2 Endoscopic Endonasal Transsphenoidal Approach

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2.1 Indications

The standard endoscopic endonasal transsphenoidal approach to the sella is suitable for the removal of pituitary tumors, both microadenomas and macroadenomas, and the indications are the same as those for conventional microscopic pituitary surgery [4, 13, 39].

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Surgery for pituitary tumors has the goals of resection of tumor mass, normalization of hormonal hypersecretion, preservation or restoration of normal pituitary function, prevention of recurrence, and tissue sampling for diagnosis and research studies. The progressive visual loss from mass effect is a common indication for surgery as well as pituitary apoplexy, a condition caused by hemorrhage or necrosis into an existing pituitary tumor, characterized by sudden visual loss associated with headache, cranial nerves palsies, and sometimes acute adrenal insufficiency [6, 47, 57].

In case of nonfunctioning macroadenomas, owing that no medical treatment is clearly effective, the first therapeutic option is surgery being the transsphenoidal approach as the most effective [6]. Indeed, mass effect with visual defects or endocrine dysfunction (partial or total hypopituitarism) is an indication for surgical treatment; a conservative treatment can be preferred for those lesions smaller than 10 mm that do not alter any neurologic or endocrine condition [27].

Concerning secreting adenomas, transsphenoidal surgery has been advocated as the primary treatment for growth hormone-secreting lesions; however, it is worth reminding that preoperative treatment with somatostatin analogues is useful to improve the clinical conditions of the patient and can be adopted as an alternative in those cases with extremely increased surgical risk [8, 23, 25, 26].

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As well, the transsphenoidal surgical treatment is the first choice for the removal of radiologically evident ACTH pituitary adenomas causing Cushing's disease.

On the other hand, prolactinomas usually shrink with dopamine-agonist therapy [24]; however, in case of resistance or medical treatment-related complications, or in case patients don't tolerate or refuse it, surgical removal should be performed [14, 22, 35].

The use of the endoscopic transsphenoidal approach offers extra advantages in case of recurrent and/or residual tumors that are already treated with a transsphenoidal operation. The wide anatomical view of the surgical field provided by the endoscope helps to overcome disorientation related to eventual distorted anatomy, nasal synechiae, septum perforations, sphenoidal mucoceles, and intrasellar scars. Indeed, the direct and closeup control given along the entire procedure has reduced the risk of injury of intra- and parasellar structures [3, 20]. Furthermore, the endoscopic technique is preferred by patients having already been treated by means of the transsphenoidal microsurgical approach, thanks to the lesser postoperative nasal and breathing discomfort.

Recently, the endoscopic endonasal approach has permitted also the removal of giant adenomas, defined as lesions 4 cm or greater in maximum diameter with prevalent intracranial extension. In these cases the so-called "extended" variation of the approach with a wider bone opening over the planum sphenoidale provides a direct view of the suprasellar extension of the tumor along with a safer tumor removal [10, 30, 40, 45].

The introduction of the "extended" endoscopic endonasal approach (EEEA) has widened the indications of this technique to different pituitary adenomas such as dumbbell-shaped adenomas and pure suprasellar, recurrent, and/or fibrous lesions [7, 30]. A standard approach can be turn into an extended one when a relatively large suprasellar remnant of the lesion fails to descend and therefore cannot be removed. In such cases the use of the EEEA allows complete tumor removal, thus reducing the risk of swelling of the tumor remnant. In case of patients who have undergone a prior craniotomy, the EEEA offers a virgin surgical route, which allows the management of aspects of the lesion that could have not been accessed in the first transcranial operation. The EEEA indeed provides a double surgical corridor, intracapsular and extracapsular [30], making it complementary to craniotomy in some difficult-to-treat pituitary adenomas or representing an alternative to it [40, 45].

It has to be reminded that pituitary adenomas originate within the sella turcica so that, notwithstanding they could reach huge dimensions, the transsphenoidal route—with its standard or extended variations—represents the most direct and natural corridor to access this area. Conversely, when the tumor shows a significant intracranial extension that results out of the visibility and maneuverability of the endoscopic endonasal route, the transcranial approach still represents the most effective and viable surgical option [10].

We should conceive an "extended approach" also in its infrasellar variation, which thanks to the technique with a wider removal of nasal structures allows the surgeon to obtain an easier removal of those giant adenomas with a prevalent esocranial extension, such as adenomas invading the whole sphenoid sinus cavity, eroding the clival bone, or extending in the pterygopalatine fossa or into the nasal cavities [10].

Despite the surgeon must always attempt a "maximum-allowed" surgical outcome, it is very important to keep in mind that a wide variety of different options—medical, surgical, and radiotherapy—are now effective treatment in terms of long-term results. His/ her mind should be forged to relate the goal of surgery to the patient's needs, selecting the best option for the actual condition of the patient among all the options available, surgical or otherwise [10].

2.2 Anatomy of the Approach

The endoscopic endonasal approach represents a direct and minimally traumatic route for the removal of sellar and suprasellar lesions. Between the vestibule of the nasal cavities and the sellar floor, there are no major anatomical structures to be removed—aside from anterior wall of the sphenoid sinus—so that sella can be exposed just inserting an endoscope into the nostril and piercing the natural sphenoid ostium. As a matter of facts, the exposure does not allow a surgical procedure that requires a proper corridor to fit the instruments and handle them safely [17, 58].

Once the endoscope is inserted into the nasal cavity, the first two landmarks that are identified are the nasal septum and the lateral wall of nasal cavity that is lined out by three nasal turbinates: the inferior is the most anterior and it is recognizable as soon as the endoscope enters the nasal vestibule. Sliding further deeply, between the tail of the inferior turbinate and the nasal septum, it is possible to visualize the choana; this latter represents the most important landmark during this step, allowing the definition of the limit between the nasopharynx and the anterior wall of the sphenoid sinus. The middle and the superior turbinates are molded off the ethmoid bone; the first one can be seen angling the endoscope about 30° upward from the floor of the nasal cavities. The head of the middle turbinate can be less or more pneumatized. Its tail usually lies at the level of the sphenopalatine foramen through which the sphenopalatine artery enters into the nasal cavity. Thereafter, it divides in two branches, the nasopalatine artery medially and the posterior nasal artery, laterally. Though, the tail of the middle turbinate represents an important landmark for the control of eventual arterial bleeding during the anterior sphenoidotomy.

Posteriorly, superiorly, and medially to the middle turbinate, it is possible to identify the superior turbinate.

Above the choana, the sphenoethmoid recess forms the posterior wall of the nasal cavity: in its upper portion the sphenoid ostium can be identified, variable for shape, dimension, and location being sometimes covered by the tail of the superior turbinate. It represents the natural communication between the nasal cavity and the sphenoid sinus. Accordingly, during the surgical procedure, it is not mandatory to identify the sphenoid ostium, which definitely should not be considered as a main landmark of the approach (Fig. 2.1).

Hence, at the level of the sphenoethmoid recess, the nasal septum is detached from the prow of the anterior wall of the sphenoid bone; this latter is opened circumferentially and thus far the endoscope enters into the sphenoid cavity, often divided by one or more septa. The degree of pneumatization of the sphenoid bone is an important factor for the identification of the bony protuberances and depressions inside it. Depending on the degree of its pneumatization, a series of protuberances and depressions molded on its posterior and lateral walls can be identified. The sellar floor is at the center, the sphenoid planum is above, and the clival indentation is below; lateral to the sellar floor, the bony prominences of the intracavernous carotid artery and the optic nerve can be observed. Between them, the lateral optocarotid recess lies; it is molded by the pneumatization of the optic strut of the anterior clinoid process. The intracranial aspect of the upper border of the lateral optocarotid recess is covered by a thickening of the dura and periosteum that forms the distal dural ring, which separates the optic nerve from the clinoidal segment of the internal carotid artery (ICA). The inferior border of the lateral optocarotid recess also presents a thickening of the dura and periosteum, which forms the proximal dural ring, which separates the intra-cavernous portion of carotid artery from the clinoidal segment. The lateral aspect of tuberculum sellae represents the point where the bony prominences of the carotid artery and the optic nerve join medially (medial optocarotid recess). This recess is less evident than the lateral one; rather it represents the lateral limit to be opened to unlock the suprasellar area (Fig. 2.2).

The sella turcica is limited superiorly by the diaphragma sellae, a fold of dura with a central opening through which is pierced by the pituitary stalk and its blood supply. The diaphragma sellae separates the anterior lobe of the pituitary gland from the optic chiasm and the suprasellar cistern. The intercavernous sinus (anterior and posterior) lies in the anterior and posterior borders of the diaphragma sellae. Additional small venous sinuses in the base of the pituitary fossa drain into the intercavernous sinuses [53].

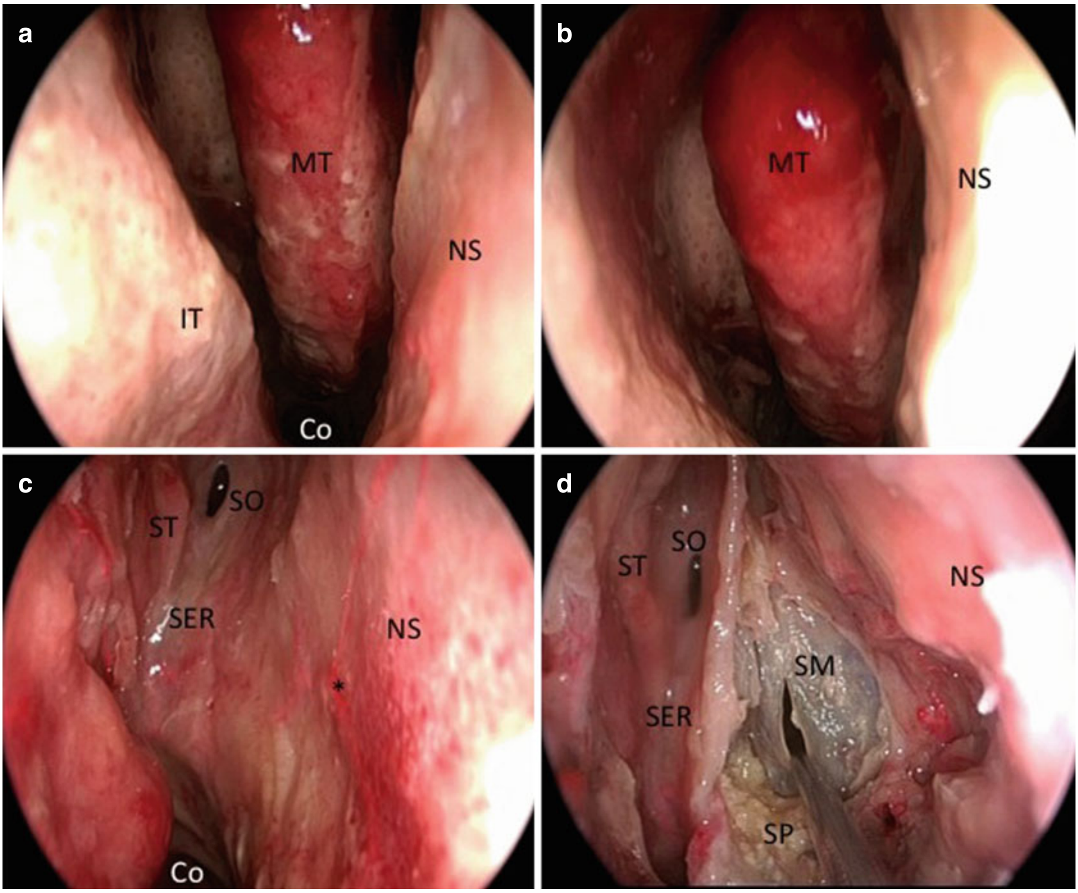

Fig. 2.1 Anatomical images of endoscopic exploration of the right nostril and identification of the nasal landmarks. (**a**) The inferior portion of the right nostril. (**b**) The middle turbinate. (**c**) The sphenoethmoid recess. (**d**) The sphenoid sinus mucosa after the opening of its anterior wall. *IT* inferior turbinate, *MT* middle turbinate, *SER* sphenoethmoid recess, *NS* nasal septum, *Co* choana, *SO* sphenoid ostium, *ST* superior turbinate, *SP* sphenoid prow, *SM* sphenoid mucosa, * branches of the nasopalatine artery

