Chapter 12

VASCULAR ANATOMY AND COMPLICATIONS OF PITUITARY ADENOMAS, AND TREATMENT WITH ENDOSCOPIC ENDONASAL TRANSSPHENOIDAL SURGERY

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ABSTRACT

In general, transsphenoidal surgery has been considered to have a low rate of complication and mortality. Among the postoperative complications associated with transsphenoidal surgery (TSS), such as cerebrospinal fluid leakage, hypopituitarism, diabetes insipidus, vascular injury, meningitis, cranial nerve neuropathy, and nasal bleeding, vascular injury is unusual, but most possibly fatal complication. Therefore, the pituitary neurosurgeons need to have the knowledge about the possible incidence during the intra- and post-operative phase. Vascular injuries during the TSS described in the literature include fatal hemorrhage from internal carotid artery (ICA), ICA occlusion, pseudoaneurysm formation, carotid cavernous fistula, subarachnoid hemorrhage, vasospasm, and distal embolism with cerebral infarction. It is important to understand the patient's vascular anatomy at the sella and its surrounding structures, during the preoperative examination of the TSS, to avoid the vascular complications. Although recent advancement of the operative techniques and instruments of transsphenoidal approach enable the neurosurgeons to dissect arteries derived from the ICA and external carotid artery (ECA) during the surgery, it remains a difficult problem to preserve intact vessels even for the expert pituitary neurosurgeons. In particular, the introduction of endoscope into the TSS dramatically improved intraoperative visualization and diminished traumatization. Subsequently, the operative indication for performing TSS gradually developed to include the suprasellar, parasellar, clival, and cervicomedullary junction (extended transsphenoidal surgery). However, since the indications for the use of

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TSS have grown, this fact can lead to increasing chances of intraoperative vascular injuries, and till now has not been reached a definite conclusion, whether TSS has a significant difference in the complication rate between endoscope and microscope techniques. Another advancement of preoperative neuroradiological investigation to detect such arteries derived from the ICA and the ECA is also useful for their precise localization and avoidance of fatal complications. Especially, the role of digital subtraction angiography in the operating room is significant, because, once the arterial injury during TSS happens, the emergent detection of affected vessel(s) and the management of the trauma is required. In addition, the development of endovascular surgery both in the techniques and the instruments remarkably changed the principles of treatment for intraoperative vascular injury during the TSS. Especially, in cases of ICA injury, the endovascular treatment with parent artery occlusion can be performed with acceptable morbidity and mortality rates. This technique can be also applied to the pseudoaneurysm, which arises from the injury site of the ICA at the postoperative delayed period, and causes fatal and massive epistaxis. However, vascular injury during endoscopic endonasal TSS is not well studied or reported, despite it is still a feared complication. The anatomic substrate for such complication in each stage of the TSS (naso-sphenoidal, spheno-planum, dural, intrasellar, and suprasellar phase) is discussed with respect to operative and neuroradiological aspects, identification of risk factors, management strategies for avoidance of such serious vascular complications, and their outcomes.

Keywords: transsphenoidal surgery, pituitary, vascular, complication, endoscope

1. Introduction

Pituitary adenomas constitute approximately 10-22.5% of all primary intracranial tumors, and surgical removal is the first optional management except for prolactinoma [1-4]. The transsphenoidal surgery (TSS) for removal of pituitary tumors has been originally applied due to its effectiveness and safety, with serious morbidity and mortality rates typically less than 1% [5, 6]. Recent advancement in operative and neuroradiological technologies has had a major impact on the treatment strategies for pituitary tumors, and TSS has become increasingly popular all over the world. In particular, the introduction of endoscope into the TSS has made a great progress not only on the resection rate of the tumor but also on the preservation of normal endocrinological function and the remission rate for the functioning adenoma [1, 7-9]. Moreover, the indication for the use of TSS has grown for the suprasellar, parasellar, clival, and craniocervical junction, since it has been regarded as extended TSS, and many surgeons reported its effectiveness in the management of craniopharyngioma, clival chordoma, and pituitary adenoma with invasion into the cavernous sinus [10-12].

Historically, the TSS was originally introduced by Schloffer and Cushing during the first decade of the 20th Century [13-15]. The adaptation of the transsphenoidal route as a surgical corridor is based on the concept that this surgery is significantly less dangerous for the patients with pituitary tumors compared to the craniotomy, which was considered to be extraordinary difficult on the contrary, because the instrumentation, lightning, cautery, anesthesia, and medication were not available in those days [13, 14]. This revolutionary introduction was followed by the addition of the radiofluoroscopy by Guiot, as well as the operating microscope and specialized instruments by Hardy 60 years later [16, 17]. Therefore, concerning TSS, safety should be secured both through the operation by the surgical techniques and the anatomical knowledge of the pituitary region. However, many authors have reported various complications associated with the TSS including cerebrospinal fluid leakage, hypopituitarism, diabetes insipidus, meningitis, cranial nerve neuropathy, nasal bleeding, and vascular injury [1-7, 16, 18].

Despite the advancement of TSS, one of the most serious problems during this approach is vascular complications, in which injury to the cavernous ICA most commonly occurs at the sellar dural incision, and has been reported tooccur in 0-3.8% of cases [5, 18-22]. Even expert pituitary neurosurgeons experienced a 0.6-0.8% incidence of vascular injuries [23-25]. Therefore, all neurosurgeons trying to perform TSS should try to avoid the ICA injury and prepare to manage its risk with the appropriate preoperative evaluation, such as digital subtraction angiography (DSA) or 3-dimensional computed tomographic angiography (3D-CTA), fusion images with magnetic resonance imaging (MRI) and 3D-CTA, and computer graphics. The overall incidence of ICA injury was reported to be 1.1%, and the rate of ICA injury was inversely proportional to the surgeon's transsphenoidal experience, being 1.4% for the least experienced surgeons, 0.6% for those with intermediate experience, and 0.4% for the most experienced [19].

