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OTHER ARTICLES

Tips and Tricks to Safely Perform an Endoscopic Endonasal Trans-Sphenoidal Pituitary Surgery: A Surgeon's Checklist

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Abstract The authors aimed to develop an extensive preoperative checklist of CT scan findings during endoscopic access to the ventral skull base and implement it in clinical practice. A comprehensive literature review was conducted to identify the radiological landmarks crucial to endoscopic skull base surgery. Four electronic databases were searched: PubMed, MEDLINE, EMBASE, and Google Scholar using search terms/keywords such as "radiological landmarks," "endoscopic skull base surgery," "CT scan," "pituitary surgery," "anatomical variations," "internal carotid," "optic nerve," "sphenoid sinus," "pneumatization," "dehiscence," and "protrusion". Inclusion criteria were limited to original articles and systematic reviews published in English, between the years 2000 and 2021, which pertained to the radiological landmarks to be identified during endoscopic skull base surgery. Full-text articles were retrieved and collated into a narrative review focused on a 12-item checklist the authors agreed upon. The mnemonic "O ROAD TO SELLA" was used to represent the checklist and include the following landmarks: Sphenoid **O**stium, Sphenoid **R**ostrum, **O**nodi cells, **A**natomic variations of the sphenoid sinus, **D**istance between the carotids, **T**umor characteristics, **O**ptic nerve dehiscence/protrusion, **S**eptation/insertion of the sphenoid sinus, **E**ntrance to the sellar floor, **L**ateral recess of the sphenoid sinus, c**L**inoid process pneumatization, and internal carotid **A**rtery dehiscence/protrusion. The checklist is designed to be used by attending physicians, fellows, and residents and the authors intend to implement it into electronic medical records at the institution's medical center to monitor the outcomes of EEPS after implementation.

Keywords Endoscopic sinus surgery · Preoperative checklist · Pituitary surgery · Radiological landmarks · Anatomical variations

Introduction

The origins of pituitary surgery date back to the early 20th century when Sir Victor Horsely performed a temporal craniotomy. This approach was associated with high mortality rates ranging from 50 to 80%. To reduce morbidity, transnasal approaches were developed, with the first being the transethmoidal-transsphenoidal approach by Schloffer in 1907 which was further followed by Cushing's transseptal-transsphenoidal technique that became the gold standard for pituitary surgery over several decades [1]. With advancements in technology, surgical equipment, and techniques, minimally invasive approaches to pituitary surgery evolved. In the late 20th century, Carrau introduced endoscopic endonasal transsphenoidal surgery (EEPS) as a less invasive alternative to traditional pituitary surgery. The EEPS approach accesses the tumor through the nasal cavity, allowing the surgeon to visualize the surgical field with an endoscope with increased accuracy and preservation of critical structures during the procedure [2]. Studies have shown that EEPS has a low complication rate and results in favorable clinical outcomes, such as reduced hospital stays and quicker recovery times compared to traditional approaches, and has become the standard of care for access to the ventral skull base [3].

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Endoscopic endonasal pituitary surgery carries potential complications, with an overall incidence ranging from 2 to 20%. Intraoperative and postoperative complications can include CSF (cerebrospinal fluid) leak, vascular injuries, cranial nerve injuries, diabetes insipidus, anterior pituitary dysfunction, bleeding, infections, and visual deficits among others [4–6]. Preoperative BMI (Body Mass Index), age, size of the tumor, and presence of intracranial extension may predispose to these complications [7].

The sphenoid sinus is a complex paranasal sinus in the cranial cavity due to its proximity to critical structures such as the optic nerve, carotid artery, and pituitary gland. Its anatomy includes anterior and posterior walls, roof, floor, and lateral walls, with variability in size, shape, and pneumatization pattern among patients [8]. The roof of the sphenoid sinus is a crucial landmark in endoscopic endonasal transsphenoidal surgery, while its pneumatization pattern can affect surgical access and outcomes [9]. Thus, thorough knowledge of the sphenoid sinus anatomy and anatomic variants is important for safe access and successful endoscopic transsphenoidal surgery.