If the surgeon wants to explore the cavernous sinus, the bone that covers the intracavernous carotid artery (carotid protuberance) must be removed in order for both the medial and lateral compartments of the cavernous sinus to be exposed [15]. The space between the ICA and the pituitary gland varies depending on the anatomy of both structures. The medial wall may consist of tenacious connective tissue or may be fenestrated, incomplete, or inexistent, offering little or no anatomical resistance against tumor invasion. Surgical access to the medial and posterior wall of the cavernous sinus is possible by elevating or retracting the pituitary gland medially and by retracting the C4 (intracavernous segment) or C4–C5 bend of the ICA, laterally [21, 56]. The carotid artery itself is located in the major portion of the cavernous sinus so that the entire cavernous sinus will be disclosed only when the carotid artery is mobilized medially. Upon opening of the medial wall, the posterior and upper parts of the cavernous sinus are entered. The inferior hypophyseal artery is identified inferolaterally to the pituitary gland, arising from the meningohypophyseal trunk together with the dorsal meningeal and tentorial artery. Anteriorly to it, the inferolateral trunk, with its collaterals to the cavernous sinus cranial nerves, is detected, branching off the lateral aspect of the ICA; its origin can be seen by medial dislocation of the

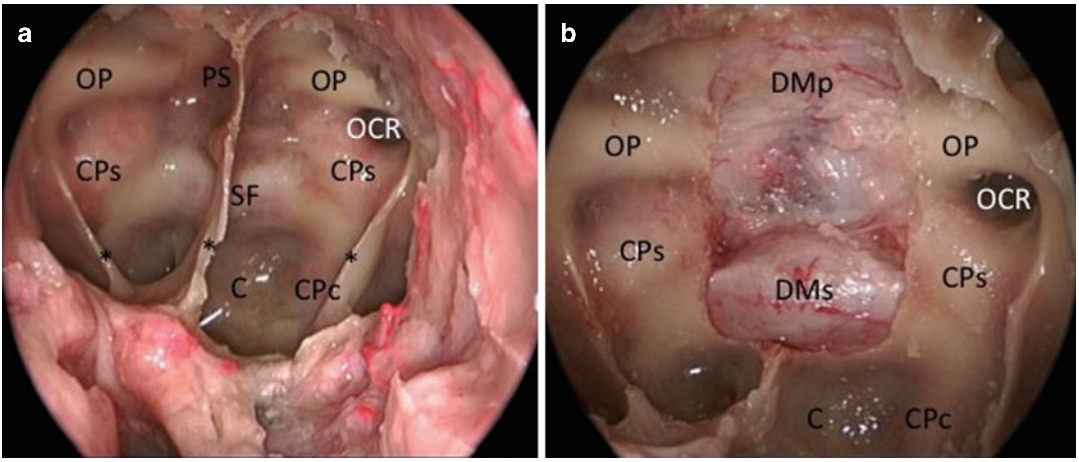

Fig. 2.2 Exposure of the sphenoid sinus after opening of its anterior wall and identification of the anatomical landmark. (**a**) Panoramic endoscopic view of the sphenoid sinus. (**b**) Bone removal of the sellar floor, the tuberculum sellae, and the posterior portion of the planum sphenoidale. *C* clivus, *SF* sellar floor, *PS* planum sphenoidale, *CPs* bony protuberance covering the parasellar tract of the intracavernous internal carotid artery, *CPc* bony protuberance covering the paraclival tract of the intracavernous internal carotid artery, *OP* bony protuberance covering the optic nerve, *OCR* opticocarotid recess, * sphenoid septum remnant. *DMp* dura mater of the planum sphenoidale, *DMs* sellar dura mater

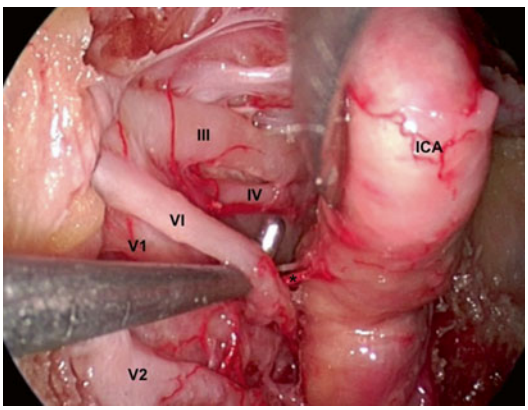

Fig. 2.3 Exploration of the cavernous sinus and medialization of the internal carotid artery. *ICA* internal carotid artery, *III* third oculomotor nerve, *IV* trochlear nerve, *VI* abducens nerve, *V1* ophthalmic branch of trigeminal nerve, *V2* maxillary branch of the trigeminal nerve, * inferolateral trunk (artery of the inferior cavernous sinus)

intracavernous segment of the ICA. Inferior hypophyseal artery divides into a medial and a lateral branch, which anastomose with the corresponding vessels of the opposite side, forming an arterial ring around the hypophysis [16, 28, 54] (Figs. 2.3, 2.4, and 2.5). The inferolateral trunk supplies all the cavernous sinus nerves, with the exception of the proximal segment of the VI cranial nerve, which receives blood from the tentorial artery. The oculomotor and trochlear nerves can be visualized from the sella through the C-shaped portion of the intracavernous sinus ICA. The oculomotor nerve enters the cavernous sinus under the posterior clinoid and then runs along the middle of the C-shaped ICA to enter into the cavernous sinus apex. At the apex, it runs along the inferior margin of the optic strut triangle until it reaches the superior orbital fissure. The trochlear nerve runs parallel and just inferior to the oculomotor nerve. When the ICA is displaced medially, the oculomotor nerve, the trochlear nerve, and the proximal and distal dural ring can be seen. The ophthalmic division of the trigeminal nerve runs obliquely in a rostral and anterior direction toward the cavernous sinus apex reaching the oculomotor and trochlear nerves at the superior orbital fissure. The abducens nerve passes through Dorello's canal approximately 5–10 mm inferior to the sellar floor at the medial aspect of the ICA and a few millimeters below the sellar floor at the lateral aspect of the ICA. The abducens nerve heads toward the orbital apex running inferiorly to the medial aspect of the ophthalmic branch of the trigeminal nerve [21, 31, 33, 34, 43] (Fig. 2.3).

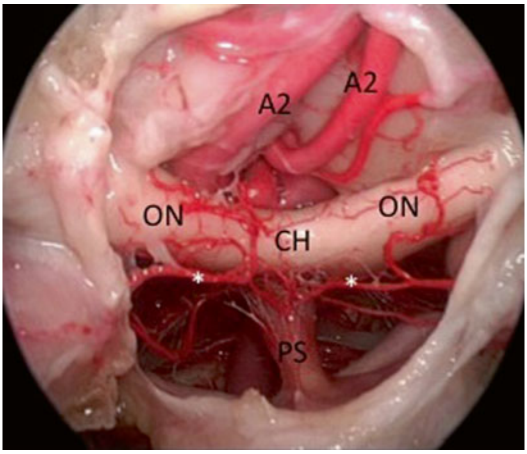

Fig. 2.4 Endoscopic endonasal view of the neurovascular structures localized above the pituitary gland. *CH* chiasm, *PS* pituitary stalk, *ON* optic nerve, *A2*, post communicating anterior cerebral artery, * superior hypophyseal artery (sha)

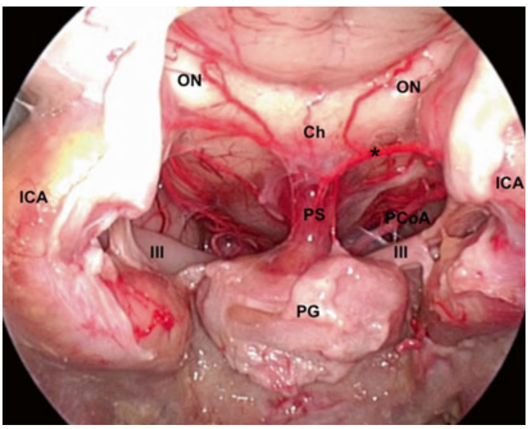

Fig. 2.5 Endoscopic endonasal view of the pituitary gland and surrounding neurovascular structures. *CH* chiasm, *PS* pituitary stalk, *Pg* pituitary gland, *ON* optic nerve, *PCoA* posterior communicating artery, *III* third cranial nerve, * superior hypophyseal artery

The exposure of the suprasellar region requires a more anterior trajectory: the posterior ethmoid cells and the anterior wall of the sphenoid sinus have to be widely removed. Above the sella, the angle formed by the convergence of the sphenoid planum with the sellar floor corresponds to the tuberculum sellae. This structure named after the classic Latin word "tuber," which etymologically means "small swelling, pimple, protuberance," appears to fit such a description when observed from above via a transcranial route, but it does not as seen from below through an endoscopic endonasal corridor. As a matter of fact, through direct visualization via an endoscopic endonasal approach, it has recently renamed "suprasellar notch" (SSN), that means "angular or V-shaped cut indentation" [29]. Indeed, in the majority of cases, the inferior point of view coincides with a sort of indentation between the superior aspect of the sella turcica and the declining part of the planum sphenoidale. Moving anteriorly, we can recognize the sphenoid planum, laterally delimited by the protuberances of the optic nerves. At this point, the bone of the suprasellar notch and the planum sphenoidale can be removed 1.5–2 cm in a posteroanterior direction and laterally up to the optic protuberances. The sellar and suprasellar dura are then opened to permit the exploration of the neurovascular structures localized above the diaphragma sellae. In the suprachiasmatic region, the chiasmatic and the lamina terminalis cisterns with relative contents are accessible. The anterior margin of the chiasm and the medial portion of the optic nerves, the anterior cerebral arteries, the anterior communicating artery, and the recurrent Heubner arteries, together with the gyri recti of the frontal lobes, can be identified. In the subchiasmatic space, the pituitary stalk is at the center of the field below the chiasm, with the superior hypophyseal artery and its perforating branches, supplying the inferior surface of the chiasm and the optic nerves. The superior aspect of the pituitary gland and the dorsum sellae are also visible. The superior hypophyseal arteries supply the optic chiasm, the floor of the hypothalamus, and the median eminence.

