partial resection of the posterior part of the inferior turbinate is often necessary to achieve optimal exposure for lateral transposition of the PPF, meticulous surgical techniques can effectively preserve the mucosa, and, thus, mitigate the risk of atrophic rhinitis. Specifically, submucosal dissection, where the turbinate mucosa is carefully elevated and protected during bony resection, should be utilized to maximize the chances of preserving the mucosa's physiologic function. Additionally, intraoperative measures such as preserving the vascular supply of the mucosal remnant and minimizing thermal injury further contribute to maintaining mucociliary function. These techniques could allow for the necessary surgical exposure while ensuring that nasal function is preserved, reducing the risk of long-term complications such as

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dryness, crusting, or secondary infections.[9]

The PPF transposition technique proposed in this study introduces two distinct corridors through the PPF. The inferior transposition technique allows enhanced access to the inferolateral recess of the sphenoid sinus, cavernous sinus, and paramedian middle cranial fossa. The lateral transposition technique is achieved by decompressing the DPC, allowing for lateral mobilization of the PPF. This corridor is advantageous for accessing ITF and Eustachian tube.[2,14] By integrating these two corridors into the surgical armamentarium, surgeons can tailor their approach to the specific anatomical and pathological requirements of each case. This dual-corridor strategy enhances the flexibility and precision of endoscopic skull base surgery, contributing to improved patient outcomes and reduced postoperative complications.

From an anatomical perspective, the lateral and inferior transposition that this technique affords would be best suited for lesions that extend into the lateral ITF and the anteroinferior CS, respectively. These lesions would include trigeminal V3 and V2 schwannomas, meningiomas, juvenile nasopharyngeal angiofibromas, and meningoceles/encephaloceles involving the anteromedial triangle. While select lesions may require sacrifice of the vidian nerve to reach the most lateral and inferior limits, we would suggest attempting OPS release and descending palatine bundle transection first in attempt to preserve lacrimal function and prevent permanent post-operative dry eye. Of note, we mainly suggest this technique for benign disease as vidian nerve transection in malignant pathology may be necessitated to achieve margin negative resection.[4,6,9]

Limitations

This study represents a preliminary anatomical investigation with limited clinical experience. The current findings are based on anatomical observations and early surgical attempts, which may not fully capture the complexities and variations encountered in clinical practice. As such, a larger cases series be necessary to definitively assess the real advantages of the PPF transposition techniques for various pathologies. This includes evaluating surgical maneuverability, efficacy in different anatomical contexts, and the potential for minimizing complications.

Conclusions

Maximizing the reach of the EETPA while preserving the neurovascular contents of

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the PPF is anatomically feasible with OPS ligament release and DPC decompression. OPS ligament release affords significant inferior transposition of the PPF and opens a surgical corridor to the superior portion of the base of the pterygoid process. This allows for access to the inferolateral recess of the sphenoid sinus, the cavernous sinus, and the paramedian middle cranial fossa. DPC decompression affords significantly more lateral mobilization of the PPF and exposes the inferomedial portion of the base of the pterygoid process and the medial pterygoid plate, granting access to the Eustachian tube and ITF.

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AUTHORSHIP CONTRIBUTION

Conceptualization, E.A., and C.P.N., M.M.F.; methodology, E.A., A.Y.A. and C.P.N.; validation, E.A., A.Y.A., M.P.C., and C.P.N.; formal analysis, E.A., A.Y.A., and L.L.; investigation, E.A., A.Y.A., and R.M.; resources, E.A., M.P.C., and C.P.N.; data curation, E.A., A.Y.A., L.L., M.P.C., and C.P.N.; writing original draft preparation, E.A., and A.Y.A.; writing-review and editing, E.A., A.Y.A., M.P.C., and C.P.N.; visualization, E.A., A.Y.A., L.L., R.M., M.P.C., and C.P.N.; supervision, M.P.C., and C.P.N.; project administration, M.P.C., and C.P.N. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors have no financial or nonfinancial interests to declare.

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REFERENCES

1. Hofstetter CP, Singh A, Anand VK, Kacker A, Schwartz TH. The endoscopic, endonasal, transmaxillary transpterygoid approach to the pterygopalatine fossa, infratemporal fossa, petrous apex, and the Meckel

For Peer Review

cave. J Neurosurg 2010; 113:967-974.

2. Osawa S, Rhoton AL, Seker A, Shimizu S, Fujii K, Kassam AB. Microsurgical and endoscopic anatomy of the vidian canal. Neurosurgery 2009; 64:385-411.
3. Fortes FSG, Sennes LU, Carrau RL, et al. Endoscopic anatomy of the pterygopalatine fossa and the transpterygoid approach: development of a surgical instruction model. Laryngoscope 2008; 118:44-49.
4. Kassam AB, Vescan AD, Carrau RL, et al. Expanded endonasal approach: vidian canal as a landmark to the petrous internal carotid artery. J Neurosurg 2008; 108:177-183.
5. Agosti E, Rezende NC, Leonel LCPC, Alexander AY, Pinheiro-Neto CD, Peris-Celda M. Anatomical Step-by-Step Dissection of Complex Skull Base Approaches for Trainees: Surgical Anatomy of the Endoscopic Endonasal and Endoscopic-Assisted Transmaxillary Transpterygoid Approaches. J Neurol Surg B Skull Base 2022; 85:81-94.
6. de Lara D, Ditzel Filho LFS, Prevedello DM, et al. Endonasal endoscopic approaches to the paramedian skull base. World Neurosurg 2014; 82:S121-129.
7. Kaen A, Cárdenas Ruiz-Valdepeñas E, Di Somma A, Esteban F, Márquez Rivas J, Ambrosiani Fernandez J. Refining the anatomic boundaries of the endoscopic endonasal transpterygoid approach: the "VELPPHA area" concept. J Neurosurg 2019; 131:911-919.
8. Karci B, Midilli R, Erdogan U, Turhal G, Gode S. Endoscopic endonasal approach to the vidian nerve and its relation to the surrounding structures: an anatomic cadaver study. Eur Arch Otorhinolaryngol 2018; 275:2473-2479.
9. Pinheiro-Neto CD, Fernandez-Miranda JC, Prevedello DM, Carrau RL, Gardner PA, Snyderman CH. Transposition of the Pterygopalatine Fossa during Endoscopic Endonasal Transpterygoid Approaches. J Neurol Surg B Skull Base 2013; 74:266-270.
10. Hanakita S, Chang WC, Watanabe K, et al. Endoscopic Endonasal Approach to the Anteromedial Temporal Fossa and Mobilization of the Lateral Wall of the Cavernous Sinus Through the Inferior Orbital Fissure and V1-V2 Corridor: An Anatomic Study and Clinical Considerations. World Neurosurg 2018; 116:e169-e178.