Anatomical studies of the sphenoid sinus and sellar region are relevant, because they can improve spatial orientation to the landmarks. Injury to ICA is the most feared complication leading to the catastrophic clinical deterioration of the patients [3, 11, 26, 27]. Historically, emergency surgical ligation of the ICA, to cease massive bleeding during pituitary surgery, has been required. However, this treatment was associated with an unacceptable high incidence of major clinical neurological deficit [20, 21]. Therefore, the development of endovascular treatment, combined with bypass surgery can provide dramatic changes on the aspect of control of the bleeding, embolization of carotid cavernous fistula and pseudoaneurysm, and cerebral revascularization to maintain good clinical outcomes [28-31]. In addition, the cavernous sinuses on both sides, which exist on the boundaries of the sella turcica, are vulnerable to injury during the TSS [21, 32]. The vascular complications should be discussed in each stage of the TSS (naso-sphenoidal, spheno-planum, dural, intrasellar, and suprasellar phase) with respect to the operative and neuroradiological aspects, identification of risk factors, management strategies for the avoidance of such serious vascular complications, and their outcomes.

II. Vascular Anatomy of the Transsphenoidal Surgery

The process of the TSS was divided into five phases including naso-sphenoidal, sphenoid-planum, dural, intrasellar, and suprasellar. Vascular anatomic aspects of each stage are described.

1. Naso-Sphenoid Phase

Vascular injury can be frequently encountered on removal of the base of middle turbinate. The sphenopalatine arteries, branches of the internal maxillary artery, emerge through the sphenopalatine foramen (the height of lower margin of superior turbinate), run under the nasal mucosa, and supply the nasal structures, including nasal septum (anterior ~ posterior part: posterior septal nasal artery, inferior part: descending palatine artery) and middle turbinate (posterior lateral nasal artery). Posterior septal nasal artery, distributing nasal septum, has anastomoses with the posterior ethmoidal artery (PEA) [26]. Endoscopic observation sometimes reveals the pulsation of the artery. All the above mentioned arteries are important and should be kept in mind not to be injured. Careful attention should be paid at the procedure for dissection of mucosa at the nasal septum from the anterior wall of the sphenoid sinus. The sphenopalatine artery can be caught at the sphenopalatine foramen, through which the artery emerges, so as not to cause massive bleeding when removal of the anterior wall of the sphenoid sinus is widely required (Figure 1A) [34]. Law reported that the bleeding from the sphenopalatine artery could occur from the bone directly, from the venous diploic space or from the blood supply to stout bony structure, particularly in patients with acromegaly [20]. If the bleeding from the sphenopalatine artery is difficult to control, endovascular management, coil embolization of the maxillary artery, can be indicated. Although the midline approach would not disturb the main trunks of the sphenopalatine arteries, hemostasis of the posterior attachment of the middle turbinate, containing a branch of the sphenopalatine artery, is achieved with a suction electrocautery [34]. However, when nasoseptal pedicled flap, which is used for reconstruction of the skull base, should be made intraoperatively from the nasal septal mucosa, it is important to keep the sphenopalatine artery intact within the nasoseptal flap, whose base is required to be narrow in order to be adhered to the skull base. Therefore, the sphenopalatine artery should be stored within the narrow base of the pedicled flap [35].

Maxillary artery is the largest terminal branch of the ECA. It arises at the level of the neck of the condylar process and passes medial to it. Then, it ascends to the posterior part of the pterygopalatine fossa, and sphenopalatine artery is divided from it and run into the sphenopalatine foramen (Figure 1B). When exploring tumors, extending into the pterygoid fossa such as pituitary adenoma, adenocystic carcinoma and neurinoma, the course of the maxillary artery, which is buried in the adipose tissue at the pterygoid fossa, needs to be recognized in order to avoid an injury. Therefore, preoperative evaluation of the maxillary artery, such as 3D-CTA, is important.

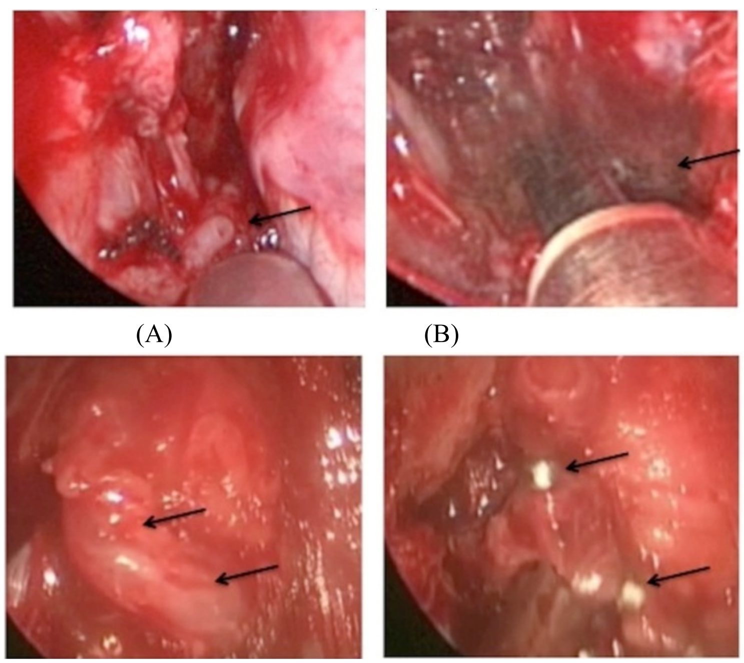
2. Spheno-Planum Phase

Vascular injury can be frequently encountered on removal of the planum sphenoidale and the posterior base of superior turbinate, especially in the case of extended TSS for the suprasellar lesion, an unusual TSS targeting for the pituitary adenoma. PEA, which has a smaller diameter than the anterior ethmoidal artery, diverges from the ophthalmic artery and passes between the medial rectal muscle and the superior oblique muscle. Afterwards, it runs through a thin, bony channel at the medial wall of the orbit along the ethmoidal roof, seen after submucosal dissection in the posterior ethmoidal sinus [12, 33].

Although the distribution of PEA has been reported to be variable, mainly it perfuses into the superior turbinate, the posterior ethmoid sinus, the posterior part of the lamina cribrosa, and the planum sphenoidale [33]. Neurosurgeons can find the unexpected hemorrhage from PEA, if the dissection around the superior turbinate and the posterior ethmoidal sinus is carried out [11]. Although the injury of PEA is considered as an extremely rare complication during TSS, the pituitary neurosurgeon should always have in mind the possibility of PEA injury.