Surgical checklists, influenced by the aviation sector, have been shown to reduce surgical complications and improve patient outcomes globally, including in the US [10]. Checklists are cost-effective, improve medical-legal situations, and are positively viewed by patients [11]. The WHO Surgical Safety Checklist has been successful in reducing postoperative complication rates and death rates in diverse clinical settings [12]. Since then, several subspecialty checklists have been developed, including those for endoscopic endonasal transsphenoidal surgery, and preoperative CT scan imaging in endoscopic sinus surgery [13–16]. However, none addresses the radiological features of anatomical landmarks crucial for safe endoscopic transsphenoidal pituitary surgery. Recent studies have developed a preoperative CT scan checklist using an 8-item mnemonic "SPHENOID" that focused on the anatomic variations of the sphenoid sinus [17]. Yet the implementation of these checklists has faced many obstacles such as unfamiliarity, staff issues, as well as logistics, and timing constraints [18]. The authors aim to develop a more extensive preoperative checklist of CT scan findings during endoscopic access to the ventral skull base and implement it in clinical practice.

Materials and Methods

A comprehensive literature review was conducted to identify the radiological landmarks crucial to endoscopic skull base surgery. Four electronic databases were searched: PubMed, MEDLINE, EMBASE, and Google Scholar. The search terms used included combinations of the following keywords: "radiological landmarks," "endoscopic skull base surgery," "CT scan," "pituitary surgery," "anatomical variations," "internal carotid," "optic nerve," "sphenoid sinus," "pneumatization," "dehiscence," and "protrusion."

Inclusion criteria were limited to original articles and systematic reviews published in English, between the years 2000 and 2021, which pertained to the radiological landmarks to be identified during endoscopic skull base surgery. Exclusion criteria were limited to non-English language articles, case reports, editorials, letters, and duplicate articles.

Two reviewers independently screened the titles and abstracts to assess eligibility. Any discrepancies were resolved through discussion, and full-text articles were retrieved and collated into a narrative review focused on a 12-item checklist the authors agreed upon. The mnemonic "O ROAD TO SELLA" was used to represent the checklist and include the following landmarks to identify preoperatively on CT scan during endoscopic endonasal transsphenoidal surgery to avoid intraoperative and postoperative complications: Sphenoid ostium, Sphenoid rostrum, Onodi cells, anatomic variations of the sphenoid sinus, distance between the carotids, tumor characteristics, optic nerve dehiscence/protrusion, septation/insertion of the sphenoid sinus, entrance to the sellar floor, lateral recess of the sphenoid sinus, clinoid process pneumatization, and internal carotid artery dehiscence/protrusion.

The checklist is designed to be used by attending physicians, fellows, and residents and the authors intend to implement it into the EPIC software for electronic medical records at the institution's medical center to monitor the outcomes of EEPS after implementation.

Discussion

Multiple anatomical landmarks are reviewed in order to safely navigate endoscopic endonasal pituitary surgery. We will be showcasing many landmarks that constituted our preoperative checklist. Studying these entities will have a great impact on the surgical outcome of pituitary surgery.

Sphenoid Pneumatization/Types of the Sphenoid Sinus

Guldner classified the sphenoid sinus into multiple types based on their pneumatization with respect to the sella: conchal, presellar, sellar, and post-sellar.

"Conchal" (Fig. 1A) type refers to minimal to no pneumatization of the sphenoid sinus. "Pre-sellar" (Fig. 1C) is when the sphenoid sinus pneumatization reaches the anterior wall of the sella. "Sellar" (Figure a-D) type is when the sphenoid sinus pneumatization is at the level of the posterior wall of the sella; whereas "post sellar" (Fig. 1E) is when the pneumatization extends beyond the posterior wall of the sella [19].