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11. Li L, London NR, Prevedello DM, Carrau RL. A novel landmark for endonasal surgery of the pterygopalatine fossa and inferior orbital fissure: The orbito-pterygo-sphenoidal ligament. Head Neck 2021; 43:4022-4029.
12. Agosti E, Alexander AY, Leonel LCPC, Pinheiro-Neto CD, Peris-Celda M. Endoscopic endonasal surgical anatomy through the prechiasmatic sulcus: the key window to suprachiasmatic and infrachiasmatic corridors. Acta Neurochir (Wien) 2022; 164:1929-1938.
13. Agosti E, Leonel LCPC, Alexander AY, Graepel S, Pinheiro-Neto CD, Peris-Celda M. Endoscopic endonasal surgical anatomy of the optic canal: key anatomical relationships between the optic nerve and ophthalmic artery. Acta Neurochir (Wien) 2023; 165:525-534.
14. Alexander AY, Agosti E, Leonel LCPC, Lanzino G, Peris-Celda M. Comparison Between the Supracerebellar Infratentorial and Precuneal Interhemispheric, Transtentorial Approaches to the Cerebellomesencephalic Fissure: An Anatomoradiological Study and Illustrative Cases. Oper Neurosurg (Hagerstown) 2023; 25:e6-e14.
15. Rindler RS, Leonel LC, Graepel S, et al. The endonasal midline inferior intercavernous approach to the cavernous sinus: technical note, cadaveric step-by-step illustration, and case presentation. Acta Neurochir (Wien) 2022; 164:2573-2580.
16. Leonel LCP, Carlstrom LP, Graffeo CS, et al. Foundations of Advanced Neuroanatomy: Technical Guidelines for Specimen Preparation, Dissection, and 3D-Photodocumentation in a Surgical Anatomy Laboratory. J Neurol Surg B Skull Base 2021; 82(Suppl 3):e248-e258.
17. Agosti E, Alexander AY, Leonel LCPC, Van Gompel JJ, Link MJ, Pinheiro-Neto CD, Peris-Celda M. Anatomical Step-by-Step Dissection of Complex Skull Base Approaches for Trainees: Surgical Anatomy of the Endoscopic Endonasal Approach to the Sellar and Parasellar Regions. J Neurol Surg B Skull Base 2022; 84:361-374.
18. Suzuki T, Komune N, Miyamoto Y, et al. Preservation of nasal function in paramedian endoscopic endonasal approaches: patient series. J Neurosurg Case Lessons 2024; 8:CASE24218.
19. Peris Celda M, Kenning T, Pinheiro-Neto CD. Endoscopic Superior Ethmoidal Approach for Anterior Cranial Base Resection: Tailoring the

For Peer Review

Approach for Maximum Exposure with Preservation of Nasal Structures. World Neurosurg 2017; 104:311-317.

20. Agosti E, Alexander AY, Leonel LCPC, et al. Anatomical Step-by-Step Dissection of Complex Skull Base Approaches for Trainees: Surgical Anatomy of the Endoscopic Endonasal Approach to the Anterior Cranial Fossa. J Neurol Surg B Skull Base 2024; 85:575-586.
21. Vescan AD, Snyderman CH, Carrau RL, et al. Vidian canal: analysis and relationship to the internal carotid artery. Laryngoscope. 2007; 117:1338-1342.

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FIGURES LEGEND

Fig. 1. Overview of the PPF anatomy. A) Bony limits in a dry skull. B) Exposure of anteromedial bony limitis after an endoscopic endonasal ethmoidectomy and medial antrostomy. C) Illustration of the anteromedial portion of PPF periosteum and rappresentation of its underlying nervous content after an endoscopic endonasal ethmoidectomy and medial antrostomy. b. - bone; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; MS - maxillary sinus; n. - nerve; OPS - orbito-pterygo-sphenoidal; PPF -- pterygopalatine fossa; PPG -- pterygopalatine ganglion; post. -- posterior; pr. -- process; V2 -- maxillary nerve.

Fig. 2. Step-by-step dissection of EETPA: exposure of the PPF content. A) identification of the bony anteromedial limits of the PPF; B) removal of the superomedial portion of the posterior wall of the maxillary sinus; C) removal of the perpendicular plate of the palatine bone; D) removal of the orbital process of the

palatine bone; E) removal of the sphenoid process of the palatine bone and enlargement of the lateral and inferior exposure of the PPF with better exposure of the OPS ligament and DPB; F) detail of the inferior orbital fissure; G) detail of the vidian nerve and pharyngeal artery at the level of the distal portion of the vidian canal and palatosphenoidal canal; H) detail of the DPB. a. - artery; b. - bone; DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; MS - maxillary sinus; n. - nerve; OPS - orbito-pterygo-sphenoidal; perpend. - perpendicular; PPF - pterygopalatine fossa; post. - posterior; pr. - process.

Fig. 3. Illustration of surgical techniques of inferior and lateral trasportion of the PPF. A) PPF inferior transposition before cutting the OPS ligament. B) Gain in PPF inferior transposition after the OPS ligament has ben cut. C) PPF lateral transposition before decompressing the DPC. D) Gain in PPF lateral transposition after the DPC has been cut. DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; infraorb. - infraorbital; IT - inferior turbinate; n. - nerve; PPF - pterygopalatine fossa; PPG - pterygopalatine ganglion; V2 - maxillary nerve.

Fig 4. Step-by-step dissection of PPF inferior transposition. A) PPF inferior transposition before the OPS ligament releasing. B) Identification of OPS ligament. C) OPS ligament releasing. D) PPF inferior transposition after OPS ligament relealing. E) Drilling of the superolateral portion of the BPP. F) Surgical corridor through the superior portion of the inferolateral recess of the sphenoid sinus. DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; n. - nerve; OPS orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

Fig. 5 Clinical case: intraoperative endoscopic endonasal images of PPF inferior trasposition technique for a meningocele of the inferolateral recess of the spenoid sinus. A) OPS ligament releasing. B) PPF inferior transpostion. C) Removal of the superolateral portion of the BPP. D) Exposure of the meningocele. E) Removal of theinferomedial portion of the PBB. F) Opening of the inferior portion of the inferolateral recess of the sphenoid sinus. G) Exposure of the inferior portion of the meningocele. H) Removal of the inferior portion of the meningocele. BPP – base of the pterygoid process; DPB - descending palatine bundle; n. - nerve; NSF - nasoseptal flap; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

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Fig 6. Step-by-step dissection of PPF lateral transposition. Endoscopic endonasal lateral transposition of the PPF content and DPC decompression. A) PPF lateral transposition before DPC decompression. B) Partial drilling of the inferomedial portion of the BPP with 360° unroofing of the distal portion of the vidian nerve. C) Complete drilling of the inferomedial portion of the BPP with mobilization of the proximal portion of the DPB. D) Removal of the inferior turbinate. E) Extension of DPB inferior decompression. F) Lateral transposition of the PPF after DPC decompression with complete drilling of the inferomedial portion of the BPP and opening of the surgical corridor to the Eustachian tube. BPP - base of the pterygoid process; DPB - desceding palatine bundle; DPC - descending palatine canal; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; ~~inf. - inferior;~~ n. - nerve; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

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Neurovascular sparing transposition of pterygopalatine fossa: Anatomical principles and techniques

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ABSTRACT

Objective: Sacrifice of pterygopalatine fossa (PPF) neurovascular structures during endoscopic endonasal transpterygoid approach (EETPA) may impact on patient's comorbidity. We present anatomical and surgical techniques for maximizing PPF transposition while preserving its neurovascular through orbito-pterygo-sphenoidal (OPS) ligament release and descending palatine canal (DPC) decompression. **Methods**: The EETPA was performed on six specimens. Two measurements were obtained to assess PPF transposition: 1) inferior transposition (distance between the superior margins of the base of the pterygoid process and PPF); 2) lateral transposition, (distance from Eustachian tube lateral margin to PPF medial margin).