In order to expose suprasellar lesions in the extended TSS approach, the superior and/or supreme turbinates should be removed along their base, taking care not to damage the turbinate lamina. During such maneuvers, it is important to avoid damaging the PEA, which frequently arises from the first segment of the ophthalmic artery and passes medially from the dura of the planum sphenoidale, to the posterior lamina cribrosa and then to the posterior ethmoidal cells [12]. Cavallo et al. reported that wide sphenoidectomy and bilateral posterior ethmoidectomy, to obtain a wider view of the planum sphenoidale, enable surgeons to clearly identify both PEAs, which are considered as “dangerous” landmarks and represent the anterior limit when opening the planum sphenoidale [10, 36]. Because the PEA branches the proximal portion of the ophthalmic artery with high blood pressure, injury of the PEA can cause massive and severe bleeding that should be avoided as much as possible.

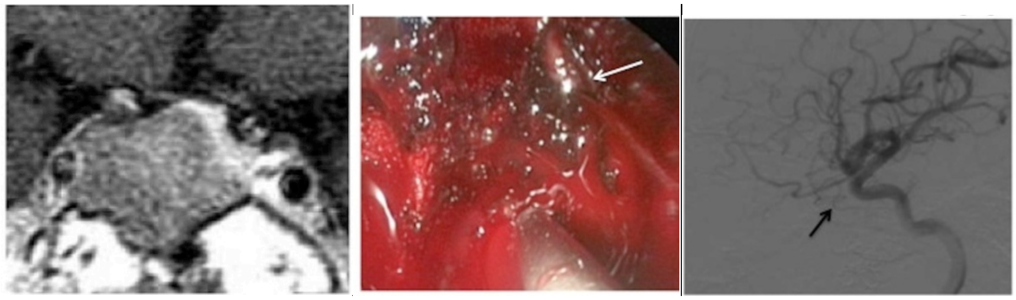
As the PEA is a large branch stemming from the ophthalmic artery, it can be detected at the planum sphenoidale or posterior ethmoidal sinus on preoperative examinations, such as CTA. If this is the case performing the extended TSS, more attention should be paid in order to avoid unexpected severe arterial bleeding during submucosal dissection of the superior and lateral nasal cavity.



(A) (B)

(C) (D)

Figure 1. A. Intraoperative endoscopic view shows the bleeding from the branch of sphenopalatine artery (posterior lateral nasal artery; A, arrow) B. is successfully coagulated with single-shaft bipolar coagulator (B, arrow) C. Intraoperative endoscopic view shows the maxillary artery (arrows) running in the pterygopalatine fossa after removal of the posterior wall of the maxillary sinus D.Hemoclips (arrows) were applied to resect the maxillary artery in the pterygopalatine fossa.



(A) (B) (C)

Figure 2. A. Magnetic resonance imaging of pituitary adenoma extending into the suprasellar region and compressing the optic nerves, with further invasion into the right cavernous sinus B. Intraoperatively, a massive hemorrhage suddenly appeared during mucosa dissection just above the sellar floor, suggesting the posterior ethmoidal artery (PEA) as the origin of the bleeding (white arrow) C. Digital subtraction angiography performed after the operation showed left PEA (arrow) to be responsible for this hemorrhage.

III. Illustrative Case

A 69-year-old man presented with a 6-month history of activity loss and visual field disturbance. MRI identified a pituitary tumor extending into the suprasellar region, compressing the optic nerves and invading the right cavernous sinus (Figure 2A). Neuro-ophthalmological investigation showed bitemporal hemianopsia, and endocrinological evaluation showed a decline of adrenocorticotrophic hormone (ACTH).

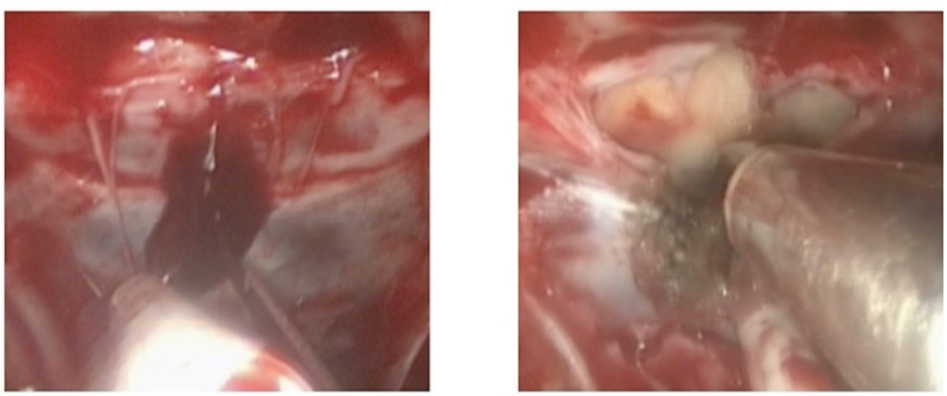
During the routine endoscopic TSS, a massive hemorrhage was suddenly encountered in the sphenoidal phase during mucosa dissection just above the sellar floor (Figure 2B). It was difficult to control this arterial bleeding, and the massive hemorrhage obstructed our endoscopic view, with the total amount of blood rising up to 2280ml. The bleeding point was found to originate from the left PEA was captured under the direct endoscopic view and was controlled with the single shaft bipolar coagulator (Karl Storz Endoscopy, Tuttlingen, Germany). Partial resection of the hard adenoma was performed, and the visual field defect and decline of ACTH level were restored. DSA performed after the operation showed left PEA, stemming from the ipsilateral ophthalmic artery, to be responsible for this hemorrhage (Figure 2C). Postoperative course was uneventful, and the residual tumor has been unchanged for four years.

1. Dural Phase

Vascular injury can be frequently encountered on opening of the dura mater of sellar floor, especially in the case of extended TSS for a suprasellar lesion, such as craniopharyngioma. Pituitary adenomas, further manifest with ballooning of the sellar floor, and compression of the intercavernous sinus for a long period and thus leading even to its complete occlusion.