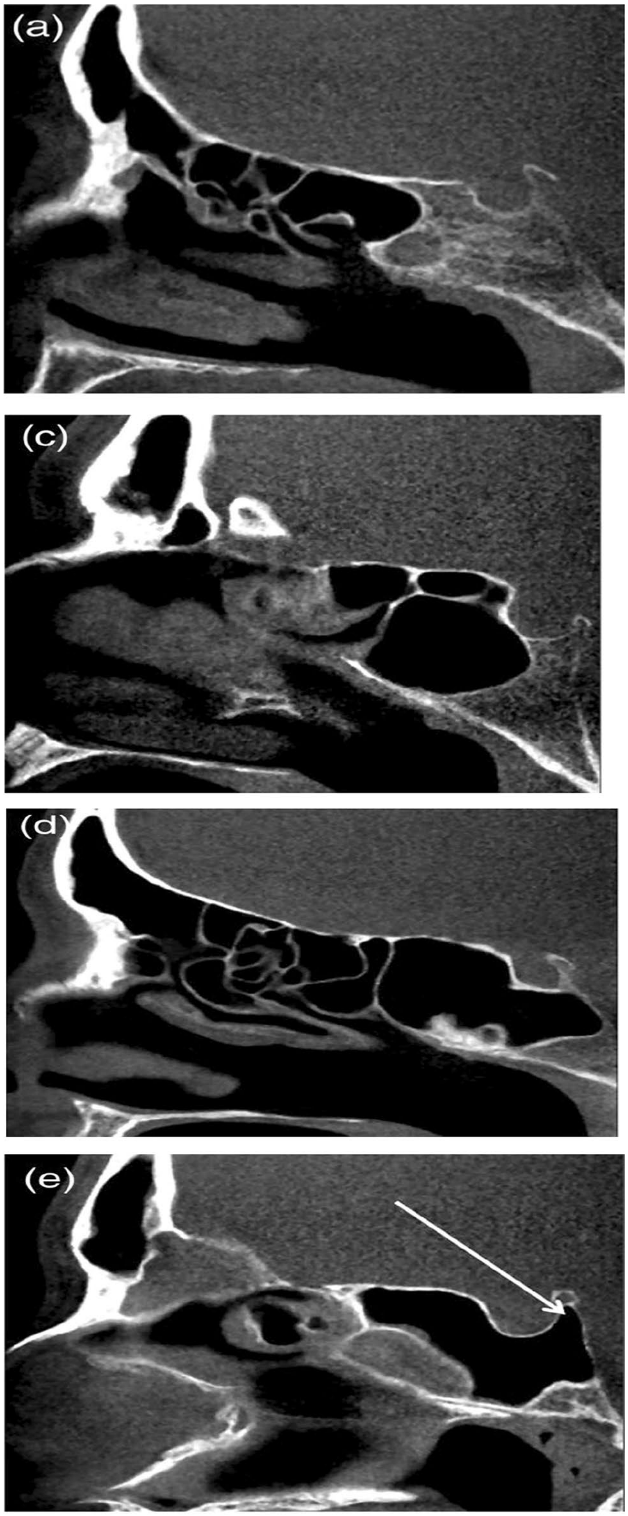

Fig. 1 CT scan showing different types of sphenoid sinus pneumatization patterns; **a** Conchal type; **c** Pre-cellar; **d** Sellar; **e** Post cellar

Localizing the sella on imaging preoperatively is essential in planning safe access to it.

Lateral Recess Pneumatization

It is the pneumatization of the sphenoid sinus beyond an imaginary line connecting the maxillary and vidian nerves [20]. (Fig. 2).

With larger lateral sphenoid sinus pneumatization, the incidence of ON and ICA protuberance and dehiscence increase. On another note, lateral recess pneumatization causes an increased risk of vidian and maxillary nerve exposure and injury affecting access to the middle cranial fossa, infratemporal fossa, and petrous apex [17].

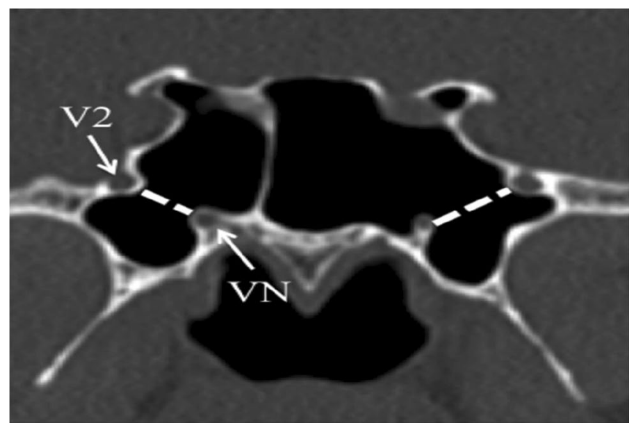

Fig. 2 CT scan showing pneumatization of the lateral recess of the sphenoid sinus