Results: After incising the OPS ligament, a mean gain of PPF inferior transposition of 7 mm (4-11 mm, $p = 0.03$) was observed, with a total inferior transposition of 12 mm (6-15 mm). Subsequently, the posterior half of the inferior turbinate was removed and the DPC was decompressed, with a mean gain of PPF lateral transposition of 12 mm (range 8-15 mm, $p = 0.01$).

Conclusion: The OPS ligament release offers a significant advantage for the PPF inferior transposition, allowing access to the inferolateral recess of the sphenoid sinus, cavernous sinus, and paramedian middle cranial fossa; while the DPC decompression provides a significant advantage for the PPF lateral transposition, granting access to the Eustachian tube and ITF.

KEY WORDS: Endoscopic transpterygoid approach; Orbito-pterygo-sphenoidal ligament; Pterygopalatine fossa transposition; Anatomical measurements; Innovative techniques.

LEVEL OF EVIDENCE: 1.

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INTRODUCTION

The endoscopic endonasal transpterygoid approach (EETPA) is as a versatile technique to access various intracranial and extracranial regions, enabling surgeons to address complex pathologies located in the middle cranial fossa (MCF), infratemporal fossa (ITF), cavernous sinus (CS), petrous apex, and clivus.[(1-4)] Compared to transcranial approaches, the EETPA offers significant advantages, including reduced morbidity and improved postoperative recovery.[5] However, the presence of critical neurovascular structures within the pterygopalatine fossa (PPF) poses a significant challenge, limiting the optimal surgical trajectory.[4,6-8] Specifically, the EETPA classically requires division of the vidian nerve to maximize inferolateral transposition of the PPF and, thus, the reach of the EETPA. Division of the vidian nerve, however, may lead to dry eye and, consequently, decreased quality of life (Fig. 1).[9]

In an attempt to maximize inferolateral transposition of the PPF without dividing the vidian nerve, in select cases we divided orbito-pterygo-sphenoidal (OPS) ligament – which tethers the PPF superiorly to the inferior orbital fissures – and decompressed the descending palatine canal (DPC) – which tethers the PPF medially.[10,11]

While this technique has provided us with subjectively increased mobilization of the PPF without sacrificing the vidian nerve, no study has quantified the benefits that release of the OPS and decompression of the DPC provides. Thus, we present a detailed examination of the anatomical with a step-by-step description of the surgical techniques of OPS release and DPC decompression, and quantify the benefit it provides in PPF transposition through an EETPA.

MATERIALS AND METHODS

All aspects of this study were approved by the Institutional Review Board and Biospecimens Committee (17-005898), as required by standard protocols. Twelve sides of 6 head specimens were dissected in the anatomy laboratory of our institution. All specimens were formalin-fixed and latex-injected using six-vessel technique previously described.[12-16] All dissections and measurements were performed with a 0-degree, 30-degree, and 45-degree endoscope (4 mm, 18 cm, Hopkins II, Karl Storz, Tüttlingen, Germany) attached to a high-definition camera and a digital video

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recorder system. Each dissection was performed until the expected quality level was achieved, so that each critical anatomical landmark was clearly documentable and measurable.

Step-by-step dissections for PPF exposure and landmarks identification

The specimen was placed supine on the dissection table in neutral position. First, a careful endoscopic inspection of the nasal cavities was performed. Then the middle turbinate was gently medialized to expose the middle meatus. An incision was performed along the anterior border of the uncinate process with a Cottle dissector to enter the ethmoid infundibulum. The uncinate process was gently medialized before transection of its superior and inferior attachments with endoscopic scissors. The removal of the uncinate process allowed great visualization of the natural ostium of the maxillary sinus and ethmoidal bulla. A bullectomy was then performed. The natural ostium of the maxillary sinus was entered with Thru-cut forceps and the posterior fontanelle of the maxillary sinus was removed. A large maxillary sinus antrostomy was carried out up to the nasolacrimal duct anteriorly, the posterior wall of the maxillary sinus posteriorly, the orbital floor superiorly, and the attachment of the inferior turbinate inferiorly. The tail of the middle turbinate was then removed.

The posterior ethmoid cells and superior turbinate were removed flush to the anterior skull base superiorly and lamina papyracea laterally. The ostium of the sphenoid sinus was identified and enlarged superiorly towards the skull base, laterally towards the orbit, and inferiorly towards the sphenoid floor.

After mucosal removal, the posterior wall of the maxillary sinus, the perpendicular plate of the palatine bone and its orbital and sphenoidal processes were identified. The anterior attachment of the Eustachian tube was identified posteromedial to the medial pterygoid plate. The sphenopalatine artery, exiting the sphenopalatine foramen, was divided. The mucosa posterior to the perpendicular plate of the palatine bone was elevated in a subperiosteal plane towards the anterior margin of the torus tubarius of the Eustachian tube. The perpendicular plate of the palatine bone was removed, unveiling the periosteum of the PPF. The orbital process of the palatine bone was removed and the medial portion of the infraorbital fissure and OPS ligament were exposed. The sphenoidal process of the palatine bone and the anterior limit of the sphenoid floor were drilled out from medial to lateral. In this way, the pharyngeal artery was identified within the palatovaginal – or palatosphenoidal – canal running

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from the PPF to the roof of the nasopharynx. The vidian nerve was identified and the superomedial limit of the PPF was progressively exposed (Fig. 2).[5,17]

Measurements

Two measurements were obtained to assess PPF transposition: 1) inferior transposition, defined as the distance from the superior margin of the base of the pterygoid process (BPP) to the superior margin of the PPF, recorded before and after maximal inferior retraction following OPS ligament release; 2) lateral transposition, defined as the distance from the medial aspect of the torus tubarius of Eustachian tube to the medial margin of the PPF, documented before and after DPC decompression and maximal lateral retraction (Fig. 3). A 1-cm flexible, graduated ruler was placed parallel to each measurement without covering any anatomical landmarks, and an endoscopic picture was taken. These pictures were then uploaded to a digital measurement tool (ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA) to calculate each distance. Student's T-test was utilized to assess for significant differences in the inferior and lateral retraction before and after OPS ligament release and DPC decompression, respectively.

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RESULTS

OPS ligament release and PPF inferior transposition

While maintaining the integrity of the OPS ligament, an average inferior displacement of the PPF by 5 mm (range 2-7 mm) was recorded. After incising the OPS ligament, an average gain of inferior transposition distance of 7 mm (range 4-11 mm) was observed ($p = 0.03$), with a total inferior transposition of 12 mm (range 6-15 mm). Upon achieving maximal inferior transposition, the superolateral portion of the BPP was drilled, providing access to the inferolateral recess of the sphenoid sinus (ILRS) and the CS (Fig. 4).