2.3 Neuroimaging

Magnetic resonance imaging (MRI) has replaced other techniques for the morphological study of the sellar region, because of the elevated tissue contrast and multiplanar capability. A complete MR protocol should include, at least, T1- and T2-weighted images and T1-weighted post-contrast (gadolinium) images, in the three orthogonal planes at max 3 mm sections. Complementary

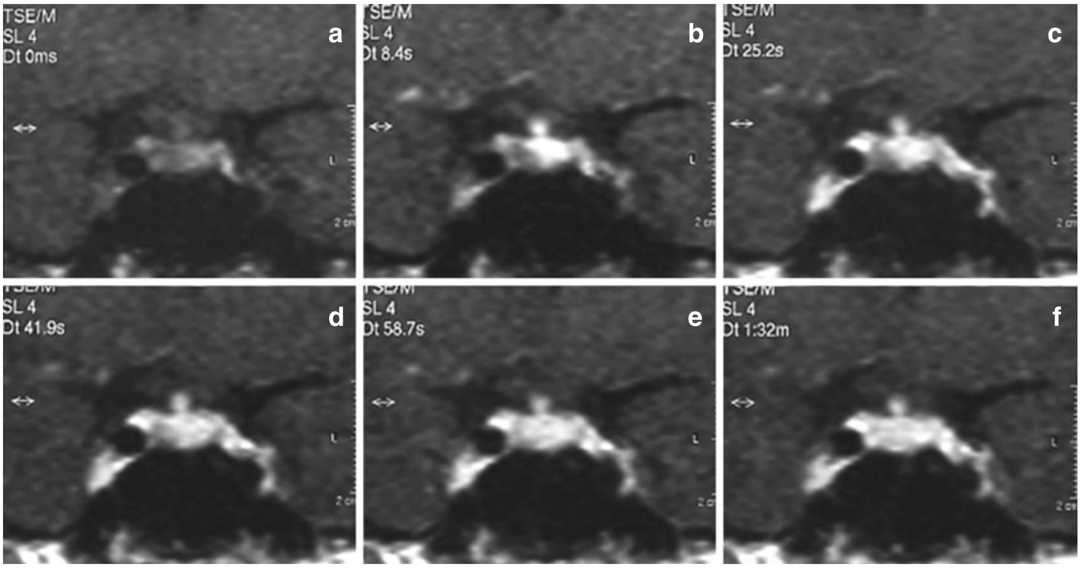

Fig. 2.6 Microadenoma. (**a**–**f**) Coronal T1-weighted dynamic images during contrast medium injection. Presence of a small hypointense area within the right lateral part of the gland, better demonstrated during the early phases of the dynamic scan (**b**–**d**), not identifiable in the delayed acquisition (**f**)

sequences, i.e., MR angiography, are also useful, especially upon the suspicion of a possible vascular nature of sellar lesion. Computed tomography (CT) should be used only in selected cases, to provide further details whether calcified components of the lesion are present, to achieve an accurate definition of the bony boundaries at presurgical planning of the approach, mainly sphenoid sinus septations. At the presurgical planning, CT remains the diagnostic imaging study of choice in patients who are unable to undergo an MR study. The purposes of the neuroradiologic study of pituitary adenomas are: to identify the lesion,; to define the spatial relationships of the lesion (presurgical planning), to monitor the medical treatment, and to clear the entity of the lesion (postsurgical follow-up) [2].

Pituitary microadenomas comprise lesions measuring 10 mm or less. They are the most common intrasellar neoplasms. The neuroradiologic diagnosis of microadenomas is drawn on the presence of indirect and direct findings. The indirect findings that should lead to diagnosis of microadenoma are: the lateral dislocation of the pituitary stalk and the alteration of the pituitary gland (upward convexity) or of the sellar floor (depression, slope, angulation). The stalk is usually found dislocated controlaterally off the tumor, but there have been reports describing homolateral stalk dislocation; as well it can be absent in contrast to tumor presence. The direct findings reveal proper MRI features of pituitary macroadenomas; they can be identified as rounded or ovular, sometimes flattened intrasellar lesions, and hypointense on T1-weighted images compared to the unaffected anterior pituitary gland (Fig. 2.6). Microadenomas can also exhibit hyperintensity on the T1-weighted images, due to the hemorrhage of a part or of whole lesion. At the T2-weighted images, pituitary microadenomas present a variety of aspects, according to the line of endocrine activity. T2 hyperintensity could be found in 80 % of prolactin-secreting microadenomas, while iso- or hypointensity is disclosed in ca 70 % of growth hormone-secreting microadenomas. The use of intravenous contrast medium injection becomes mandatory to further refine the diagnosis; upon half-dose gadolinium (0.05 mmol/kg) injection, most of microadenomas enhance less rapidly than the normal pituitary gland, appearing as hypointense areas. Late scans, 30–40 min after the injection, can sometimes show a late enhancement of the adenoma. Sometimes, in patients harboring a small lesion—particularly in case of Cushing disease—difficult to detect, specific dynamic techniques are performed to rule out diagnosis. This technique consists of repeated scans of the gland immediately upon intravenous injection of contrast medium, so that the progressive enhancement of the stalk and then of the gland is observed. The early phases of the acquisition demonstrate lesions that are not identifiable on conventional contrast-enhanced studies. In presence of clinical signs and symptoms of a functioning adenoma, with no lesion detected at the MRI, the inferior petrosal sinuses could be run to evaluate the hormonal output of the pituitary gland. This is most commonly performed in patients with Cushing's syndrome, because the corticotropin-secreting tumors may be extremely small and difficult to visualize [52].

On the other side, pituitary macroadenomas are bigger intrasellar masses, usually extending out of the sella. The aim of the neuroradiologic study is to clarify the origin side of the lesion (pituitary or not), its consistency (firm, cystic, necrotic, or hemorrhagic), and its relationships with anatomical surrounding structures. From these data an accurate differential diagnosis can be reached [11]. MRI typically demonstrates a mass arising from the pituitary fossa, completely filling the sella, which appears remodeled and enlarged. The normal pituitary tissue is compressed: after contrast medium injection, the normal gland appears as a strongly enhancing tissue, representing the pseudocapsula of the adenoma, usually posteriorly and/or on one side, between the tumor and the cavernous sinus. The posterior lobe and pituitary stalk appear more hyperintense as compressed and or displaced.

Pituitary macroadenomas may appear as homogeneous, soft-tissue masses, with variable signal intensity, often similar to gray matter. At the T2-weighted images, areas of inhomogeneous signal can be identified, because many macroadenomas harbor cystic, necrotic, or hemorrhagic components (Figs. 2.7 and 2.8). The adenoma may appear predominantly cystic, showing a typical hyperintense signal on the T1- and T2-weighted images (Fig. 2.9). Hemorrhage occurs in about 20 % of pituitary macroadenomas, revealed by spontaneous hypersignal intensity on the T1-weighted images. A fluid-fluid level can sometimes be seen within the hemorrhage, due to blood cell membranes remnants and hemoglobin residues. The clinical syndrome known as "pituitary apoplexy," representing hemorrhage into a pituitary adenoma, can be defected also on CT as hyperdense material in the pituitary fossa and possibly in the suprasellar cistern, within the lesion. MRI could differentiate various stages of the hemorrhage evolution. Small linear or curved spots, caused by hemosiderin deposits, can sometimes be found after intratumoral hemorrhage on the T2-weighted images. Concerning the consistency of the lesion, the T2-weighted scans are more helpful in providing relevant details: hyperintense lesions could be presumed as cystic, while hypointense ones as firmer. Additional data can be obtained by the diffusion-weighted imaging (DWI).

The use of contrast medium injection helps in defining the structure of the lesion, homogeneous or inhomogeneous, and the degree of its vascularization. After contrast medium, the tumor enhances moderately at early stage and retains this signal feature at later delayed scans.

The extension of the macroadenoma and its relationships with the surrounding structures constitute key-points of the neuroradiologic diagnosis. The tumor usually extends upward, to impinge and/or compress the optic chiasm, remaining subdiaphragmatic or breaching the diaphragma sellae with a typical "figure-eight" appearance, compressing the floor of third ventricle and sometimes the foramen of Monro. The adenoma can also extend downward, into the sphenoidal sinus, or laterally toward the cavernous sinus. Whether the cavernous sinus is compressed or invaded is of crucial importance for the neurosurgeon; this radiological diagnosis can be very difficult because the medial wall of the sinus is often thin and not directly visualized. The cavernous sinus invasion can be excluded in presence of normal pituitary tissue lying between the tumor and the sinus. In case of massive involvement of the cavernous sinus, complete encircling of the

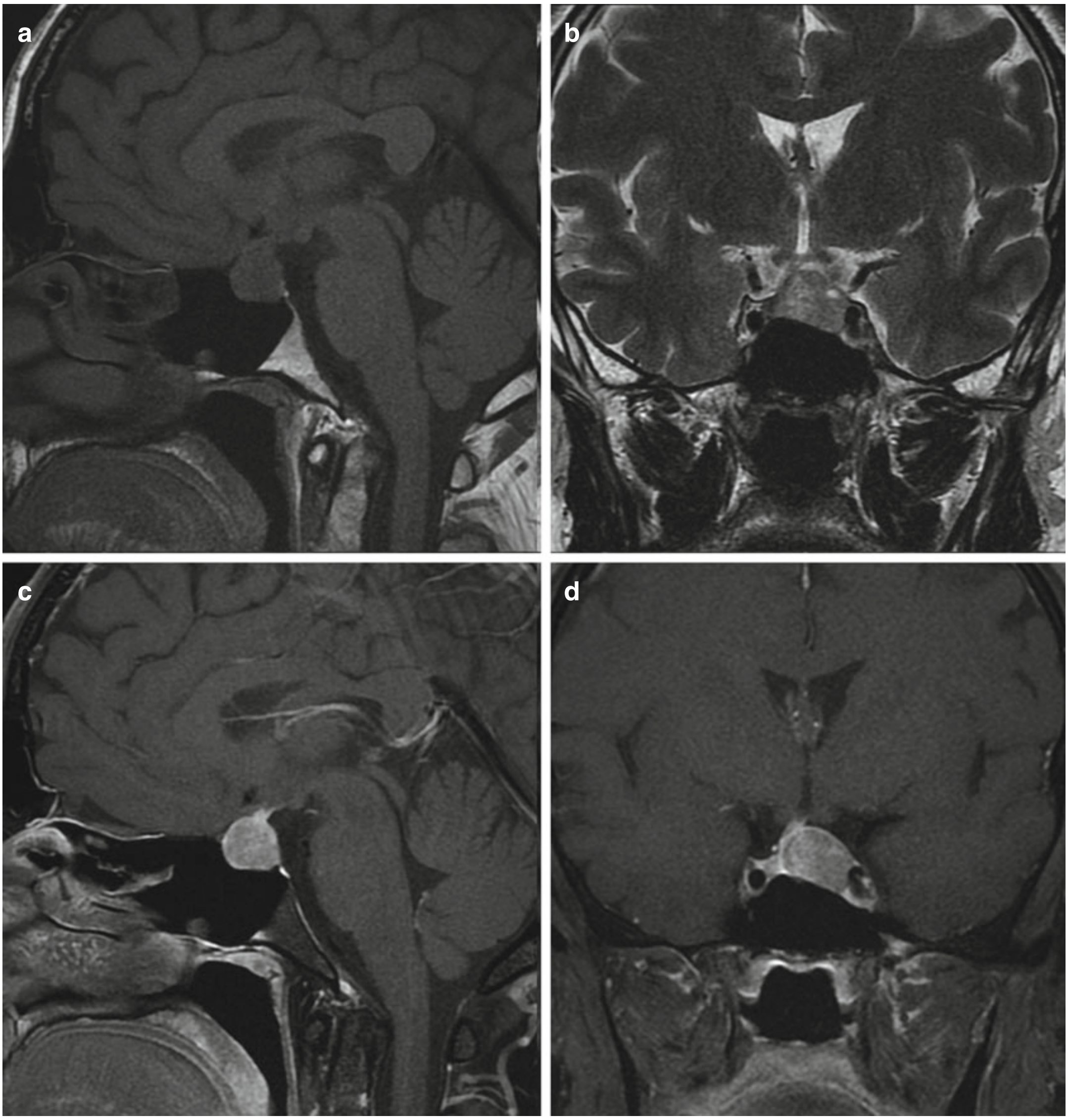

Fig. 2.7 Macroadenoma. (**a**) Sagittal T1-weighted image; (**b**) coronal T2-weighted image; (**c**–**d**) sagittal and coronal T1-weighted images after contrast medium injection. Presence of an intra- and suprasellar lesion, laterally displacing the axis and the left cavernous sinus

intra-cavernous internal carotid artery (ICA) tumor is visible and only tumor signal features are identified in this area. Prolactin or growth hormone-secreting adenomas are more often found to enter the cavernous sinus as compared to non-secreting tumors [44]. A grading system with a high predictive value for the identification of true cavernous sinus invasion has been proposed by Knosp et al., in 1993 [44] (Fig. 2.10).