Fig. 3 CT scan showing anterior clinoid process pneumatization

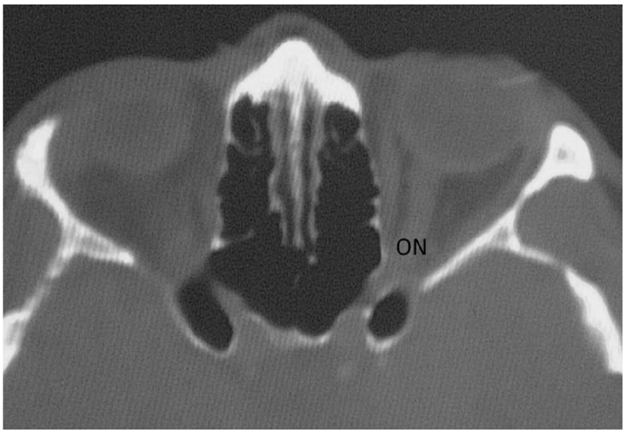

Fig. 4 CT scan showing a free-floating optic nerve

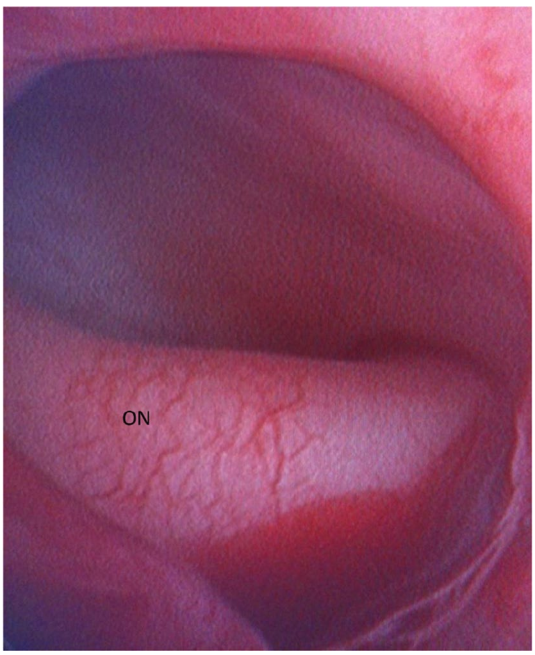

Fig. 5 Intra-operative endoscopic demonstration of a free-floating optic nerve

Anterior Clinoid Process Pneumatization

Anterior clinoid process pneumatization (Fig. 3) is present in a minority of cases (6–29%) [8]. The more the pneumatization beyond the optic strut is; the higher the likelihood of having a protruded optic nerve or even a free-floating optic nerve into the sphenoid sinus (Figs. 4 and 5).

Sphenoid Ostium

The natural sphenoid ostium (Fig. 6) is one of the principal landmarks for accessing safely the sphenoid sinus [21]. The