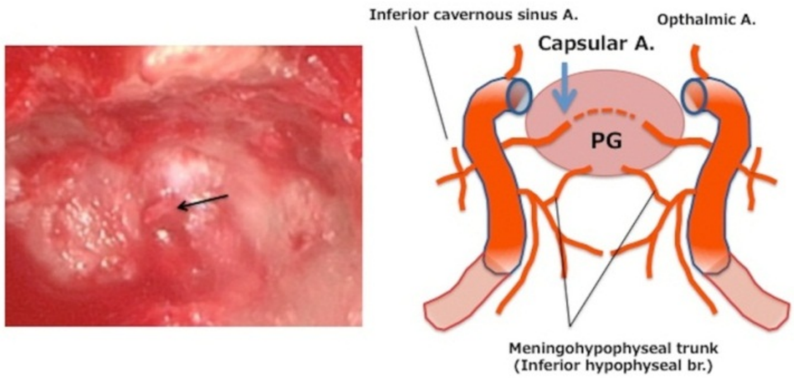
The cavernous sinuses on either side of the sella are vascular structures filled with venous blood under venous pressure. The two cavernous sinuses frequently connect through dural channels, most commonly superior and inferior intercavernous sinus. These connecting channels can be injured during the opening of the dura mater. The dura itself consists of two layers, and between them, vascular channels commonly proliferate and are diminished by compression of macroadenoma for a long period. In particular, superior intercavernous sinus usually locates between the sellar floor and the tuberculum sellae (tuberculum recessus), and coagulation and cut off of the superior intercavernous sinus is required, to advance into the suprasellar lesion during the extended TSS (trans-tuberculum sellae approach). The size and location of the superior intercavernous sinus can also influence the bone removal of the tuberculum sellae [20]. If bleeding once occurs in the cutting of the sinus, the surgical procedure will be slow and more difficult. Therefore, the incisions are made in the dura mater anteriorly and inferiorly to the superior intercavernous sinus, and the sinus is coagulated and then divided to obtain a direct view of the suprasellar cistern without disturbance by the pituitary gland [37]. In order to coagulate this sinus, the low-profile, single shaft bipolar coagulator is very useful (Figure 3).

The capsular artery, which feeds the capsule (dura mater) of the pituitary, usually is clinically insignificant and arises from the distal and medial portion of the cavernous ICA, commonly supply the sellar dura, and can also proliferate to feed any possible pituitary lesion [20, 21]. These vessels have anastomosis with the contralateral ones at the midline, and have the potential of causing technical difficulty, when dealing with the lesion directly. Zada et al. reported the midline dural filum at the sellar floor, in half of the cases examined. This filum is identified as a strand-like dural extension or as a small vascular dural structure [38]. From our intraoperative observation, active bleeding was identified from the dural filum in many of the cases, which was thought as a result of the blood supply from the anastomosis of the capsular arteries (Figure 4).



(A) (B)

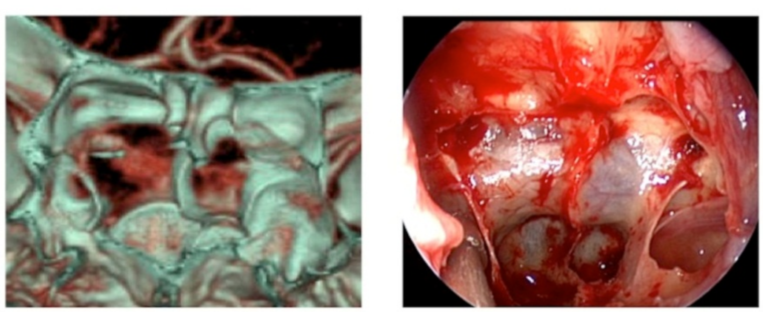
Figure 3. A. Bleeding from the superior intercavernous sinus is detected when cutting with a micro-knife and B. Coagulating with the single-shaft bipolar coagulator, in order to obtain a direct view of the suprasellar cistern without disturbing the pituitary gland.



(A) (B)

Figure 4. A. Intraoperative endoscopic observation identifies the dural filum and the bleeding from it (arrow), which was thought to originate from the capsular arteries
B. A scheme of the arterial supply over the dura mater of the sella.

The carotid artery frequently produces a bony prominence into the sphenoid sinus wall, below the floor and along the anterior margin of the sella bilaterally (carotid prominence). Moreover, usually the optic canals protrude into the superolateral portion of the sinus, and the carotid prominence, a diverticulum of the sinus, often projects laterally between the optic canal and the carotid prominence. The dura mater over the medial surface of the cavernous sinus is exposed after removing the mucosa and bone at the lateral wall of the sphenoid sinus. Subsequently, the cavernous ICA is exposed after dural opening of the sella. Rhoton reported that there is an area between optic nerves and carotid arteries where bone thickness less than 0.5 mm from the mucosa of the sphenoid sinus in some of the cases, and meanwhile, no bony thickness is found between these structures in a few cases. The absence of such bony protection over the wall of the cavernous sinus may lead to a serious injury of the cranial nerves and the ICA during the TSS. The bone of the calvaria is often thinner over the carotid arteries than over the anterior margin of the pituitary gland [39]. Pituitary neurosurgeons are required to recognize these bony structures, related to the ICA, in order to avoid unnecessary ICA injury. 3D-CTA with thin slices of bone images is useful as a preoperative evaluation. In our institute, oblique-coronal image (sections perpendicular to the line from lower margin of the nostril to the top of the posterior clinoid process) as “transsphenoidal view” is taken routinely in the preoperative evaluation of the TSS (Figure 5).



(A) (B)

Figure 5. A. 3D-CT reconstruction of oblique-coronal image (sections perpendicular to the line, from lower margin of the nostril to the top of the posterior clinoid process) as “transsphenoidal view”, is obtained as a routine preoperative evaluation of the transsphenoidal surgery for the pituitary tumors B. Intraoperative endoscopic view for the sellar floor and its surroundings after wide sphenoidectomy.