The neuroradiology techniques play also an important role in evaluating the effects of the medical therapy for functioning adenomas [51].

In case of PRL-secreting adenomas, dopamine agonists can reduce the size of lesions since the 10th day of treatment and could last for several years. The shrinkage of macroadenomas caused by the medical treatment can determine the downward displacement of the optic tracts and

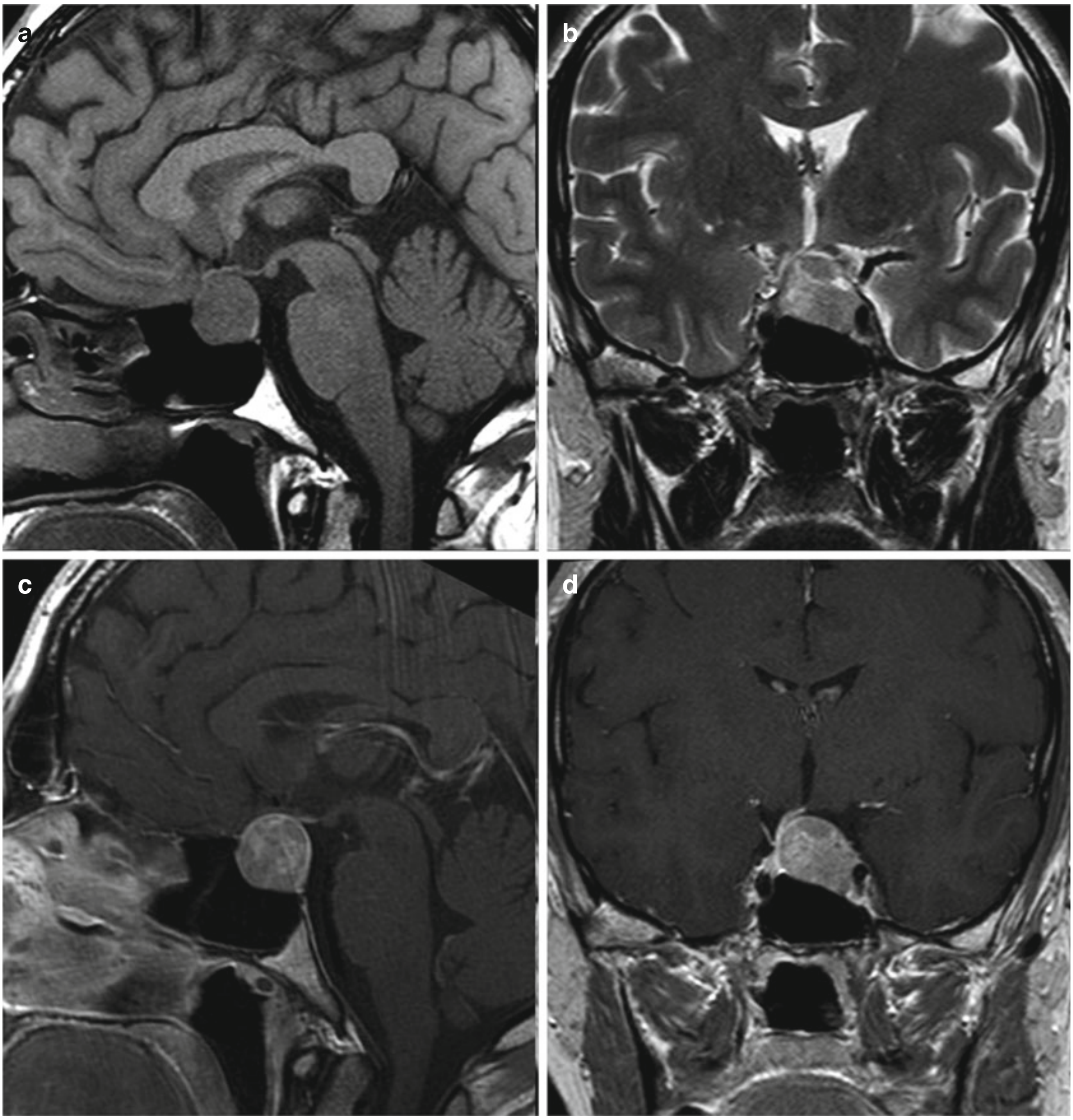

Fig. 2.8 Macroadenoma. (**a**) Sagittal T1-weighted image; (**b**) coronal T2-weighted image; (**c**–**d**) sagittal and coronal T1-weighted images after contrast medium injection. Presence of a large intra- and suprasellar lesion, clearly infiltrating the left cavernous sinus

chiasm although this usually doesn't produce symptoms. Within macroadenomas focal areas of necrosis or cysts, revealed by hypointense signal on T1-wieghted and hyperintense signal on T2-weighted images and an increasing T2 signal intensity, can occur. Hemorrhage within prolactinomas has also been observed.

It is worth reminding that, when an EEA is planned for the removal of pituitary adenoma, MRI and CT ease presurgical planning, giving details in regard to the bony boundaries of the approach, the anatomy of the nasal and paranasal sinuses, and eventual variations.

Thin-slice axial and coronal CT scans allow a detailed overview of major nasal cavities and bony structures, which are anatomical landmarks of the endoscopic route (nasal turbinates, uncinate processes, sphenoid ostium, etc.) and of the sinusal structures (symmetry and aeration of the sphenoid sinus and the relationships of the sphenoid septa with the sellar floor and carotid canal).

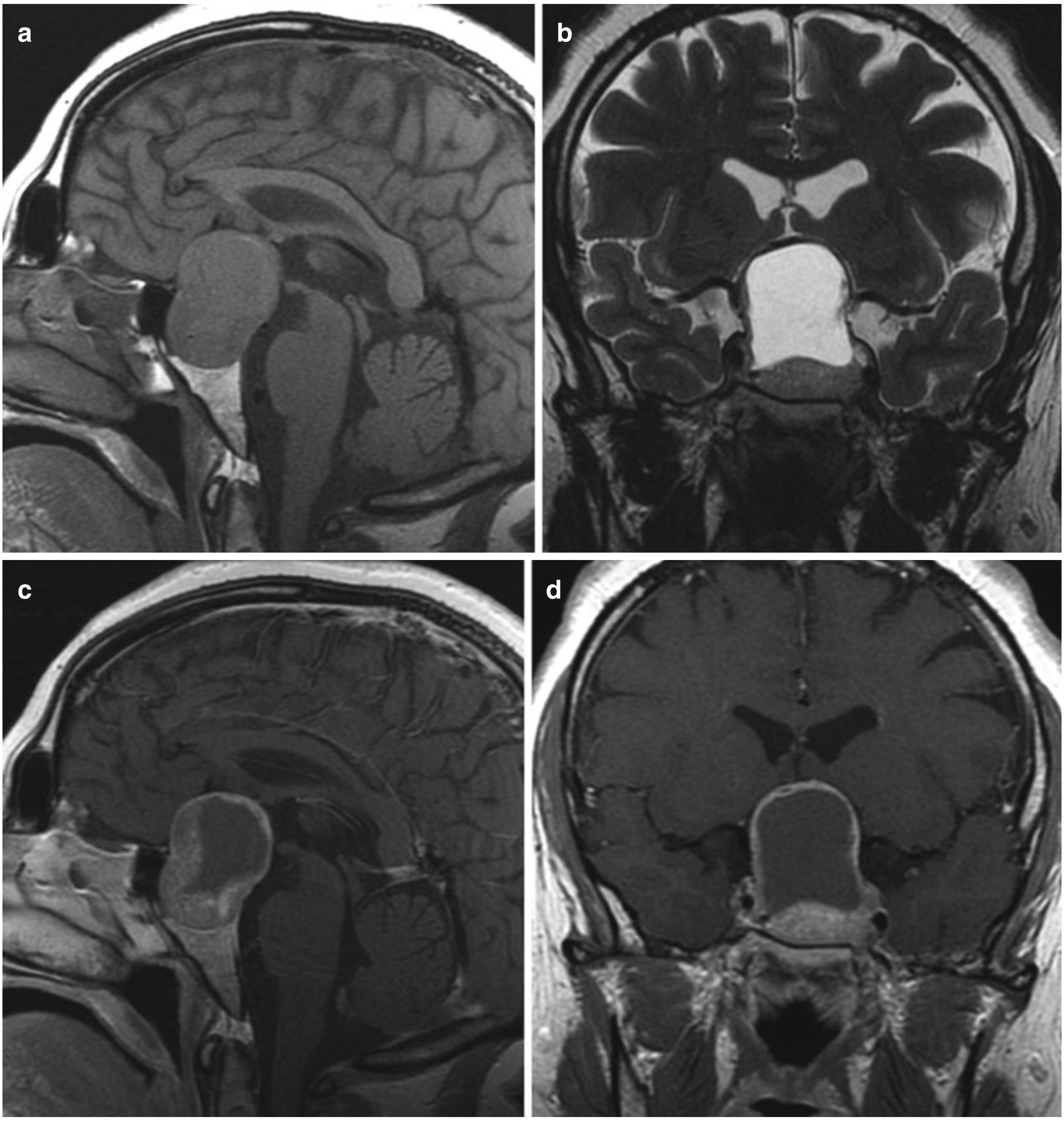

Fig. 2.9 Macroadenoma. (**a**) Sagittal T1-weighted image; (**b**) coronal T2-weighted image; (**c**–**d**) sagittal and coronal T1-weighted images after contrast medium injection. Presence of a very large intra- and suprasellar lesion with a prevalent, non-enhancing colliquative component