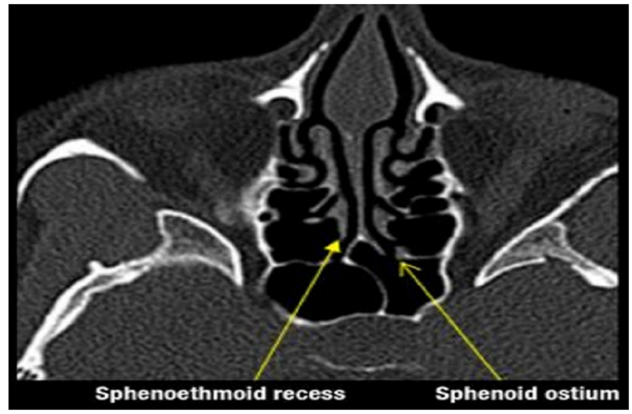

Fig. 6 CT scan showing the natural sphenoid ostium and sphenoethmoid recess

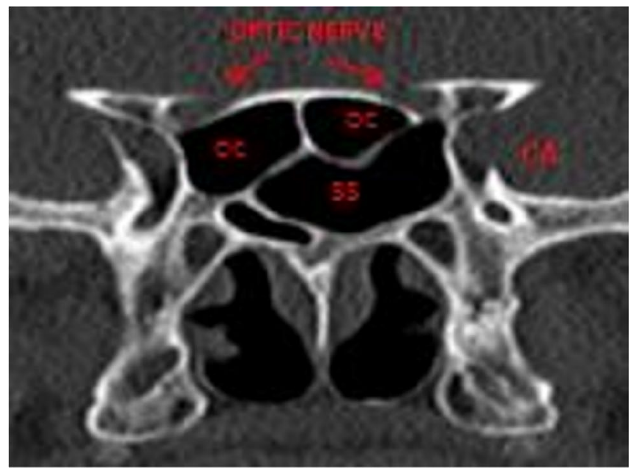

Fig. 7 CT scan showing vital structures surrounding the sphenoid ostium such as the optic nerve, internal carotid artery, and the cavernous sinus

SO is surrounded by multiple structures (Fig. 7). Superiorly is the skull base, inferiorly is the sphenopalatine artery and medially is the nasal septum. Understanding its position with respect to the anterior sphenoid face and skull base is of utmost importance [5]. The sphenoid ostium can also be identified through different references such as the posterior inferior end of the superior turbinate (posterior medial to it) [21], the distance from the nasal spine [22], and the location of the ostium on the vertical axis of the anterior sphenoid face [23]. Moreover, the different pneumatization of the sphenoid sinus itself and any adjacent structure will affect the location of the ostium [24, 25]. Not being able to localize the sphenoid ostium during surgery will lead to dreadful complications since the ostium is near the optic nerve, internal carotid artery, sella, and cavernous sinus [24]. A sphenoid rostrum pneumatization will deflect the ostium laterally making it at the mid-third of the horizontal plane (vs in a non-pneumatized sphenoid rostrum, the ostium is at the medial third) [26]. The lateral wall pneumatization of the sphenoid sinus will also deflect the SO laterally. The distance between the SO and the choana plays a role in influencing the entry point to the sinus. This distance is lengthened with the presence of Onodi cells making the sphenoid ostium higher with regard to the choana. However, it is relevant to note that this distance did not affect the distance between the SO and the skull base [26].

Tumor Characteristics

Numerous studies agree that the increased tumor size (defined as macroadenoma if > 1 cm or giant adenoma if > 4 cm; tumor volume > 30cm^3; tumor diameter > 3 cm) and tumor extension (defined by a high Knosp grade, cavernous sinus invasion; intraventricular, parasellar, and anterior cranial fossa extension) are significantly associated with increased complication rate after EETS [27, 28]. Every 1 cm increase in the tumor size decreases the likelihood of complete removal by around threefold, and the invasion of the cavernous sinus, determined by a Knosp grade of 3 or 4 is among the factors strongly associated with incomplete tumor resection and hence increased complication rate [29]. Tumor type and biology are not significantly associated with surgical morbidity. However, non-functioning adenomas as compared to secreting adenomas may predispose to increased morbidity and rate of complications [30, 31].

Onodi Cells

These cells are the most posterior ethmoid air cells that pneumatize supero-laterally into the sphenoid sinus adjacent to the optic nerve (Fig. 7). At least 1 Onodi cell will pneumatize into the sphenoid sinus (12%) [17]. This variant carries the risk of injury to the optic nerve if the surgeon dissects through it thinking he/she is in the sphenoid sinus. Recognizing these cells is imperative in evading complications [32]. (Fig. 8).

Inter-Sphenoid Sinus Septum: Number and Insertion

In the majority of cases, one septum is usually found (63%) while some other sphenoid sinuses might have multiple septa (either complete or incomplete). It is noted that there is a 49% chance for the inter-sphenoid septum to insert into the internal carotid artery (Fig. 9). As the number of sphenoid sinus septa increases, at least one septum will insert into the ICA. No case was found to have the same ICA connecting with more than 1 septum [33]. The inter-sphenoid septum can also insert on the ON. These occurrences are so common that the actual incidence of injury to these neurovascular