During the TSS approach to the sella, complete midline orientation should be maintained all the time to avoid the injury of the ICAs. Besides, the cavernous portion of the ICA is vulnerable to damage during the exposure of the sella. In the dural phase, in most cases, the injury of ICA can be encountered with the dural opening of the sellar floor. Therefore, careful preoperative evaluation of bony structure in the sphenoid sinus as well as measurement of intercarotid distance is essential to avoid the serious ICA injury [20]. Perdoni et al. reported that the mean intercarotid distances found at the level of tuberculum sellae, sellar floor and clivus were 13.32, 18.00 and 18.90 mm respectively. The distance between ICAs at the tuberculum sellae is narrower than that at the sellar floor. The mean distance found between the ICAs at the level of the 18 mm sellar floor can be considered a “safe zone” to access the hypophysis, and other researchers reported similar value [40]. However, endoscopy is very useful in providing a panoramic view of the depth in the sphenoid sinus, including bilateral carotid prominence and opticocarotid recessus. Fujii et al. reported an interesting study, showing the various parts regarding bony thickness of the posterior wall of the sphenoid sinus. In this chapter, the thickness of the bone of the sphenoid sinus together with the intracranial ICAs was described as follows; the thickness of the bone separated the ICA and sinus is less than 0.5 mm in 88% of cases, and areas of bone defect were present in 8% of them [41]. Therefore, fine maneuvers are required and easy cautery should be avoided as much as possible. In this connection, the vidian canal can be a critical landmark for the petrous and parasellar ICA [12]. Identification of this landmark and the parasellar and paraclival carotid prominence is also critical in staying oriented to the petrous ICA [42]. The bone over these prominences can be carefully and safely removed to have the ICA in view [43].

IV. ILLUSTRATIVE CASE

A 38-year-old man presented with activity loss and visual field deficits that had been ongoing for the last two months. He had consulted previously another clinic, where a large-sized suprasellar extended tumor was detected with MRI, and was referred to our department where neurological evaluation revealed bitemporal hemianopsia, and endocrinological evaluation showed reduced levels of baseline cortisol, ACTH, and thyroid hormones. MRI showed a calcified solid mass with remarkable suprasellar extension compressing both optic nerves upward (Figure 6A). Extended endoscopic endonasal TSS was performed, and gross total removal of the tumor was achieved and subsequently visual function was remarkably improved. Pathological diagnosis of the surgical specimen was non-functioning pituitary adenoma.

Intraoperatively, during right-sided dissection of the dural phase of the TSS, arterial bleeding emerged from the right ICA, during the removal of the bone at the carotid prominence (Figure 6B). Hemostasis was immediately carried out with continuous aspiration of the hemorrhage without leading to catastrophic hemorrhage. Tumor was successfully removed via extended TSS, and the patient was discharged without any neurological deficit.

However, one month later, follow-up MRI revealed de novo flow void mass at the cavernous ICA (Figure 6C). DSA was performed to demonstrate aneurysm formation at the right cavernous ICA, and it was most suspected to be pseudoaneurysm (Figure 6D). The risk of aneurysm rupture is considered to be quite high. Therefore, in order to prevent rupture the aneurysm, endovascular embolization of parent ICA to occlude pseudoaneurysm and superficial temporal artery-middle cerebral artery anastomosis for cerebral revascularization was successfully performed. Postoperative DSA revealed disappearance of aneurysm and restoration of the blood supply from the ECA to the ICA (Figure 6E, 6F). Cerebral blood flow measurement showed no perfusion defect and MRI showed no ischemic changes on the right hemisphere. The patient left the hospital with no neurological deficit. In a later time-point, residual tumor was managed with conservative treatment.

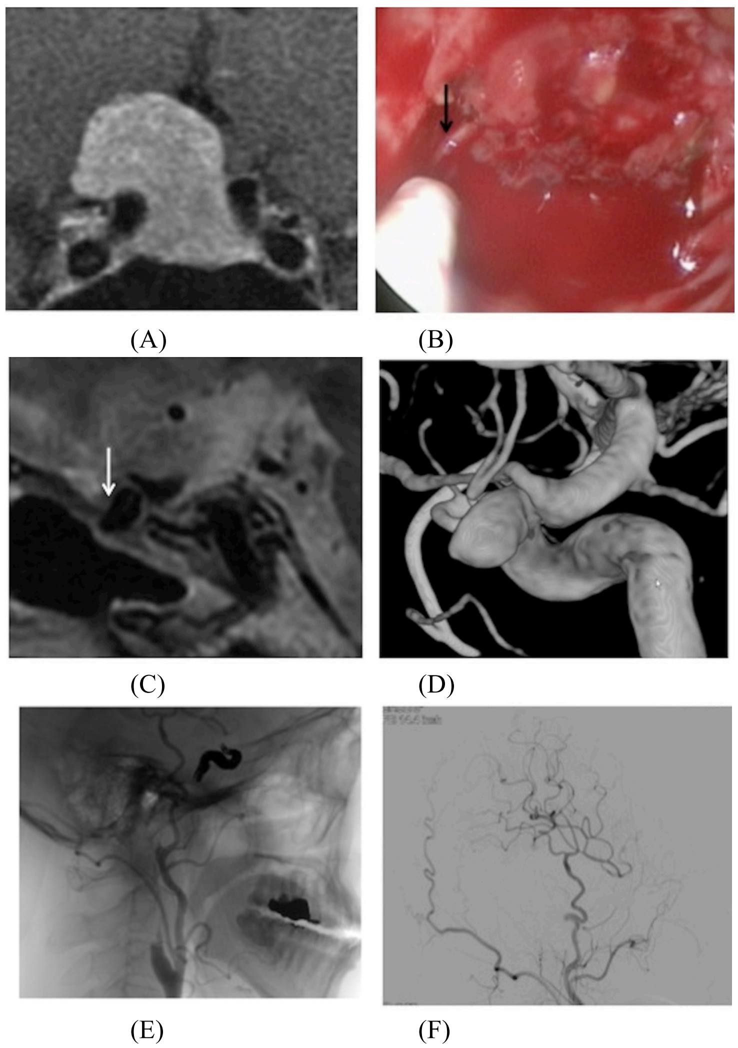


Figure 6. A. Magnetic resonance imaging (MRI) reveals the non-functioning pituitary adenoma extending into the suprasellar cistern B. During right-sided dissection of the dural phase of the transsphenoidal surgery, arterial bleeding emerged from the small branch of the right ICA (arrow) during the removal of the bone at the carotid prominence C. MRI obtained one month later revealed de

novo flow void mass with anterior protrusion at the right cavernous ICA D. DSA demonstrated aneurysm formation at the right cavernous ICA, suggesting pseudoaneurysm E. Endovascular embolization of parent ICA to occlude pseudoaneurysm and superficial temporal artery-middle cerebral artery anastomosis for cerebral revascularization was successfully performed. Postoperative DSA revealed disappearance of the aneurysm and F. excellent restoration of the blood supply from the ECA to the ICA.