Finally, when MRI is adopted to diagnose any complication of surgery or to define eventual residual tumor or recurrence, the usual postoperative distortion of sellar anatomy should not be underestimated. Indeed, in the first 1 or 2 weeks following transsphenoidal resection, a sizeable "mass" may still be present; the surgical cavity is often filled with packing material (gelatin foam, autologous fat), soaked with blood and secretions, which slowly dissolves along following 2 or 3 months. The slow reduction of the "mass" in the surgical cavity, despite significant or complete removal of the tumor, reflects the reabsorption time of the reconstruction material or may represent peritumoral scars preserving the cavity from collapsing. Therefore, MRI examination should be required after 2 or 3 months after surgery (Fig. 2.11), after these changes have regressed. If fat or muscle grafts are used to reconstruct the sellar cavity, their reabsorption

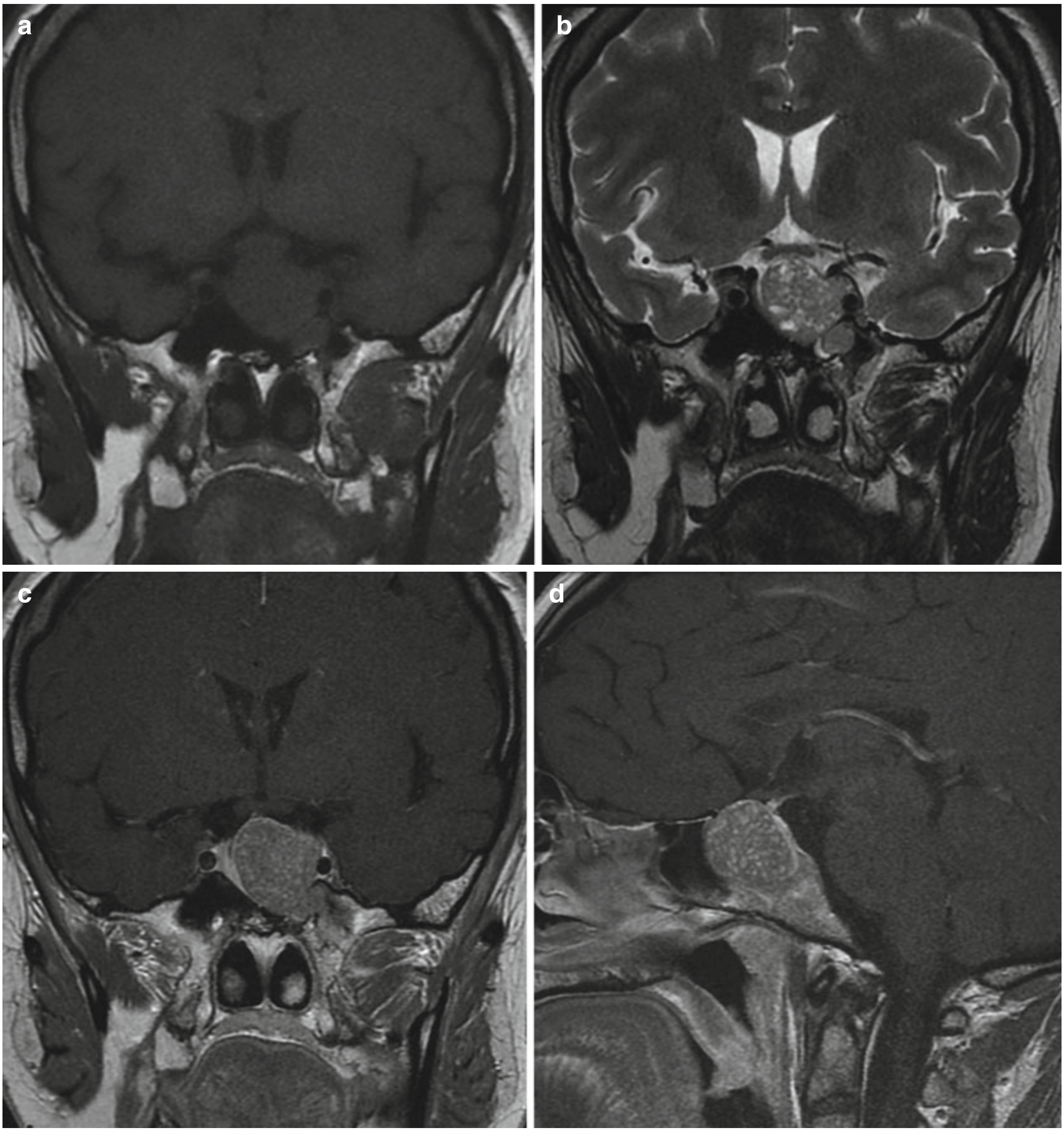

Fig. 2.10 Macroadenoma. (**a**) Coronal T1-weighted image; (**b**) coronal T2-weighted image; (**c**–**d**) coronal and sagittal T1-weighted images after contrast medium injection. Presence of a large intra- and suprasellar lesion, clearly infiltrating the left cavernous sinus and the sphenoid sinus

requires more time: that is, the fat may exhibit a hyperintense signal up to 2 or 3 years after surgery [55, 59].

2.4 Surgical Technique

Since the endoscopic transsphenoidal technique has been introduced during the 1990s, several variations of this procedure (endonasal, transnasal, single or binostril, with or without the use of the microscope, etc.) have been used worldwide for the removal of pituitary adenomas and of other variety of sellar lesions [3, 13, 32, 38, 48]. In this section we will describe the binostril procedure we currently adopt for the removal of the pituitary adenomas.

The patient is positioned supine with the trunk elevated 10° and the head turned 10° toward the surgeon seated in a horse-hole headrest.

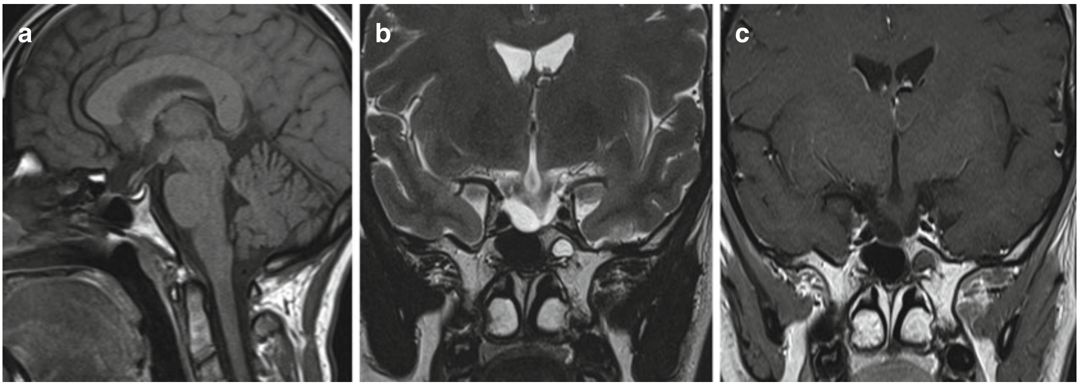

Fig. 2.11 Postoperative changes. (**a**) Sagittal T1-weighted image; (**b**) coronal T2-weighted image; (**c**) coronal T1-weighted image after contrast medium injection. The sellar cavity is completed filled by cerebrospinal fluid ("empty sella"), with downward retraction of the axis and the optic chiasm

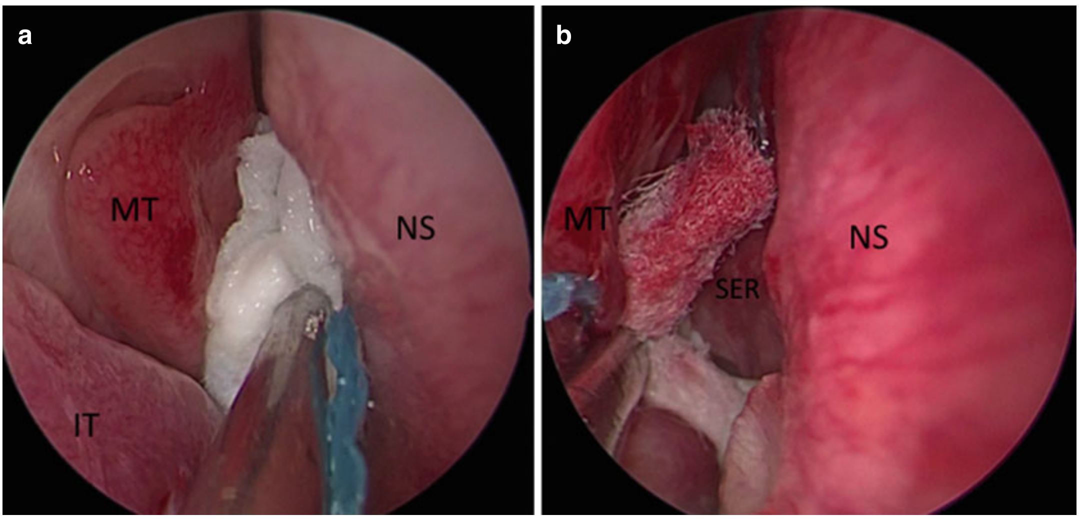

Fig. 2.12 Endoscopic endonasal intraoperative view through the right nostril (nasal phase of the approach). (**a**) Positioning of a cottonoid between the middle turbinate and the nasal septum. (**b**) Lateralization of the middle turbinate in order to reach the sphenoethmoid recess. *NS* nasal septum, *MT* middle turbinate, *SER* sphenoethmoid recess, *IT* inferior turbinate

Initially, cotton pledgets soaked in 3.5 % povidone iodine solution are placed along the floor of the nasal cavities and in the space between the nasal septum and the middle turbinates using a small Killian-type nasal speculum. Thereafter, with the same procedure described above, cotton pledgets soaked in a decongestant solution (2 ml of adrenaline, 5 ml of 20 % diluted lidocaine, and 4 ml of saline solution) are placed in order to reduce as much as possible blood tearing from the richly vascularized nasal mucosa. Though, they are left in place for ca. 10 min. Patient nose is prepped and draped and all the endoscopic equipment is set.