DPC decompression and PPF lateral transposition

Before DPC decompression, the PPF was laterally mobilized as much as possible, with a mean lateral transposition of 9 mm (range 6-15 mm). Subsequently, the posterior half of the inferior turbinate was removed, the DPC was decompressed preserving only its posterior wall, and the proximal portion of the descending palatine bundle (DPB) was exposed. This maneuver allowed for a mean lateral transposition of

19 mm (13-24 mm), with a mean gain in lateral transposition of 12 mm (range 8-15 mm) ($p = 0.01$), better exposing the inferomedial portion of the BPP and medial pterygoid plate. These portions of the pterygoid process were then drilled out, providing access to Eustachian tube and ITF (Fig. 5 and 6).

At the end, a 360° skeletonization of the distal portion of the vidian nerve, pharyngeal artery, and DPC was achieved. In all dissections the vidian nerve, DPB, IOF neurovascular structures, and the periosteal sac enclosing the PPF neurovascular content were preserved.

DISCUSSION

The transpterygoid approach provides surgical access to several extra- and intracranial regions, including Eustachian tube, ITF, CS, Meckel's cave and paramedian MCF, and petrous apex. Often, this approach requires division of the vidian nerve as it enters the PPF. In our study, we show that transposition of the pterygopalatine fossa can be greatly enhanced by OPS ligament release and DPC decompression.

Preservation of neurovascular structures during surgery is paramount to minimizing patient morbidity.[9,18-20] Damage to the vidian nerve can result in dry eye syndrome and reduced nasal secretion, adversely affecting the patient's quality of life. Similarly, injury to the greater palatine nerve and artery can lead to sensory deficits in the roof of the ipsilateral hard palate.[3,11,21] Even if we demonstrate that anatomical preservation of the vidian nerve and the DPB is possible while maximizing the reach of the EETPA, further clinical studies are required to demonstrate that functional preservation of these structures is also possible.

Another important issue of this approach is the management of the inferior turbinate. While partial resection of the posterior part of the inferior turbinate is often necessary to achieve optimal exposure for lateral transposition of the PPF, meticulous surgical techniques can effectively preserve the mucosa, and, thus, mitigate the risk of atrophic rhinitis. Specifically, submucosal dissection, where the turbinate mucosa is carefully elevated and protected during bony resection, should be utilized to maximize the chances of preserving the mucosa’s physiologic function. Additionally, intraoperative measures such as preserving the vascular supply of the mucosal remnant and minimizing thermal injury further contribute to maintaining mucociliary function. These techniques could allow for the necessary surgical exposure while ensuring that nasal function is preserved, reducing the risk of long-term complications such as dryness, crusting, or secondary infections.[9]

The PPF transposition technique proposed in this study introduces two distinct corridors through the PPF. The inferior transposition technique allows enhanced access to the inferolateral recess of the sphenoid sinus, cavernous sinus, and paramedian middle cranial fossa. The lateral transposition technique is achieved by decompressing the DPC, allowing for lateral mobilization of the PPF. This corridor is advantageous for accessing ITF and Eustachian tube.[2,14] By integrating these two corridors into the surgical armamentarium, surgeons can tailor their approach to the specific anatomical and pathological requirements of each case. This dual-corridor strategy enhances the flexibility and precision of endoscopic skull base surgery, contributing to improved patient outcomes and reduced postoperative complications.

From an anatomical perspective, the lateral and inferior transposition that this technique affords would be best suited for lesions that extend into the lateral ITF and the anteroinferior CS, respectively. These lesions would include trigeminal V3 and V2 schwannomas, meningiomas, juvenile nasopharyngeal angiofibromas, and meningoceles/encephaloceles involving the anteromedial triangle. While select lesions may require sacrifice of the vidian nerve to reach the most lateral and inferior limits, we would suggest attempting OPS release and descending palatine bundle transection first in attempt to preserve lacrimal function and prevent permanent post-operative dry eye. Of note, we mainly suggest this technique for benign disease as vidian nerve transection in malignant pathology may be necessitated to achieve margin negative resection.[4,6,9]

Limitations

This study represents a preliminary anatomical investigation with limited clinical experience. The current findings are based on anatomical observations and early surgical attempts, which may not fully capture the complexities and variations encountered in clinical practice. As such, a larger cases series be necessary to definitively assess the real advantages of the PPF transposition techniques for various pathologies. This includes evaluating surgical maneuverability, efficacy in different anatomical contexts, and the potential for minimizing complications.

Conclusions

Maximizing the reach of the EETPA while preserving the neurovascular contents of

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the PPF is anatomically feasible with OPS ligament release and DPC decompression. OPS ligament release affords significant inferior transposition of the PPF and opens a surgical corridor to the superior portion of the base of the pterygoid process. This allows for access to the inferolateral recess of the sphenoid sinus, the cavernous sinus, and the paramedian middle cranial fossa. DPC decompression affords significantly more lateral mobilization of the PPF and exposes the inferomedial portion of the base of the pterygoid process and the medial pterygoid plate, granting access to the Eustachian tube and ITF.

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Not applicable.

AUTHORSHIP CONTRIBUTION

Conceptualization, E.A., and C.P.N., M.M.F.; methodology, E.A., A.Y.A. and C.P.N.; validation, E.A., A.Y.A., M.P.C., and C.P.N.; formal analysis, E.A., A.Y.A., and L.L.; investigation, E.A., A.Y.A., and R.M.; resources, E.A., M.P.C., and C.P.N.; data curation, E.A., A.Y.A., L.L., M.P.C., and C.P.N.; writing original draft preparation, E.A., and A.Y.A.; writing-review and editing, E.A., A.Y.A., M.P.C., and C.P.N.; visualization, E.A., A.Y.A., L.L., R.M., M.P.C., and C.P.N.; supervision, M.P.C., and C.P.N.; project administration, M.P.C., and C.P.N. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors have no financial or nonfinancial interests to declare.

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REFERENCES

1. Hofstetter CP, Singh A, Anand VK, Kacker A, Schwartz TH. The endoscopic, endonasal, transmaxillary transpterygoid approach to the pterygopalatine fossa, infratemporal fossa, petrous apex, and the Meckel

For Peer Review

cave. J Neurosurg 2010; 113:967-974.

2. Osawa S, Rhoton AL, Seker A, Shimizu S, Fujii K, Kassam AB. Microsurgical and endoscopic anatomy of the vidian canal. Neurosurgery 2009; 64:385-411.
3. Fortes FSG, Sennes LU, Carrau RL, et al. Endoscopic anatomy of the pterygopalatine fossa and the transpterygoid approach: development of a surgical instruction model. Laryngoscope 2008; 118:44-49.
4. Kassam AB, Vescan AD, Carrau RL, et al. Expanded endonasal approach: vidian canal as a landmark to the petrous internal carotid artery. J Neurosurg 2008; 108:177-183.
5. Agosti E, Rezende NC, Leonel LCPC, Alexander AY, Pinheiro-Neto CD, Peris-Celda M. Anatomical Step-by-Step Dissection of Complex Skull Base Approaches for Trainees: Surgical Anatomy of the Endoscopic Endonasal and Endoscopic-Assisted Transmaxillary Transpterygoid Approaches. J Neurol Surg B Skull Base 2022; 85:81-94.
6. de Lara D, Ditzel Filho LFS, Prevedello DM, et al. Endonasal endoscopic approaches to the paramedian skull base. World Neurosurg 2014; 82:S121-129.
7. Kaen A, Cárdenas Ruiz-Valdepeñas E, Di Somma A, Esteban F, Márquez Rivas J, Ambrosiani Fernandez J. Refining the anatomic boundaries of the endoscopic endonasal transpterygoid approach: the "VELPPHA area" concept. J Neurosurg 2019; 131:911-919.
8. Karci B, Midilli R, Erdogan U, Turhal G, Gode S. Endoscopic endonasal approach to the vidian nerve and its relation to the surrounding structures: an anatomic cadaver study. Eur Arch Otorhinolaryngol 2018; 275:2473-2479.
9. Pinheiro-Neto CD, Fernandez-Miranda JC, Prevedello DM, Carrau RL, Gardner PA, Snyderman CH. Transposition of the Pterygopalatine Fossa during Endoscopic Endonasal Transpterygoid Approaches. J Neurol Surg B Skull Base 2013; 74:266-270.
10. Hanakita S, Chang WC, Watanabe K, et al. Endoscopic Endonasal Approach to the Anteromedial Temporal Fossa and Mobilization of the Lateral Wall of the Cavernous Sinus Through the Inferior Orbital Fissure and V1-V2 Corridor: An Anatomic Study and Clinical Considerations. World Neurosurg 2018; 116:e169-e178.