1. Intrasellar Phase

Vascular injury of ICA and its perforator can be encountered on removal of tumor invading into the cavernous sinus or incision of cavernous sinus wall. The ICA sometimes can be tortuous and protrude to the midline [32]. Therefore, ICA injury in this phase frequently leads to the fatal neurological and systemic complications, with published rates, occurring by the use of traditional open approaches ranging from 3% to 8%. [44, 45], whereas for standard microscopic TSS for pituitary tumors ranging from 0.2% to 1.4% [5, 18, 20]. On the other hand, cases in which endoscopic endonasal surgery was used, a limited number of ICA injuries were reported, suggesting that these were indeed rare [37, 46, 47]. Moreover, increased use of the endoscopic endonasal approach for skull base lesions can provide wide exposure and visualization of its surroundings with remarkable advancement of the specialized instrumentation [8, 9]. It can allow improved localization and control of the ICAs. However, increased chances of dissection due to endoscopic wide visualization around the ICAs may result in a higher rate of ICA injury [26]. In some cases, the parasellar ICA protrudes inside the adenoma with remarkably tortuosity. Cautious preoperative evaluation is required to prevent fatal ICA injury and remove the tumor efficiently (Figure 7).

Because little or no separation exists between the medial portion of the ICA and the lateral surface of the pituitary gland, blunt instrument should be used for the dissection of the tumor periphery inside the sella. Perforation or laceration of the ICAs in the cavernous sinus represents a very serious problem and unfortunately is a common type of injury in the TSS [21]. In the cases of large invasive pituitary adenomas eroding the skull base, tumors may actually surround the ICAs and, occasionally, may invade the adventitial wall of the vessels, which causes injury to the integrity of the ICAs, when the tumor is removed radically. Dissection of tumors away from the ICAs or displacement of the ICAs in the cavernous sinus during an attempt to achieve hemostasis can lead to thrombosis of the ICAs, resulting in occlusion and occasionally embolization.

Important branches of the ICA, supplying the pituitary gland with blood, arise from the meningohypophyseal trunk, which arises between the carotid segment C4 and C5 and supplies the pituitary gland and the pituitary stalk [20]. This trunk can also proliferate to provide blood supply to pituitary tumors. It divides into three branches, inferior hypophyseal branch, dorsal meningeal branch, and tentorial branch. Inferior hypophyseal branch is the largest of these three, and runs medially to supply the posterior pituitary lobe, appearing as the latter’s net of terminal vessels [12, 44].

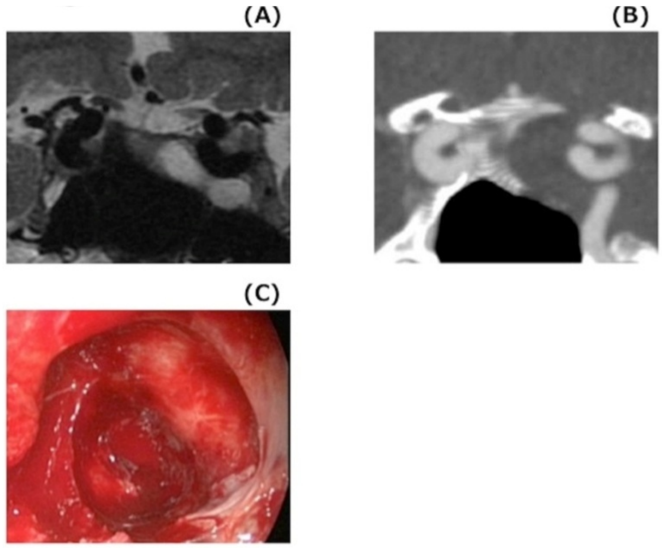


Figure 7. In a representative case was shown the ICA protrusion into pituitary adenoma, the latter invading into the cavernous sinus. A. Preoperative MRI revealed that the cavernous ICA was involved in the adenoma. An intratumoral cyst was identified B. Preoperative CTA revealed tortuous cavernous ICA protruding into the adenoma C. Intraoperative endoscopic view after opening of the intratumoral cyst clearly showing the tortuous ICA to be adjacent to the cyst.

Direct injury to the carotid artery frequently leads to formation of a pseudoaneurysm, like in our case described above, even if the artery appears to be intact up to the point of maintaining its flow inside the ICAs without further bleeding. According to some authors' reports, the rates of pseudoaneurysm formation after ICA injury are generally very high, and carotid cavernous fistula and thrombosis can occur either [26, 48]. Kai et al. reported a case of a patient who suffered a pseudo ICA aneurysm following TSS, and cerebral angiograms showed a pseudoaneurysm arising from the C4 portion of the left ICA. It was successfully treated with bypass surgery and ICA occlusion involving the pseudoaneurysm using coil embolization. Postoperative angiograms showed that the pseudoaneurysm was completely occluded and the bypass was fully patent. Authors addressed that massive arterial bleeding is encountered during TSS, therefore the patient should be carefully monitored to detect early the development of a pseudoaneurysm. When such an aneurysm is found to have ruptured, interventional surgery has proved effective in the management of this complication [49].

The ICA can be placed into mechanical spasm by causing dissection around the ICAs or injury to them. TSS complicated by peritumoral hemorrhage is associated with a significant rate of neurological deterioration, due to delayed cerebral vasospasm, and this spasm can clearly cause arterial insufficiency and stroke [26]. Therefore, early recognition and proper management, according to guidelines used for postaneurysmal subarachnoid hemorrhage (SAH), may help to prevent deterioration of outcomes in those patients [19, 50]. Puri et al. reported three cases of developed vasospasm of the intracranial vessels after TSS, with extension of peritumoral hemorrhage into the subarachnoid space, starting as early as postoperative day 5 and continued as late as postoperative day 10. The outcomes of these three cases were not excellent; therefore, they concluded that the vasospasm after TSS associates with the significant risk of neurological morbidity [50]. The timing and distribution of cerebral vasospasm after TSS is similar to that observed in the patients after SAH due to aneurysmal rupture. Therefore, the management of the vasospasm including early vascular imaging evaluation, aggressive hyperdynamic therapy, and neurointerventional procedures should be applied to prevent upcoming ischemic complications [50-52].