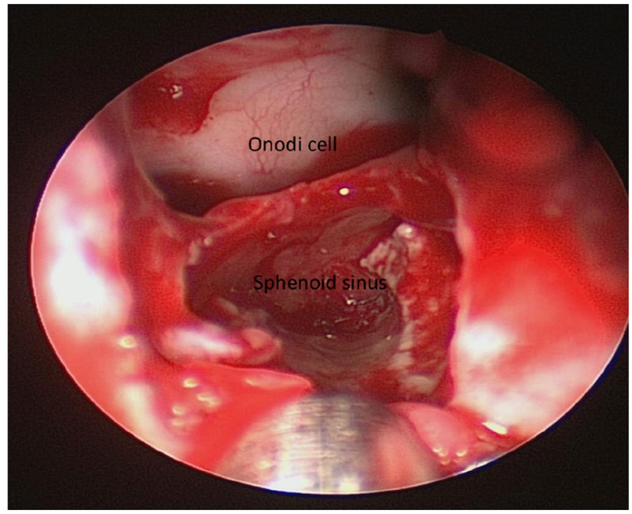

Fig. 8 Intra-operative endoscopic view of the sphenoid sinus with an adjacent Onodi cell

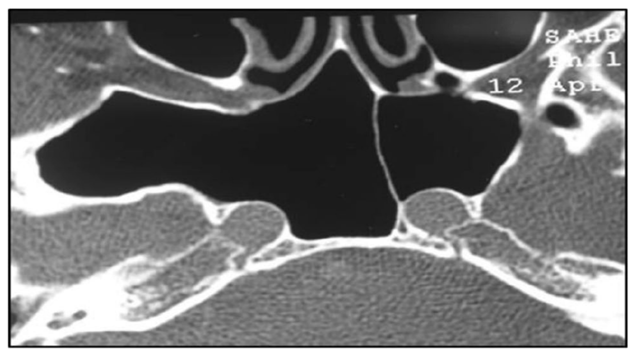

Fig. 9 CT scan showing the insertion of the inter-sphenoid sinus septum on the internal carotid artery

structures is low [34]. However, training to identify these structures is still beneficial in an attempt to prevent unfavorable outcomes.

Optic Nerve Dehiscence and/or Protrusion

Bony dehiscence over the optic nerve was initially defined as the absence of visible bone density separating the sinus from the course of the nerve, although some may consider the presence of bony thickness of less than 0.5 mm as dehiscence as well [35, 36]. In one study, ON dehiscence occurred in 24% and varied depending on the relationship of the nerve with the posterior paranasal sinuses [37]. Type 2 (ON causes indentation on the lateral wall of SS) and type 3 (ON courses through the sphenoid sinus) had the highest rate of bony dehiscence (82 and 100% respectively) compared to type 1 (ON adjacent to the lateral wall of the sphenoid sinus without indentation) and type 4 (ON lateral to the posterior ethmoid and sphenoid sinuses). In other cohorts, using the same definition, bony dehiscence over the ON was identified in 13.5–17.5%. Types 2 and 3 were most commonly associated with dehiscence, albeit to a lesser degree than in the previous study [38, 39]. All studies agreed that the type 3 ON or those with greater exposure to the sphenoid sinus are at the greatest risk of dehiscence and tend to be associated with protrusion and anterior clinoid process pneumatization [8].

Protrusion of the optic nerve into the ethmoid and the sphenoid sinus was first described by Dessi et al. as a bulging of more than 50% of the optic canal into a pneumatized paranasal sinus and reported a prevalence of 8% protrusion into the sphenoid sinus [34]. However, further studies evaluating the anatomic variations of the sphenoid sinus and its related structures noted a higher prevalence of ON protrusion of around 31% [40, 41]. (Figs. 5, 10 and 11).