For Peer Review

11. Li L, London NR, Prevedello DM, Carrau RL. A novel landmark for endonasal surgery of the pterygopalatine fossa and inferior orbital fissure: The orbito-pterygo-sphenoidal ligament. Head Neck 2021; 43:4022-4029.
12. Agosti E, Alexander AY, Leonel LCPC, Pinheiro-Neto CD, Peris-Celda M. Endoscopic endonasal surgical anatomy through the prechiasmatic sulcus: the key window to suprachiasmatic and infrachiasmatic corridors. Acta Neurochir (Wien) 2022; 164:1929-1938.
13. Agosti E, Leonel LCPC, Alexander AY, Graepel S, Pinheiro-Neto CD, Peris-Celda M. Endoscopic endonasal surgical anatomy of the optic canal: key anatomical relationships between the optic nerve and ophthalmic artery. Acta Neurochir (Wien) 2023; 165:525-534.
14. Alexander AY, Agosti E, Leonel LCPC, Lanzino G, Peris-Celda M. Comparison Between the Supracerebellar Infratentorial and Precuneal Interhemispheric, Transtentorial Approaches to the Cerebellomesencephalic Fissure: An Anatomoradiological Study and Illustrative Cases. Oper Neurosurg (Hagerstown) 2023; 25:e6-e14.
15. Rindler RS, Leonel LC, Graepel S, et al. The endonasal midline inferior intercavernous approach to the cavernous sinus: technical note, cadaveric step-by-step illustration, and case presentation. Acta Neurochir (Wien) 2022; 164:2573-2580.
16. Leonel LCP, Carlstrom LP, Graffeo CS, et al. Foundations of Advanced Neuroanatomy: Technical Guidelines for Specimen Preparation, Dissection, and 3D-Photodocumentation in a Surgical Anatomy Laboratory. J Neurol Surg B Skull Base 2021; 82(Suppl 3):e248-e258.
17. Agosti E, Alexander AY, Leonel LCPC, Van Gompel JJ, Link MJ, Pinheiro-Neto CD, Peris-Celda M. Anatomical Step-by-Step Dissection of Complex Skull Base Approaches for Trainees: Surgical Anatomy of the Endoscopic Endonasal Approach to the Sellar and Parasellar Regions. J Neurol Surg B Skull Base 2022; 84:361-374.
18. Suzuki T, Komune N, Miyamoto Y, et al. Preservation of nasal function in paramedian endoscopic endonasal approaches: patient series. J Neurosurg Case Lessons 2024; 8:CASE24218.
19. Peris Celda M, Kenning T, Pinheiro-Neto CD. Endoscopic Superior Ethmoidal Approach for Anterior Cranial Base Resection: Tailoring the

For Peer Review

Approach for Maximum Exposure with Preservation of Nasal Structures. World Neurosurg 2017; 104:311-317.

20. Agosti E, Alexander AY, Leonel LCPC, et al. Anatomical Step-by-Step Dissection of Complex Skull Base Approaches for Trainees: Surgical Anatomy of the Endoscopic Endonasal Approach to the Anterior Cranial Fossa. J Neurol Surg B Skull Base 2024; 85:575-586.
21. Vescan AD, Snyderman CH, Carrau RL, et al. Vidian canal: analysis and relationship to the internal carotid artery. Laryngoscope. 2007; 117:1338-1342.

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FIGURES LEGEND

Fig. 1. Overview of the PPF anatomy. A) Bony limits in a dry skull. B) Exposure of anteromedial bony limitis after an endoscopic endonasal ethmoidectomy and medial antrostomy. C) Illustration of the anteromedial portion of PPF periosteum and rappresentation of its underlying nervous content after an endoscopic endonasal ethmoidectomy and medial antrostomy. b. - bone; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; MS - maxillary sinus; n. - nerve; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa; PPG - pterygopalatine ganglion; post. - posterior; pr. - process; V2 - maxillary nerve.

Fig. 2. Step-by-step dissection of EETPA: exposure of the PPF content. A) identification of the bony anteromedial limits of the PPF; B) removal of the superomedial portion of the posterior wall of the maxillary sinus; C) removal of the perpendicular plate of the palatine bone; D) removal of the orbital process of the

palatine bone; E) removal of the sphenoid process of the palatine bone and enlargement of the lateral and inferior exposure of the PPF with better exposure of the OPS ligament and DPB; F) detail of the inferior orbital fissure; G) detail of the vidian nerve and pharyngeal artery at the level of the distal portion of the vidian canal and palatosphenoidal canal; H) detail of the DPB. a. - artery; b. - bone; DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; MS - maxillary sinus; n. - nerve; OPS - orbito-pterygo-sphenoidal; perpend. - perpendicular; PPF - pterygopalatine fossa; post. - posterior; pr. - process.

Fig. 3. Illustration of surgical techniques of inferior and lateral trasportion of the PPF. A) PPF inferior transposition before cutting the OPS ligament. B) Gain in PPF inferior transposition after the OPS ligament has ben cut. C) PPF lateral transposition before decompressing the DPC. D) Gain in PPF lateral transposition after the DPC has been cut. DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; infraorb. - infraorbital; IT - inferior turbinate; n. - nerve; PPF - pterygopalatine fossa; PPG - pterygopalatine ganglion; V2 - maxillary nerve.