2. Suprasellar Phase

Pituitary adenoma with remarkable suprasellar extension, in particular, in the case with significant anterior skull base extension, the extended transtuberculum sellae-transplanum sphenoidale approach is required to remove the pituitary adenoma. With this approach, the suprasellar cistern is fully exposed during and after the surgery [53, 54]. Vascular injury, at the level of supraclinoid ICAs and their branches, can be encountered on dissection between the tumor and the vessels involved or adhered to the tumors at the suprasellar, the interpeduncular, and the prepontine cisterns. Thus, ICA, superior hypophyseal artery, anterior and posterior communicating arteries, posterior cerebral artery, basilar artery and its perforators, and superior cerebellar artery, are the vessels affected during the extended endoscopic TSS (Figure 8). Therefore, during the manipulation of the vessels in the suprasellar phase, neurosurgeons should take into consideration the anatomy of the Circle of Willis and its integrity with respect to its collateral flow [48]. Concerning their branches and perforators, special attention should be paid to the injuries of the hypothalamic arteries, but also prevention of a direct hypothalamic trauma, which could cause recent memory disturbance [25]. Once the pituitary stalk can be seen in the subchiasmal spaces, the superior hypophyseal artery and the perforating branches for the inferior surface of the chiasm are apparent, and the posterior communicating artery and its perforator are also detected in the deeper parts of the operative field [10]. During the removal and dissection of the tumors at the TSS, the vascular anatomy around the suprasellar cistern turns to be very complex and is frequently distorted in the cases of large tumors. Besides, above the diaphragm sellae, a circuminfundibular venous plexus exists and can elaborate to feed pituitary lesions. As mentioned above, more expanded approach to obtain wide operative field and excellent visualization, with greater ICAs manipulations and subsequent ICAs' exposure, could increase the risk of vascular injuries [12, 27]. However, in some series, it was indicated that lateral exposure of pituitary tumors enable wider range of endoscope access than microscope and does not lead to a remarkable incidence of injuries overall of for tumors. In the cases of vascular injuries described above, massive bleedings flow into the sphenoid sinus and nasal cavity. However, in this phase, massive bleeding due to the vascular injuries "attacks" hypothalamus, intraventricle and brainstem, causing fatal neurological deteriorations. Besides, once the vascular injury occurs, it is very difficult to control the bleeding, so as to maintain visualization at the deep and narrow operative field, thus higher techniques are required to find the bleeding point [27].

Needless to say, the best strategy for managing ICA injuries during the TSS is prevention. Therefore, considerable preoperative neuroradiological assessment of the course of the ICAs at the suprasellar cistern is essential, as well as tumor and patient risk factors (e.g., ICA involvement with tumor, atherosclerosis in patients with acromegaly or Cushing disease) [27].

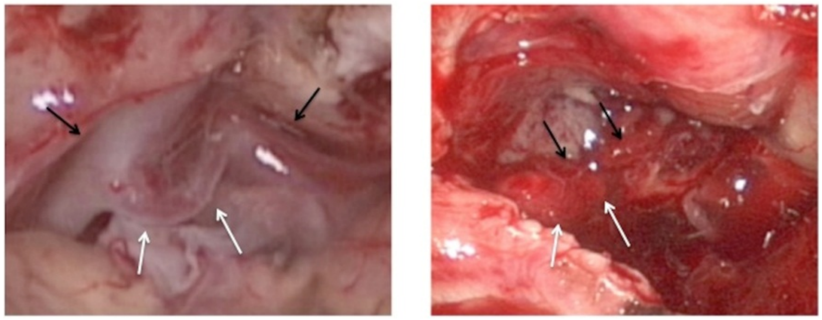


Figure 8. A. Intraoperative endoscopic view clearly revealed the anterior communicating artery (white arrows) and anterior cerebral arteries (black arrows) and B. the ICA (white arrows) and the superior hypophyseal artery (black arrows) after removal of pituitary adenoma via the extended transtuberculum sellae approach.

When exploring a suprasellar lesion below the optic chiasm such as craniopharyngioma, preservation of chiasm vascularization, fed from the superior hypophyseal artery is partially important, and extended transsphenoidal approach with endoscope offers an excellent visualization, in order to avoid any vascular injury resulting during the dissection between the tumor and the vessels [11]. An avulsion of perforator arising from the P1 portion of posterior cerebral artery during the resection of the part of suprasellar extension of pituitary adenoma may occur, and Kassam et al. used a topical hemostatic agent to control the bleeding, but as a result of this forcible tearing, the patient suffered from severe transient dysphagia [36].

V. Procedures and Instrumentations for the Prevention and Control of Bleeding

As mentioned above, the first problem related to this approach concerns the control and prevention of bleeding, especially in the procedures of intra- and supra-sellar phases. Because it is difficult to control massive bleeding coming from the main vessels, as many neurosurgeons addressed, it is important to make all surgical maneuvers under the direct endoscopic view [16].

In particular, in the suprasellar phase, angled 30° or 45° 4 mm rigid endoscope was used to assess the completeness of tumor removal and to help observe the tumor-neurovascular interface clearly [1, 9, 37]. Dusick et al. reported that the use of the micro-Doppler probe for carotid localization before dural opening and angled hook blades for lateral dural opening are potentially simple and effective surgical adjuncts that can help minimize the risk of ICA injury, and recommended for all TSS as routine intraoperative examination (Figure 9)[19, 22]. Kitano and Taneda reported the use of the micro-Doppler probe later during tumor resection within the cavernous sinus, in order to confirm the ICA course, as a technique that they strongly recommended [55]. In addition, the Doppler is more reliable than neuronavigation systems, because it gives real time feedback, whereas the latter are prone to varying degrees of inaccuracy even for fixed cranial-base landmark [2, 56]. Indocyanine green fluorescence shows promise as an intraoperative marker in differentiating pituitary tumors from normal gland, and virtually identifying areas of dural invasion without development of any adverse events [57]. Yano et al. clearly demonstrated intraoperative visualization of the intercavernous sinus before dural incision and the cavernous ICA in the intrasellar phase, and encouraged the improvement of the tumor resection with more safety and effectiveness [35]. Although the indocyanine green fluorescence has not yet become popular in the TSS, these results support the further development of fluorescence-guided tumor resection techniques, since these can lead to improved outcomes, from the aspect of preservation of normal gland, extent of tumor resection, and avoidance of vascular injury. Dusick et al. also addressed that the use of low-profile hook blades for dural opening can reduce the risk of the ICA and other vascular injuries because the blade angle allows the cutting force to be directed away from the intradural surface and back toward the surgeon instead [19]. Rhoton proposed that angled piston-gripped dural scissors could be used for this purpose [58].