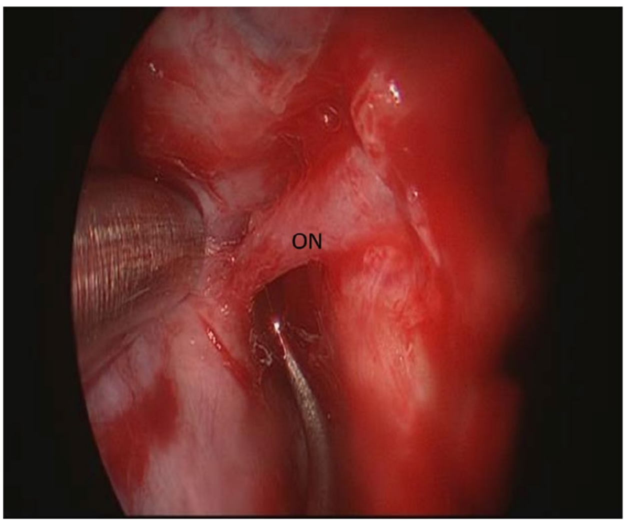

Fig. 10 Intra-operative endoscopic image of a free-floating optic nerve

Intercarotid Distance

The intercarotid distance in the setting of no sellar pathology has an average of 18 mm [17]. This distance changes with the type of pituitary pathology. It is usually measured at the level of the mid-cavernous ICA level where it usually protrudes into the sphenoid sinus [42, 43]. With large pituitary tumors, the ICD increases, however with growth hormone tumors there is a narrowing of the ICD, with cases reported as “kissing carotids” [17] (Figs. 12 and 13). Being aware of these variations will prevent dreadful complications to the vasculature.

Internal Carotid Artery Dehiscence and/or Protrusion

Similar to ON, ICA dehiscence is defined as a soft carotid bulge without a visible bony coverage or with a submillimetric overlying bone (Fig. 14). The protrusion is defined as a projection of more than 50% of the ICA into the sphenoid sinus. In a cadaveric study on 188 sphenoid sinuses by Kennedy et al., clinical dehiscence over the ICA was identified in 22% of cases [44], which is higher than what was reported in later studies where ICA dehiscence ranged from 1.5 to 14.4% [45–47]. To be more precise in the evaluation of protrusion and dehiscence, it’s important to look at the parasellar and paraclival segments of the ICA. One study involving 90 CT scans reported dehiscence of the pcICA in 3.6% but not of the psICA. Additionally, protrusion of psICA occurred in 26% while that of pcICA occurred in 35% [48]. It’s worth mentioning that the average thickness of bone covering the ICA is around 0.5–1 mm which is higher than that covering the ON, which ranges between 0.28 and