Fig 4. Step-by-step dissection of PPF inferior transposition. A) PPF inferior transposition before the OPS ligament releasing. B) Identification of OPS ligament. C) OPS ligament releasing. D) PPF inferior transposition after OPS ligament relealing. E) Drilling of the superolateral portion of the BPP. F) Surgical corridor through the superior portion of the inferolateral recess of the sphenoid sinus. DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; n. - nerve; OPS orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

Fig. 5 Clinical case: intraoperative endoscopic endonasal images of PPF inferior trasposition technique for a meningocele of the inferolateral recess of the spenoid sinus. A) OPS ligament releasing. B) PPF inferior transpostion. C) Removal of the superolateral portion of the BPP. D) Exposure of the meningocele. E) Removal of theinferomedial portion of the PBB. F) Opening of the inferior portion of the inferolateral recess of the sphenoid sinus. G) Exposure of the inferior portion of the meningocele. H) Removal of the inferior portion of the meningocele. BPP – base of the pterygoid process; DPB - descending palatine bundle; n. - nerve; NSF - nasoseptal flap; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

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Fig 6. Step-by-step dissection of PPF lateral transposition. Endoscopic endonasal lateral transposition of the PPF content and DPC decompression. A) PPF lateral transposition before DPC decompression. B) Partial drilling of the inferomedial portion of the BPP with 360° unroofing of the distal portion of the vidian nerve. C) Complete drilling of the inferomedial portion of the BPP with mobilization of the proximal portion of the DPB. D) Removal of the inferior turbinate. E) Extension of DPB inferior decompression. F) Lateral transposition of the PPF after DPC decompression with complete drilling of the inferomedial portion of the BPP and opening of the surgical corridor to the Eustachian tube. BPP - base of the pterygoid process; DPB - desceding palatine bundle; DPC - descending palatine canal; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; n. - nerve; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

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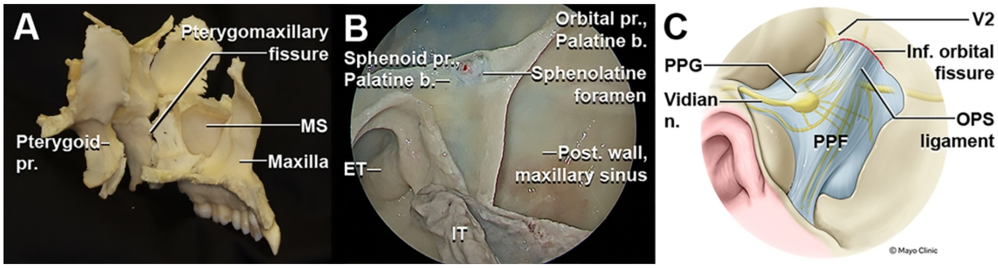

Overview of the PPF anatomy. A) Bony limits in a dry skull. B) Exposure of anteromedial bony limitis after an endoscopic endonasal ethmoidectomy and medial antrostomy. C) Illustration of the anteromedial portion of PPF periosteum and rappresentation of its underlying nervous content after an endoscopic endonasal ethmoidectomy and medial antrostomy. b. - bone; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; MS - maxillary sinus; n. - nerve; PPF - pterygopalatine fossa; PPG - pterygopalatine ganglion; post. - posterior; pr. - process; V2 - maxillary nerve.

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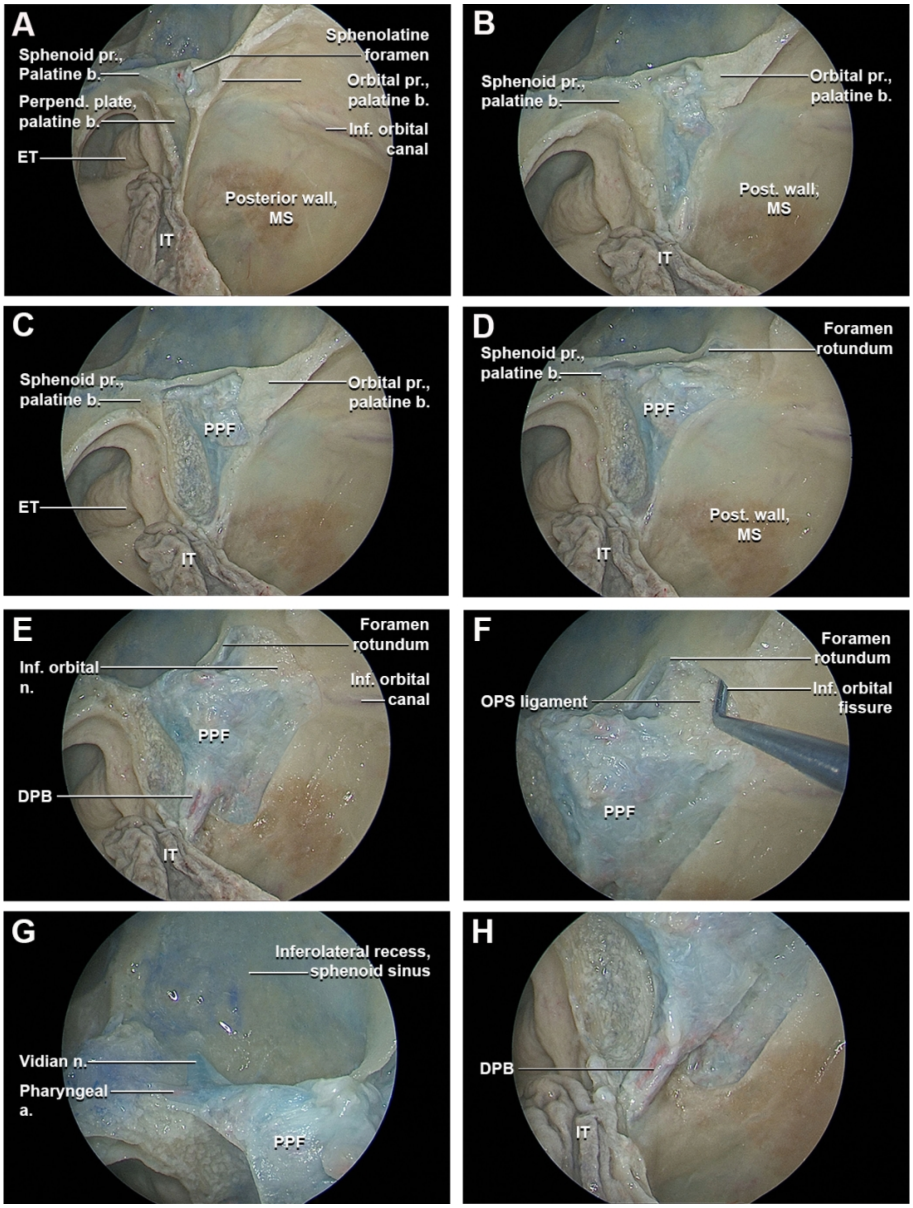

Step-by-step dissection of EETPA: exposure of the PPF content. A) identification of the bony anteromedial limits of the PPF; B) removal of the superomedial portion of the posterior wall of the maxillary sinus; C) removal of the perpendicular plate of the palatine bone; D) removal of the orbital process of the palatine bone; E) removal of the sphenoid process of the palatine bone and enlargement of the lateral and inferior exposure of the PPF with better exposure of the OPS ligament and DPB; F) detail of the inferior orbital fissure; G) detail of the vidian nerve and pharyngeal artery at the level of the distal portion of the vidian canal and palatosphenoidal canal; H) detail of the DPB. a. - artery; b. - bone; DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; MS - maxillary sinus; n. - nerve; OPS orbito-pterygo-sphenoidal; perpend. - perpendicular; PPF - pterygopalatine fossa; post. - posterior; pr. - process.