The endoscope is then introduced into the right nostril where it is possible to identify the inferior turbinate laterally and the nasal septum medially. The gently lateral dislocation of the middle turbinate protected with a cottonoid allows to widen the working space creating an adequate surgical corridor; sliding along the floor of the nasal cavity the choana and the sphenoethmoid recess can be identified (Fig. 2.12). A gentle monopolar coagulation of the mucosa of the sphenoethmoid recess

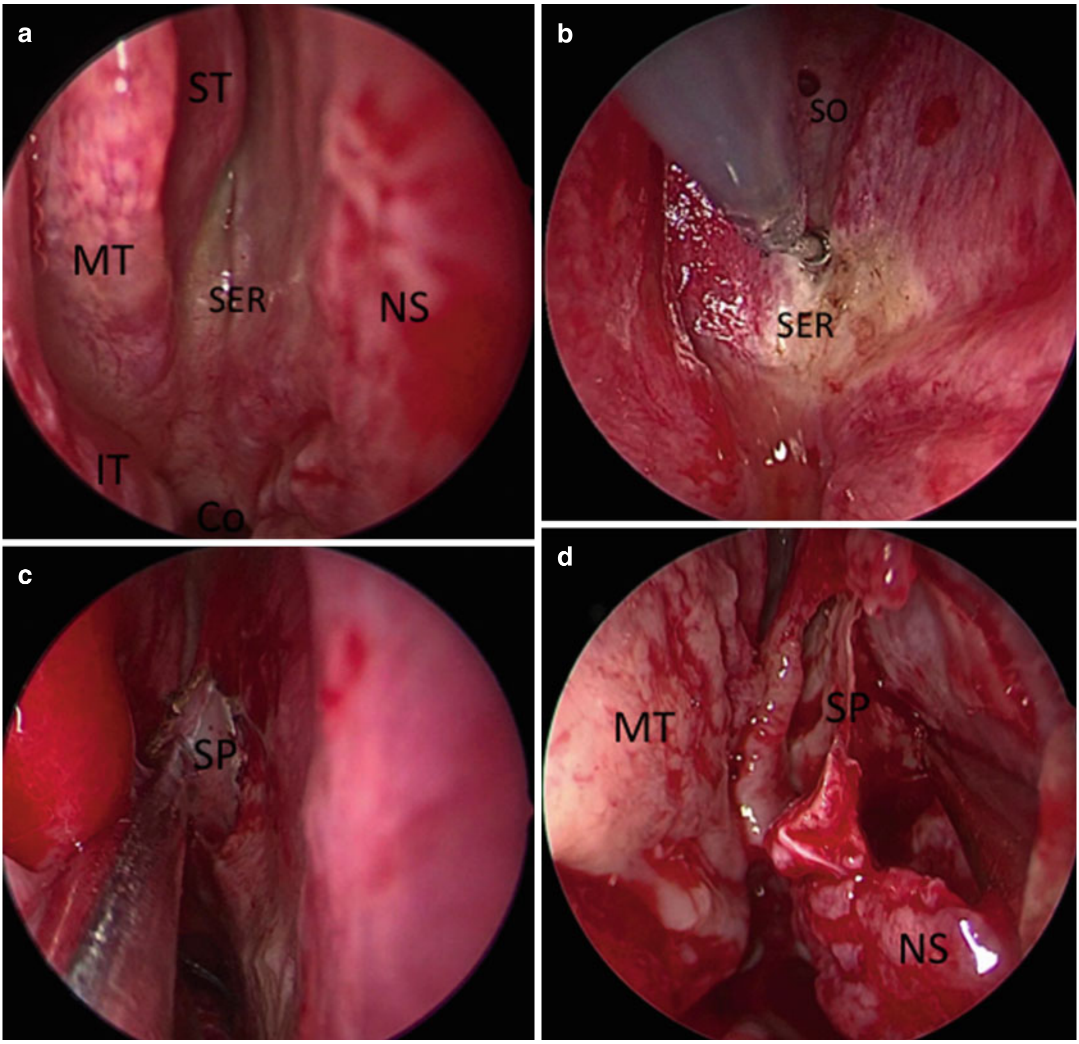

Fig. 2.13 (**a–b**) Coagulation of the sphenoethmoid recess. (**c–d**) Submucosal dissection performed in order to expose the sphenoid prow. *SP* sphenoid prow, *NS* nasal septum, *Co* choana, *MT* middle turbinate, *SO* sphenoid ostium, *ST* superior turbinate, *SER* spheno-ethmoid recess, *IT* inferior turbinate

prevents the bleeding of the septal branch of the sphenopalatine artery (Fig. 2.13). Thereafter, the nasal septum is detached from the sphenoid bone, thus allowing the exposition of the anterior wall of the sphenoid sinus; this latter is removed using a microdrill or bone punches paying particular attention in the inferolateral direction where sphenopalatine artery or its major branches lie. The wide opening of the anterior wall of the sphenoid sinus is a key point, to allow the proper maneuverability of the instruments inside the sphenoid sinus and later at the level of the sella (Fig. 2.14). An accurate check of eventual bleeding from the edges of the sphenoidotomy that could obscure the lens during the next steps has to be performed. The coagulation with bipolar forceps of the mucosa over the anterior wall of the sphenoid sinus could ensure preventing delayed bleedings.

The endoscope is then introduced in the other nostril and the mucosa of the sphenoethmoid recess is gently opened and removed after it is pushed laterally up to the roof of the nasal cavity. In this way the endoscope and another surgical instrument can be moved inside such nostril.

After the anterior sphenoidotomy has been enlarged, the removal of septa inside it permits to

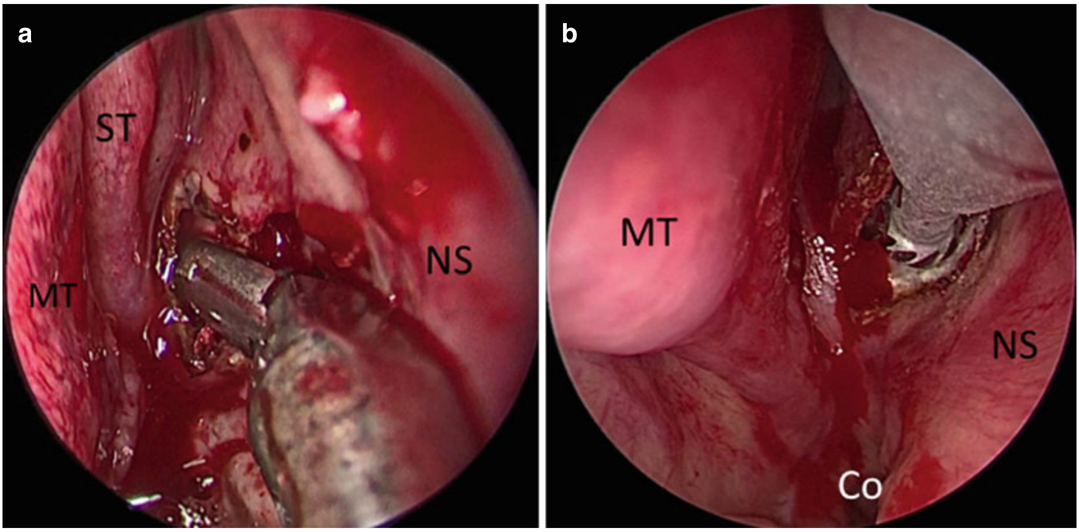

Fig. 2.14 Opening of the anterior wall of the sphenoid sinus. (**a**–**b**) Removal of the sphenoid prow. *ST* superior turbinate, *NS* nasal septum, *MT* middle turbinate, *Co* choana

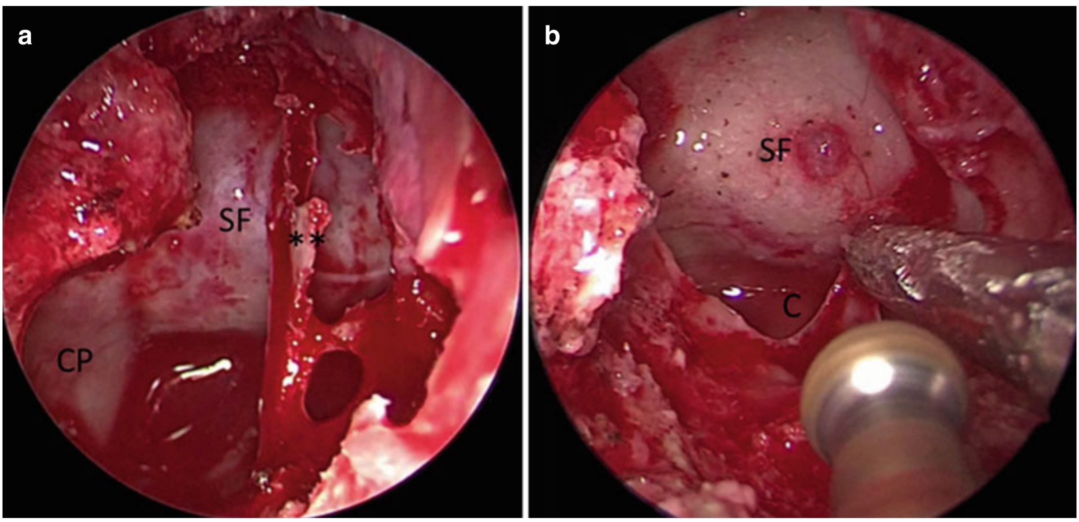

Fig. 2.15 (**a**–**b**) Enlargement of the anterior sphenoidotomy. *SF* sellar floor, *C* clivus, *CP* carotid protuberance, ** sphenoid septum

identify and to expose the posterior wall of the sphenoid sinus cavity with the sellar floor at the center, the planum sphenoidale above it, and the clival indentation below; lateral to the sellar floor, the bony prominences of the intracavernous carotid artery (ICA) and the optic nerve can be seen and between them is the optocarotid recess. In those cases where the identification of all these landmarks is not possible, or whether a presellar or conchal sphenoid sinus is present, the use of neuronavigation system can be useful, especially at the beginning of the learning curve in preventing misdirection (Fig. 2.15).

From this point on, the endoscope is hold by the second surgeon allowing the first operator to move two instruments through both nostrils.

According to the anatomical conditions of the sellar floor (intact, eroded, thinned), it can be

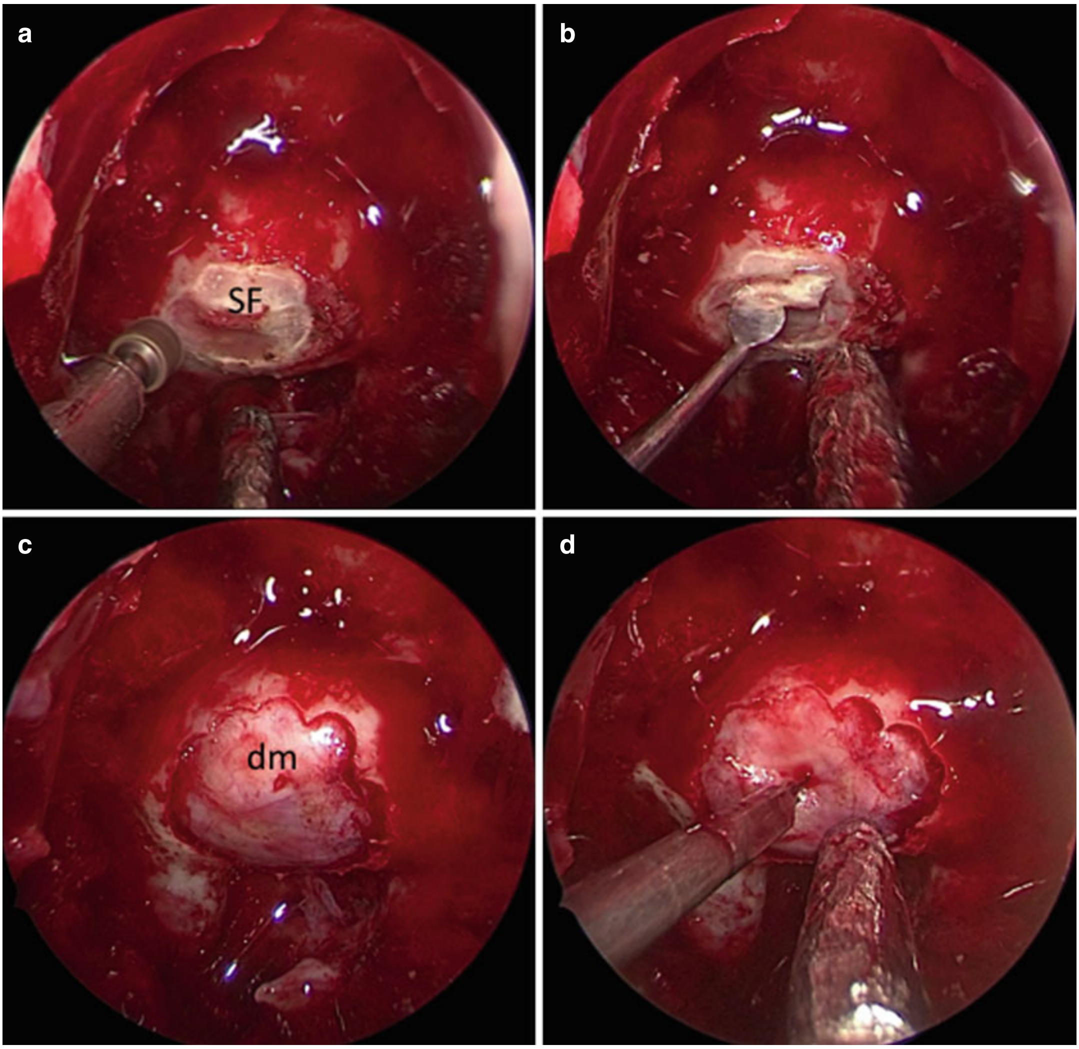

Fig. 2.16 (**a**) Drilling of the sellar floor, (**b**) enlarging the opening of the sellar floor, (**c**–**d**) incision of the dura mater using a scalpel with a telescopic blade. *SF* sellar floor, *dm* dura mater