Fig. 11 Intra-operative endoscopic image of a transected optic nerve

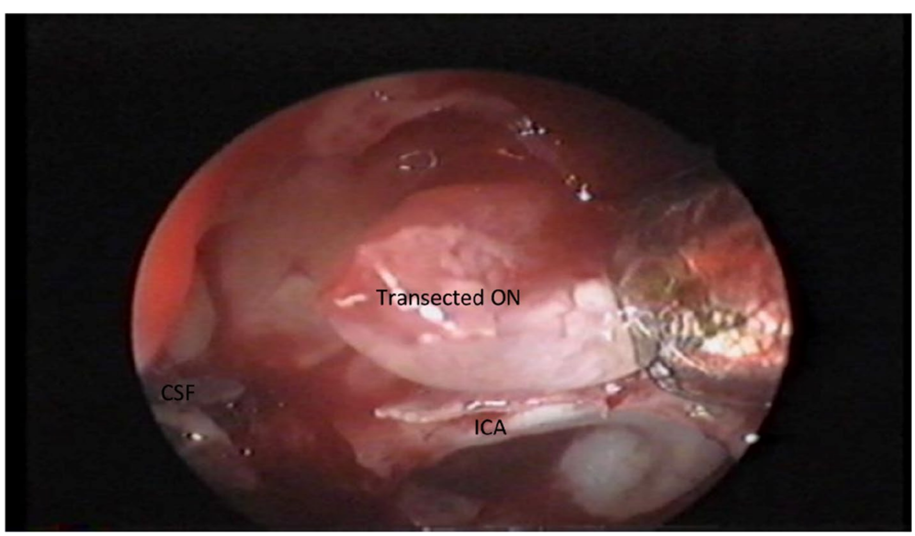

Fig. 12 MRI image showing kissing internal carotid artery

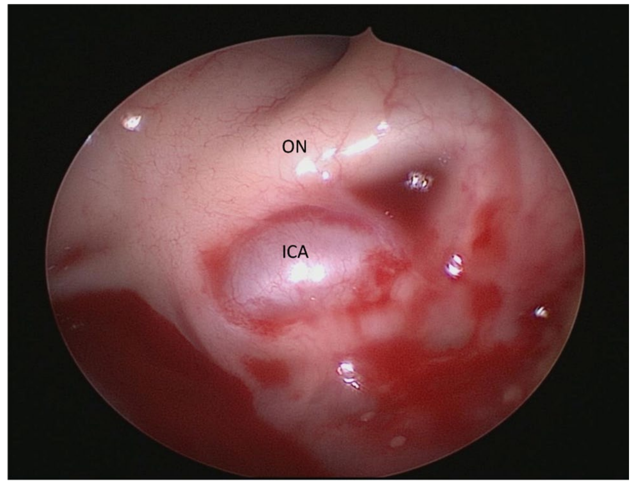

Fig. 14 Intra-operative endoscopic view of an internal carotid artery dehiscence

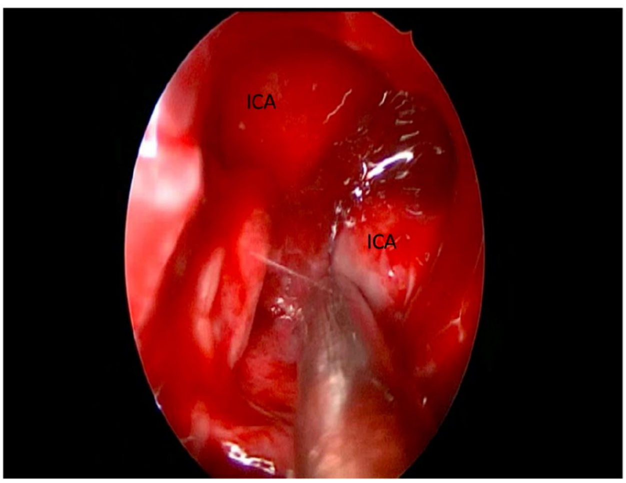

Fig. 13 Intra-operative endoscopic view of kissing internal carotid artery

0.5 mm [45]. Therefore, the definition of dehiscence may vary between both structures. The prevalence of ICA protrusion and dehiscence is also affected by the type of pathology. A study by Sasagawa et al. showed that 35.5% of acromegalic patients had ICA protrusion while 22.2% had dehiscence meaning that these vascular anomalies are more frequent in patients with acromegaly [49].

Limitations

The checklist was developed based on a review of literature published in English, which may have limited the inclusion of studies from other languages that could provide additional insights and perspectives on the subject matter. Although the authors conducted a comprehensive literature review, it is possible that some relevant studies were missed, and some important radiological landmarks may have been excluded from the checklist.

The checklist was developed based on the consensus of the authors, and there is a possibility that other experts in the field may have different opinions on which radiological landmarks are most critical for endoscopic skull base surgery.

The study did not assess the practicality or feasibility of implementing the checklist in a clinical setting, and it is possible that some radiological landmarks may be difficult to assess consistently or reliably using CT scans. The study did not evaluate the impact of using the checklist on patient outcomes, and it is unclear whether its implementation leads to improved surgical outcomes or reduced complications.

Conclusion

Following this discussion about how to safely perform an endoscopic endonasal transsphenoidal pituitary surgery; we propose a mnemonic to be utilized as a preoperative checklist to navigate safely during surgery: "**O ROAD TO SELLA**".

O–sphenoid **O**stium.

R–**R**ostrum.

O–**O**nodi cell.

A–**A**natomic variation of SS (pneumatization, previous surgery…).

D–**D**istance between carotids.

T–**T**umor pathology.

O–Optic nerve.

S–**S**eptation & Insertion.

E–**E**ntrance to sellar floor.

L–**L**ateral wall of SS (pneumatization, OC recess…).
L–c**L**inoid process pneumatization.
A–carotid **A**rtery.

Author Contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by NEH, and JH. The first draft of the manuscript was written by UEH and ZK and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability The data that support the findings of this study are available from the authors upon reasonable request.

Declarations

Conflict of interest The authors have no financial or non-financial interests to disclose.

Ethical Approval This is a review study. The Institutional Review Board at the American University of Beirut Medical Center has confirmed that no ethical approval is required.

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