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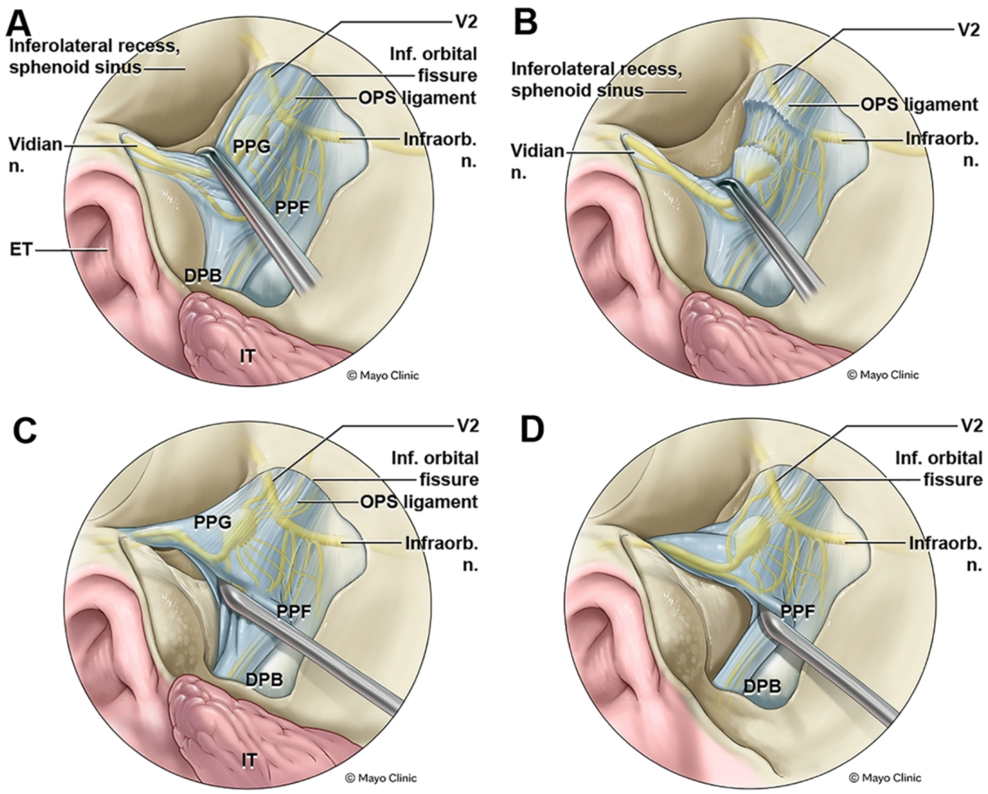

Illustration of surgical techniques of inferior and lateral trasportion of the PPF. A) PPF inferior transposition before cutting the OPS ligament. B) Gain in PPF inferior transposition after the OPS ligament has ben cut. C) PPF lateral transposition before decompressing the DPC. D) Gain in PPF lateral transposition after the DPC has been cut. DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; infraorb. - infraorbital; IT - inferior turbinate; n. - nerve; PPF - pterygopalatine fossa; PPG - pterygopalatine ganglion; V2 - maxillary nerve.

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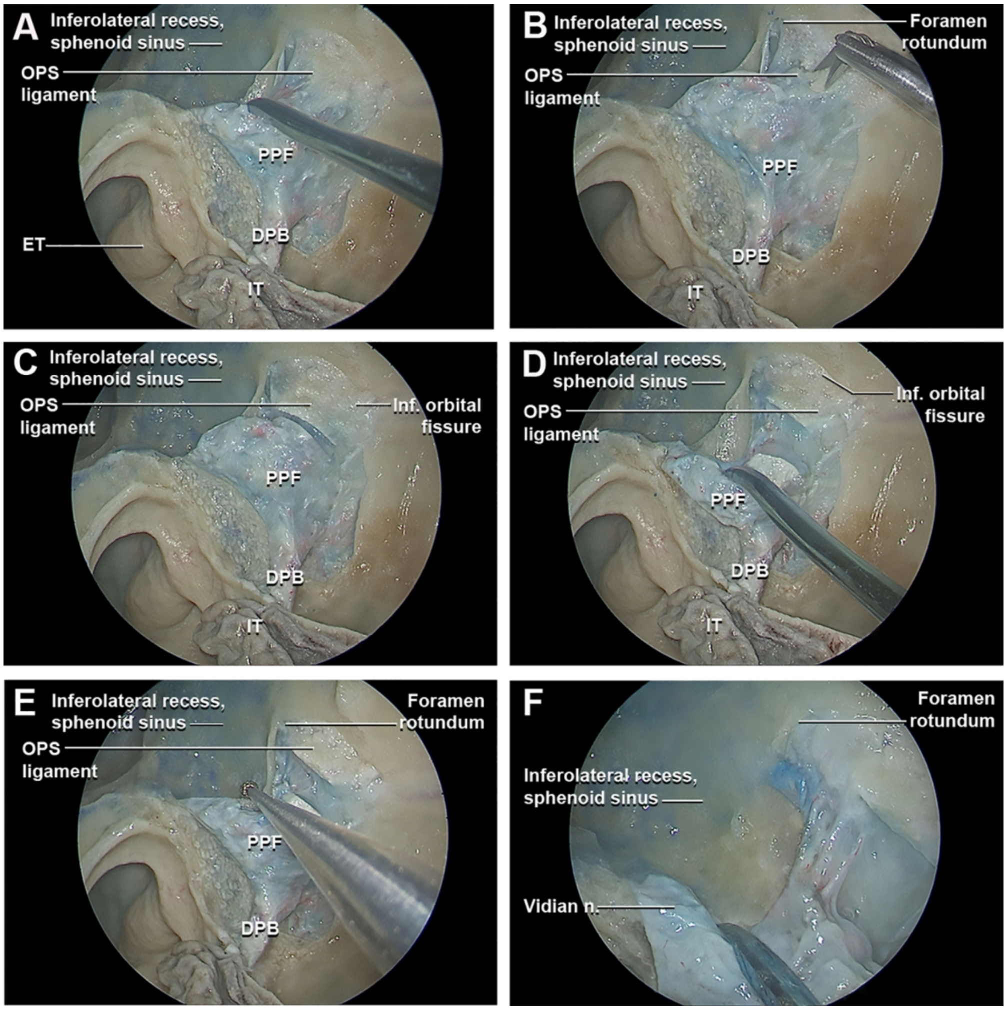

Step-by-step dissection of PPF inferior transposition. A) PPF inferior transposition before the OPS ligament releasing. B) Identification of OPS ligament. C) OPS ligament releasing. D) PPF inferior transposition after OPS ligament relealing. E) Drilling of the superolateral portion of the BPP. F) Surgical corridor through the superior portion of the inferolateral recess of the sphenoid sinus. DPB - descending palatine bundle; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; n. - nerve; OPS orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