opened in different ways and it is possible to extend the opening as required by the volume and the extension of the adenoma (Fig. 2.16). During this maneuver, care must be taken in avoiding injury of the underlying dura, which later can be incised in a linear, rectangular, or cruciate fashion. In patients with macroadenomas, inferior and superior cavernous sinuses are usually compressed making the dural incision almost bloodless; in case of microadenoma not so rarely, the inferior and/or superior intercavernous sinus has to be coagulated in order to perform an adequate dural opening.

The removal of macroadenomas must start from the inferior and lateral aspects of the lesion in order to avoid the premature delivery of the redundant diaphragm into the sella that could reduce the chance of a radical tumor removal.

After intracapsular debulking of the adenoma, its pseudocapsule can be dissected from the suprasellar cistern; it should be reminded that as the macroadenoma grows, it often stretches the residual pituitary so that it appears as a thin layer of tissue surrounding the adenoma. Nevertheless, the removal of this tissue could cause postoperative hypopituitarism (Figs. 2.17 and 2.18).

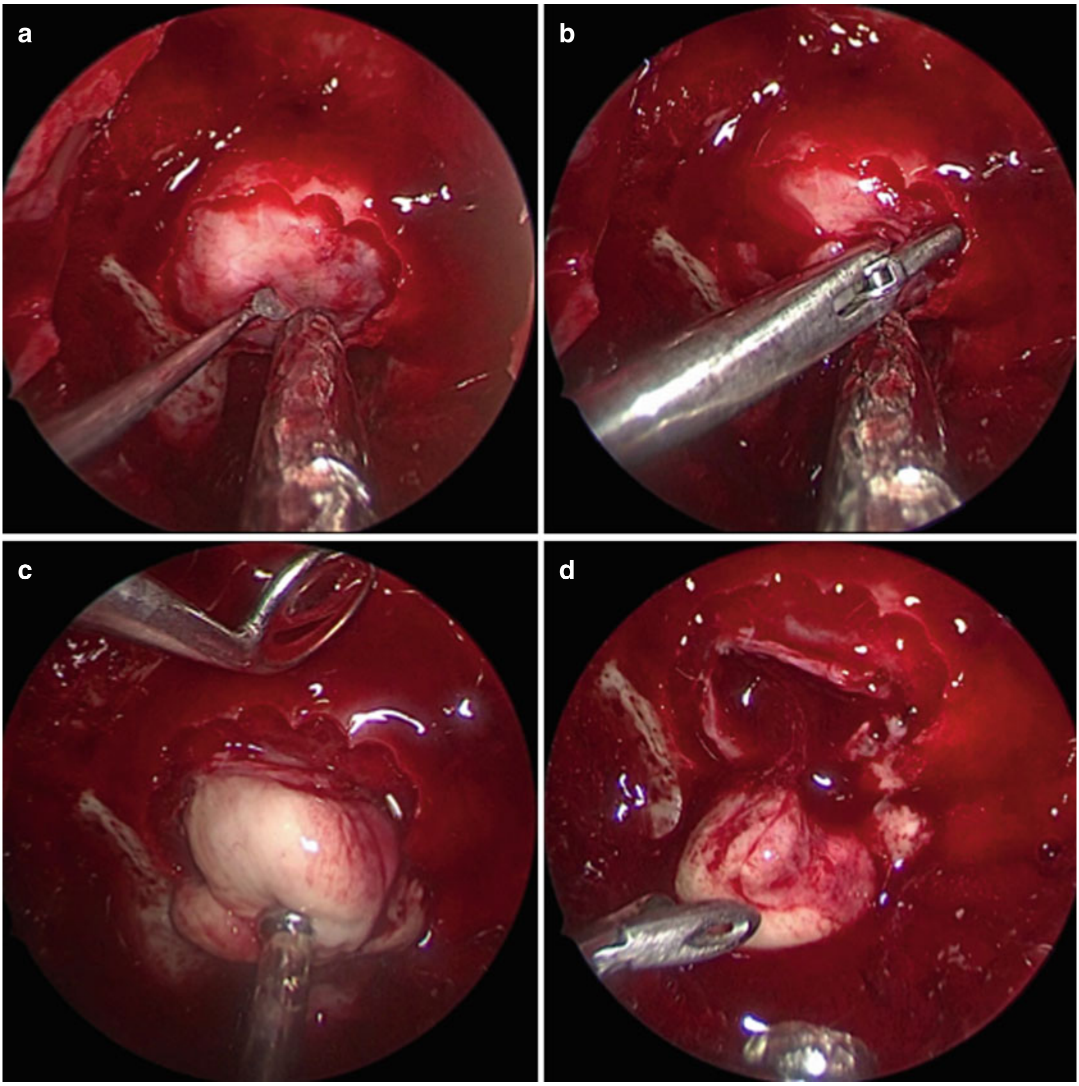

Fig. 2.17 (**a–b**) Opening of the sellar dura. (**c–d**) Extracapsular dissection and removal of the adenoma

Once the adenoma has been removed, if the descent of the suprasellar portion of the lesion is not obtained, a Valsalva maneuver can be useful (Fig. 2.19). In order to check if residual tumor is still present, the use of closeup intrasellar exploration with a 0° or angled endoscopes (30 or 45°) allows to visualize all the blind angles inside the sella. Recently, the so-called diving technique [50] that consists in the continuous irrigation into the residual cavity through the irrigation sheath of the endoscope allowing the surgeon to enter the death space filled with saline solution gives the opportunity to explore it and to eventually remove micro-residual of the lesion.

For lesions extending through the medial wall of the cavernous sinus, the removal can be performed using a curved suction cannula gently following the space within venous channels created by the lesion itself.

After tumor removal, reconstruction is properly achieved addressing the following principles: (1) protection of the suprasellar cistern; (2) filling of the "dead space," i.e., the residual sellar cavity; and (3) closure of the osteodural sellar

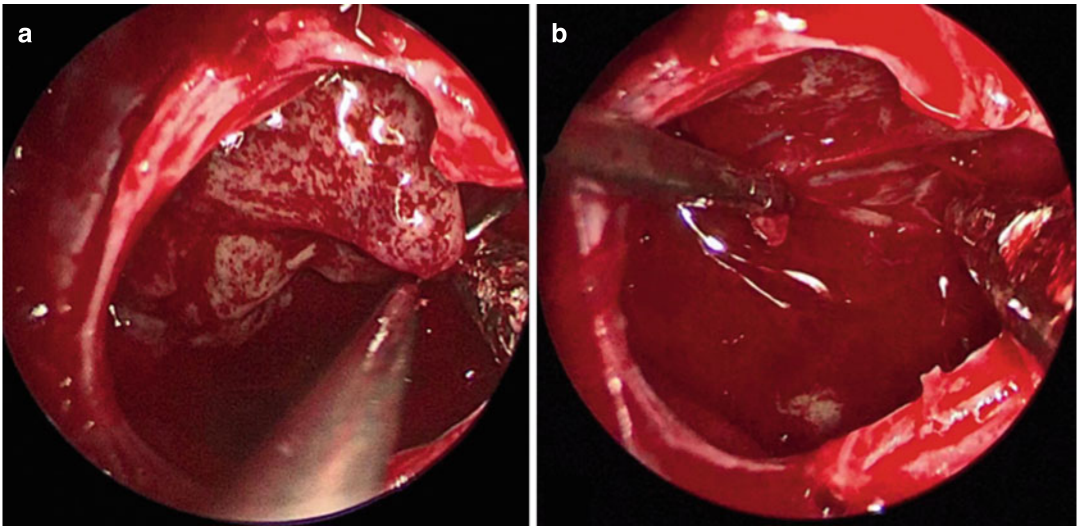

Fig. 2.18 (**a**–**b**) Dissection and removal of the tumor adherent to the suprasellar cistern

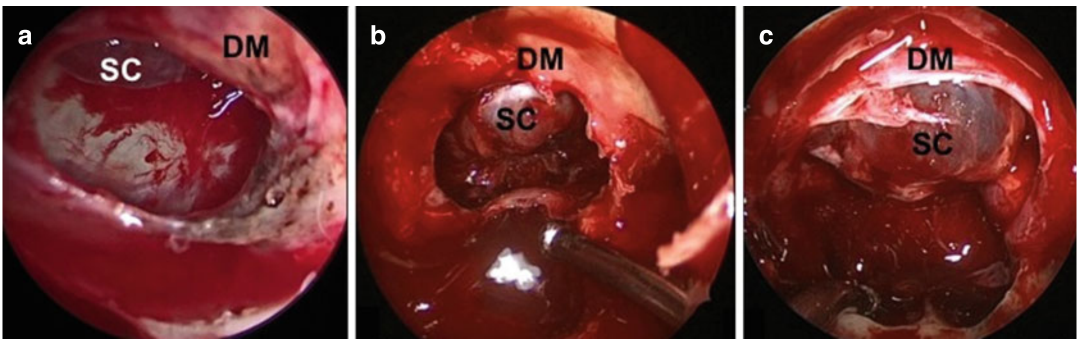

Fig. 2.19 (**a**–**c**) Different grade of descent of the suprasellar cistern after the removal of intra- and suprasellar macroadenomas in three different cases. *DM* dura mater, *SC* suprasellar cistern

defect. When no intraoperative CSF leak has occurred, it is possible to perform the reconstruction just protecting the suprasellar cistern with collagen sponge and fibrin glue to fill the eventual dead space. In case of intraoperative CSF leak, various techniques could be adopted to achieve an effective reconstruction depending mainly upon the size of the osteodural defect and of the "dead space" inside the sella. Besides the protection of the suprasellar cistern, a fat graft or pieces of collagen sponge can be positioned into the sellar cavity minding to avoid overpacking avoiding compression of the optic system. Different layers of dural substitute are positioned later in the intradural and above all extradural spaces to complete the sellar closure. It must be underlined that a good reconstruction starts from the sellar sealing. Therefore, generally it is important to preserve a good extradural plane in which the dural substitute foils should be wedged during the reconstruction. The extradural reconstruction of the sellar floor is considered the most effective in preventing postop CSF leak. Rarely, a nasoseptal pedicled flap is adopted for the reconstruction of the sella after standard endoscopic pituitary surgery or lumbar drainage is used [9, 12, 46] (Fig. 2.20).