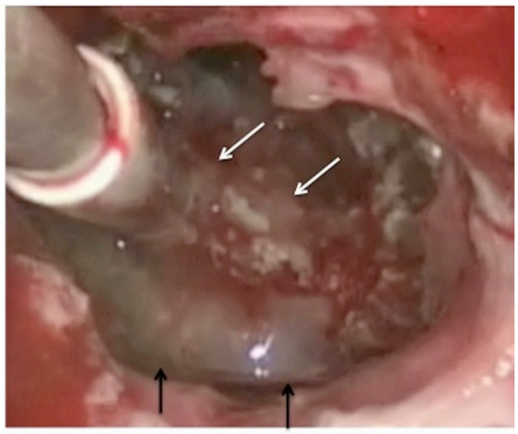


Figure 9. Micro-Doppler probe (black arrow) for localizing carotid artery (white arrow) during the removal of pituitary adenoma, to prevent the ICA injury. The procedure is recommended for every kind of transsphenoidal surgery as routine intraoperative examination.

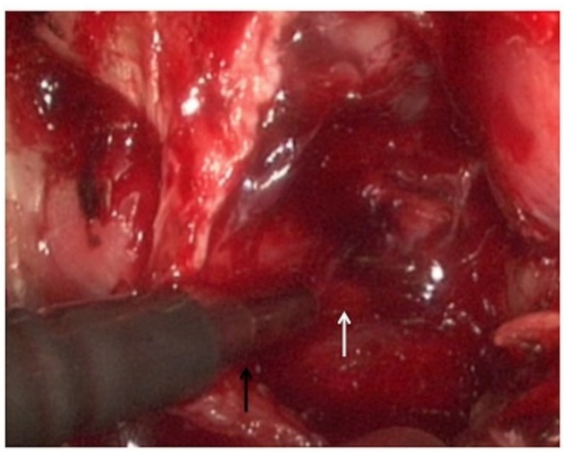


Figure 10. Low-profile bipolar coagulator for the coagulation of vessels of the tumor capsule, making possible the bipolar coagulation of arterial bleeding in narrow spaces.

Low-profile bipolar coagulator, specially designed to work through the nose, with tips up to 0.3 mm and single shaft, are now available for the coagulation of vessels of the tumor capsule, making possible the bipolar coagulation of arterial bleeding in narrow spaces (Figure 10). Vascular clips with an applicator designed for endonasal use can be useful for the bleeding control of the vascular injuries in the naso-sphenoid and sphenoid-planum phase [20]. However, these devices are not practical for the ICA injury for the fear of enlarging the hemorrhage point.

Although the bleeding due to the ICA injury during the TSS is so massive and difficult to control in the operative field, most ICA injuries originated from small puncture wounds that can be fortunately controlled in an initial phase with Gelform and cottonoids. Therefore, when the neurosurgeons encounter the ICA injury during the TSS, they must detect the accurate bleeding point of the ICA injury despite of the difficulty in controlling a massive bleeding at first moment [30]. Following the initial care, the next steps include a two-layered muslin gauze patch or collagen sponge immersed in fibrin glue or BioGlue, and then a fat graft put over the puncture point accurately. Harvested fascia with fibrin glue is strong and adhesive material, which can be applied to the puncture point for the control of the bleeding [59]. But neurosurgeons need to prepare the fascia and fat graft from abdomen or thigh in advance intraoperatively. However, overpacking the repair of injured site should be refrained, because it could result in carotid occlusion and subsequent cerebral infarction. The use of the clip to control the bleeding and preservation of the vessel patency is reported in some cases [20]. Direct suturing repair for the larger laceration of the vessel is basically not practical, because suturing technique is quite difficult and time consuming at that serious situation.

Unfortunately, if the arterial bleeding from the injured vessels is not controlled finally, trapping of the vessels with aneurysm clip is applied to the injured site or the parent artery, thus “sacrificing” the vessels. However, recent advancement of endovascular surgery has changed the methods to repair the vascular injuries [28]. As some authors have already described and vascular group of our institute performs, urgent cerebral angiography should be carried out in the operating room. After the detection of the extravasation and presentation of a pseudoaneurysm or carotid cavernous fistula, balloon is approached to the injured site and inflated to occlude the parent vessels [28, 29, 48]. After the repair of the injured site, ICAs are supposed to be involved in most of the cases, it is needed to confirm that the injured site is successfully repaired after deflation of the balloon and collateral circulation via the Circle of Willis in the case of ICA occlusion should be assessed [30]. With the appearance of pseudoaneurysm or carotid cavernous fistula, endovascular treatment, involving ICA embolization, should be immediately achieved [31, 60, 61]. In this case, since the collateral circulation is not excellent via anterior communicating artery or posterior communicating artery, the ECA-ICA bypass surgery, including superficial temporal artery-middle cerebral artery anastomosis, high flow bypass using arterial graft, should be immediately performed to prevent the subsequent ischemic complication due to the ICA embolization [49]. Even if the result of the angiography is normal after the vascular injury, it is strongly recommended to repeat DSA or 3D-CTA within five days to detect the delayed occurrence of any possible pseudoaneurysm. MRI should be also carried out and evaluated, whether cerebral infarction emerges in the case of the ICA embolization, and CT scan should be also obtained immediately after endovascular procedure, whether SAH occurred, which can lead to clinically significant cerebral vasospasm [50, 62].

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