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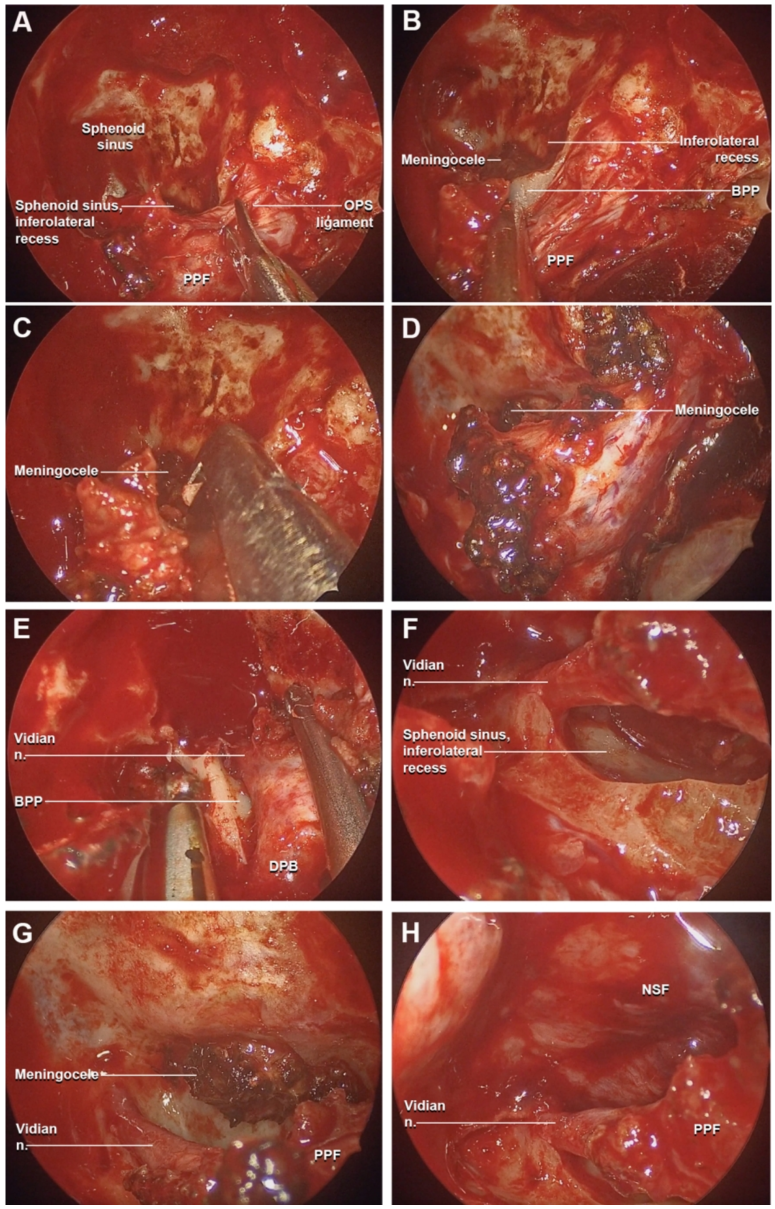
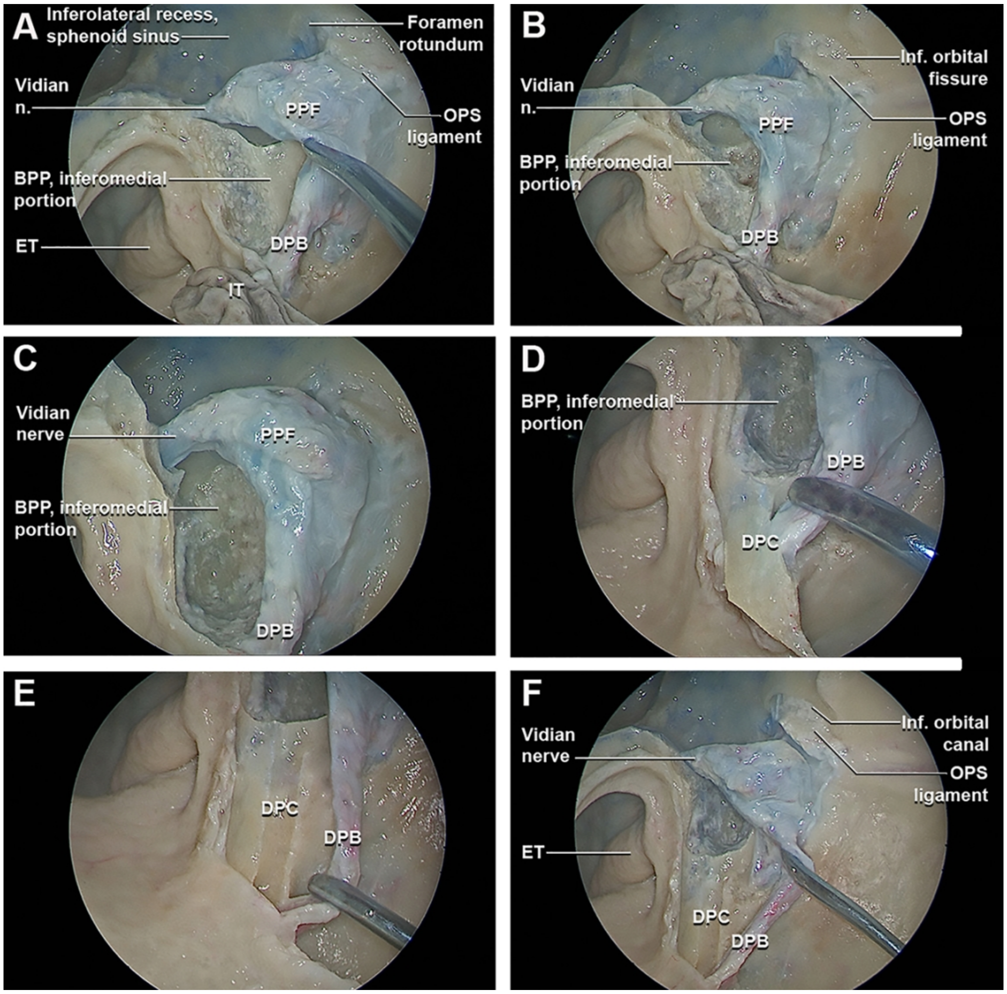


Clinical case: intraoperative endoscopic endonasal images of PPF inferior trasposition technique for a meningocele of the inferolateral recess of the spenoid sinus. A) OPS ligament releasing. B) PPF inferior transpostion. C) Removal of the superolateral portion of the BPP. D) Exposure of the meningocele. E) Removal of theinferomedial portion of the PBB. F) Opening of the inferior portion of the inferolateral recess of the sphenoid sinus. G) Exposure of the inferior portion of the meningocele. H) Removal of the inferior portion of the meningocele. DPB - descending palatine bundle; n. - nerve; NSF - nasoseptal flap; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

179x281mm (190 x 190 DPI)



Step-by-step dissection of PPF lateral transposition. Endoscopic endonasal lateral transposition of the PPF content and DPC decompression. A) PPF lateral transposition before DPC decompression. B) Partial drilling of the inferomedial portion of the BPP with 360° unroofing of the distal portion of the vidian nerve. C) Complete drilling of the inferomedial portion of the BPP with mobilization of the proximal portion of the DPB. D) Removal of the inferior turbinate. E) Extension of DPB inferior decompression. F) Lateral transposition of the PPF after DPC decompression with complete drilling of the inferomedial portion of the BPP and opening of the surgical corridor to the Eustachian tube. BPP - base of the pterygoid; DPB - desceding palatine bundle; DPC - descending palatine canal; ET - Eustachian tube; inf. - inferior; IT - inferior turbinate; inf. - inferior; n. - nerve; OPS - orbito-pterygo-sphenoidal; PPF - pterygopalatine fossa.

180x177mm (180 x 180 DPI)