At the end of the procedure, hemostasis along the basis of the anterior sphenoidotomy is performed and eventual bone residuals or blood

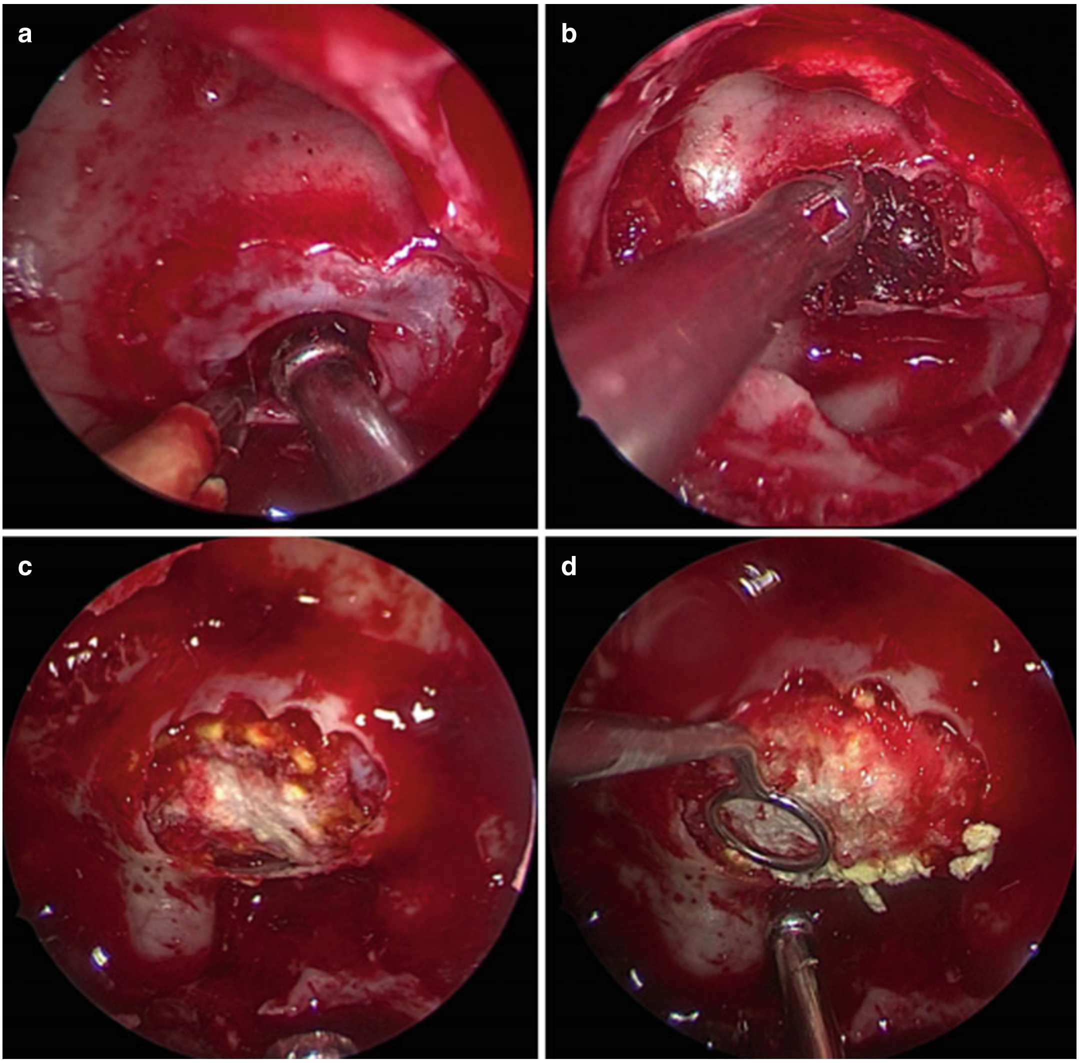

Fig. 2.20 Reconstruction of the sellar defect. (**a**) Coagulation of the inferior intercavernous sinus. (**b**) Hemostatic agent is placed to fill the sellar cavity. (**c–d**) Pieces of collagen sponge soaked with thrombin are positioned in the extradural space

clots are removed from the choanae and the rhinopharynx. Then, moving the endoscope backward, the middle turbinates are repositioned medially. Usually no nasal packing is required.

2.4.1 Extended Approaches

The exposure of the suprasellar area through an extended approach becomes necessary for those macroadenomas directly and extensively invading this area, breaching the diaphragma sellae.

A wider opening of the upper portion of the anterior wall of the sphenoid sinus is required and it can be obtained by removing the superior and/or the supreme turbinates and the opening of the posterior ethmoid cells, mostly in the nasal cavity where the endoscope will be introduced and hold by the assistant. This will allow reducing conflict between the endoscope and the surgical instruments that has to be moved along a more anterior trajectory and reach a deeper surgical target.

Once the sphenoid cavity is exposed and all the landmarks already described are recognized, the removal of the suprasellar notch and of the posterior planum sphenoidale is realized. The opening can be extended in a posteroanterior direction up to 1.5–2 cm, never beyond the anterior wall of the sphenoid sinus. Laterally, the boundaries of bone removal are represented by the protuberances of the optic nerves that, at the level of the suprasellar notch, are distant ca. 14 mm (ranging from 9 to 24 mm); therefore, the opening of the planum will have the shape of a trapezium with the smaller base posteriorly. In such cases, the superior intercavernous sinus is often obliterated as compressed by the lesion. Dura mater opening starts from the midline and diverging in a Y-shaped cut over the planum to permit the exploration of the neurovascular structures localized above the diaphragma sellae. The adenoma removal starts from the inferior and the lateral aspects as for standard pituitary adenomas. The suprasellar part of the lesion is then debulked and its capsule, dissected from the surrounding neurovascular structures, using microscissors and sharp dissection from arachnoid, as in conventional microsurgical technique. The extended approach gives the advantage of a double surgical corridor for the management of the suprasellar portion of the lesion: the first, intracapsular, allows the debulking of the adenomas, and the second, extracapsular, permits the dissection of the capsule from the surrounding neurovascular structures. This is of utmost importance, especially in case of giant adenomas with prevalent intracranial extension, to achieve safe management of the lesion, thus preventing the possibility of intralesional hemorrhage of residual tumor that often results in severe complications, seldom to death [10, 16, 30, 40, 45].

In case of adenomas extending into the cavernous sinus, it has to be highlighted that two different surgical corridors have been described to gain access to different areas of the cavernous sinus, in regard to the position of the intracavernous carotid artery (ICA); one permits access to the cavernous sinus through its medial wall, while the other one through its lateral wall. If the tumor itself enlarges the C-shaped parasellar segment of the intracavernous internal carotid artery, it could be easier to adopt a medial corridor and remove the lesion by mean of suctioning and curettage. The approach to the lateral compartment of the cavernous sinus is more rarely indicated, in those cases involving the entire cavernous sinus, i.e., Knosp grade 4 adenomas. Such tumors occupying mainly the lateral compartment of the cavernous sinus usually displace the ICA medially and push the cranial nerves laterally invading the lateral recess of the sphenoid sinus, which could be considered a "gate" to the cavernous sinus. The surgical approach requires the flattening of the pterygoid process and of the bone enclosed between the vidian canal and the foramen rotundum at the level of the anterior wall of the sphenoid sinus, in order to gain a wider exposure of the lateral recess of the sphenoid sinus. Delicate maneuvers of curettage and suction usually allow the removal of the lesion, in the same fashion as for the intrasellar portion [31, 33, 34].

When extending into nasal or paranasal cavities, giant adenomas have to be approached via a lower trajectory. The surgical approach has to be tailored to the extension of the lesion so that nasal and/or paranasal structures have to be widely removed to improve the width of the surgical field and the maneuverability of surgical instruments.

After removal of the lesion, the skull base defect must be repaired. In case of adenomas with a prevalent intra- or infrasellar extension, the reconstruction does not require peculiar strategies, namely, when the suprasellar cistern has not been violated (this latter has anyway to be protected). On the other hand, when the suprasellar cistern has been opened, i.e., after removal of giant adenomas with predominant intracranial extension, the reconstruction of the osteodural defect with multilayer technique is required; the same technique used for craniopharyngiomas or tuberculum sellae meningiomas has to be adopted. Recently we adopt the "sandwich technique" in the reconstruction of the skull base: the surgical cavity is filled with fat sutured to the inner foil of a three-layer assembly of fascia lata or dural substitute; the first two layers are positioned intradurally and the third one between the dura and the bone, wedged in the extradural space. A pedicled nasoseptal flap as described by Hadad and popularized by Kassam is used to support the reconstruction [18, 36, 37, 41, 42, 49].

Mucoperichondrium of the middle turbinate can be used as well in case of moderate intraop CSF leak and quite small skull base defect.

An inflated Foley balloon catheter, filled with 7–8 ml of saline solution, can be placed in the sphenoid sinus to support the reconstruction.

It is still controversial if the use of lumbar drainage is recommended.

2.4.2 Complications

Complications after endoscopic endonasal transsphenoidal surgery can be listed according to the anatomical region involved into the approach so that nasal, sphenoid sinus, sellar, suprasellar, and parasellar complications can be analyzed.

Nasal complications consist prevalently in the delayed bleeding from a branch of the sphenopalatine artery or in scars/crusting into the nostrils (usually after some extended approaches). In the first case, nasal packing or reoperation with coagulation of the sphenopalatine artery can be proposed, while the resolution of scars/crusting is usually achieved by irrigation of the nasal cavities with saline solution or in case of persistent ones with an endoscopic exploration of the nasal cavities and with aerosol therapy.

Concerning the sphenoid sinus complications, mucocele formation and sphenoidal sinusitis are described. In these cases the aerosol therapy can be advised. The reoperation must be considered only in symptomatic patients.

With regard to sella turcica complications, CSF leakage is the most common, even if its rate in the standard approaches is about 1 %. On the other hand, in the extended approaches, it reaches 4–5 %. When it occurs, a reoperation for a new reconstruction of the skull base is mandatory. In case of minimal discontinuous leak, it is possible to adopt the so-called awake sealant endoscopic endonasal technique [19].

There is a wide range of supra and parasellar complications depending of the anatomical, physiological, and biological features of the lesions treated. The most feared is the meningitis; this can be treated with targeted antibiotic therapy. Visual complication following optic chiasm or oculomotor nerves injuries can occur and usually could improve upon corticosteroid treatment. After an extended approach to the suprasellar region, massive pneumocephalus can be present; it usually requires bed rest and radiation therapy and CT scan have to be performed to evaluate the air reabsorption.

Although extremely rare, the injury of the internal carotid artery represents a serious intraoperative complication that can compromise surgery. Immediate sphenoid packing must be performed, so that angiography and the eventual stenting or embolization procedure could be run.

Finally, among the endocrinological complications, it should be reminded that posterior pituitary disfunction, as well as anterior pituitary defects, can occur thus leading to transient or permanent diabetes insipidus which can be managed with vasopressin administration [1, 5].

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