Making the Transition from Microsurgery to Endoscopic Trans-Sphenoidal Pituitary Neurosurgery

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KEYWORDS

• Microsurgery • Trans-sphenoidal pituitary neurosurgery
• Endoscopic

Endoscopic technology has revolutionized surgical approaches to the paranasal sinuses and the skull base. Initially limited in its scope of applications, the accepted indications for the use of the endoscope to address various disease pathologies is increasingly being adopted and advocated by both skull base surgeons and patients.[1] The evolution of endoscopic trans-sphenoidal pituitary surgery is the natural development and extension of endoscopic technology to the standard microscopic trans-sphenoidal approach to pituitary surgery.[2–7]

While endoscopy provides some inherent advantages in its ability to visualize areas of the sella that are otherwise obscured in the microscopic approach, most neurosurgeons were trained to use the microscope for pituitary surgery, and adoption of endoscopic techniques has been limited to date. There are several potential reasons, including unfamiliarity with the equipment and view. At the authors' institution, a punctuated transition from the traditional, endonasal microscopic technique to the two-surgeon, endonasal endoscopic technique occurred in early 2008. This article reviews the published experience of others plus introduce our insights into the development of an endoscopic pituitary program. While initially challenging, this transition to endoscopic trans-sphenoidal pituitary surgery can yield rewards in the form of superior visualization and potentially more complete tumor resections. The question of whether improved surgical outcomes and reduced complications will materialize will require a comparison of a large series of patients with long-term follow-up.

TRANS-SPHENOIDAL PITUITARY SURGERY

The intimate proximity of the pituitary gland to critical structures in this central location presents unique challenges in the surgical management of pituitary pathology. Victor Horsley is commonly credited with the first successful transcranial surgical management of a pituitary lesion in the late 1800s.[1,7–10] Subsequently, Schloffer is noted to have reported the first trans-sphenoidal approach for tumor removal.[1,7–9,11,12] Cushing introduced the trans-septal trans-sphenoidal procedure in 1910, and in his series reported difficulty with suprasellar extending tumors, poor

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illumination, and cerebrospinal fluid (CSF) leakage, which led to the abandonment of this approach by Cushing and his colleagues.[7,8,12–14]

In the late 1950s, Guiot reintroduced this approach with the enhancement of intraoperative fluoroscopy, which permitted an improved ability to guide instruments to the sella and an improved ability to achieve total tumor resection.[7,8,14] Hardy is credited with revolutionizing and re-establishing the trans-sphenoidal approach in the 1960s by combining intraoperative fluoroscopy with the use of the operative microscope.[1,7,9,12,15–18] The introduction of the microscope to pituitary surgery introduced the modern era of trans-sphenoidal surgery, and the wide adoption of the trans-sphenoidal approach to pituitary lesions.[1,9,13,15,17,18] Improving visualization with fluoroscopy and microscopy improved the safety and efficacy of pituitary surgery, which was refined over the subsequent 40 years.[11,12,19–41]

The surgical technique with the microscopic approach is largely limited by the narrow corridor of the nasal speculum. The width of this corridor is a function of the approach, with the purely endonasal approach[42–44] generally necessitating a narrower speculum compared with the traditional sublabial technique. The speculum creates a line-of-sight view of the sella. For intrasellar microadenomas, the surgeon is provided with complete visualization of the entire tumor with some degree of stereoscopic perspective. For larger macroadenomas, however, the field of view can be incomplete.

Because the surgeon may be unable to directly visualize the entire tumor, various blind resection techniques are used. Sweeping motions with various angled pituitary curettes can effectively deliver soft tumor tissue, particularly if aided by a descending diaphragma sella. There are situations, however, in which the probability of an incomplete resection increases. These include a limited sellar bony opening, particularly exacerbated by an incompletely pneumatized sphenoid sinus.[11,12,19–41,45–48] Firm, rubbery tumors can be particularly challenging, especially if adherent to surrounding structures. In general, invasive tumors within the cavernous sinus have been considered off limits with the speculum-based, microscopic approach.

ENDOSCOPIC TRANS-SPHENOIDAL PITUITARY SURGERY

Over the past decade, with the improvements in digital video, optics, light sources, and video monitors, endoscopic trans-sphenoidal pituitary surgery has emerged as an important innovation in pituitary surgery.[13,49–51] To some, the endoscope is simply an alternative visualization device used instead of the microscope. In many cases, surgeons have opted to use the endoscope in lieu of the microscope, performing the operation in essentially an identical manner. Although angled-lens endoscopes may offer some added value to visualize residual tumor, a smaller sellar opening and exposure is a common limiting factor. In some cases, a hybrid endoscopic-assisted approach is used, essentially augmenting the view, but not the approach, to the sella. Some of the published series of endoscopic pituitary surgery use this limited approach. Whereas the surgical endoscope is an alternative visualization device relative to the microscope, its use allows a virtually completely different surgical approach for larger tumors.

Trans-sphenoidal endoscopic approaches range from:
Endoscopic-assisted surgery using a speculum;
Single-surgeon single-nostril endoscopy with limited sellar opening
Single-surgeon, single or dual nostril endoscopy with expanded exposure
Dual-surgeon, dual nostril expanded approach (so-called expanded, endoscopic endonasal approach, or EEEA[52,53]).

The authors adopted EEEA at their institution in early 2008.

The EEEA is a fundamentally different surgical approach compared with the traditional speculum-based transnasal trans-sphenoidal. In the authors' experience, the removal of a pituitary tumor is more akin to removing a convexity meningioma. It is based on several key concepts. First is wide (expanded) exposure of the entire extent of the tumor involvement. For example, tumor involvement of the anterior cranial fossa requires removal of the tuberculum sella and possibly the planum sphenoidale, whereas wide exposure of the dura over the cavernous sinus is required for tumors involving that compartment. To do so, extensive drilling of the sphenoid sinus is often required, so much so that this technique is more invasive than other so-called minimally invasive techniques. Just as blind dissection is generally unacceptable with open craniotomy approaches to tumors, the same philosophy is applied to pituitary and other parasellar tumors.

A second concept relates to using routine microsurgical techniques, including bimanual manipulation and dissection of neurovascular structures and tumor tissue under direct visualization. The binostril approach allows more degrees

of freedom compared with uninostril and endonasal speculum-based approaches. In addition, the endoscope allows the use of standard microsurgical instruments, including the Rhoton microdissectors (Codman, Raynham, MA, USA) and ultrasonic aspirators.

To maintain constant visualization of the area of dissection, the authors use the dual-surgeon technique (**Fig. 1**). One surgeon holds the endoscope, constantly moving the endoscope to maintain the surgical field centered, as well as avoiding conflict with the instruments used by the surgeon removing the tumor. By using various angled endoscopes, areas not visualized by other approaches can be safely accessed.[4–6,9,54–57] This improved visualization may enhance the identification of critical neurovascular structures, which may reduce the complications of pituitary surgery and may improve tumor resection by identifying residual tumor in the sella.[4–6,9,12,13,55,56,58–73] Endoscopic trans-sphenoidal pituitary surgery also may reduce blood loss and improve operating time for difficult pituitary procedures.[3–6,60,74] This may be due to the reduced injury to the nasal and septal mucosa, which may result in less bleeding.[74] Hence, endoscopic trans-sphenoidal pituitary surgery may allow for access to the sella more quickly and smoothly, and provide enhanced visualization, particularly of the region near the sella turcica.[3,55,73,74] Endoscopic trans-sphenoidal pituitary surgery also may reduce hospital stay, improve patient satisfaction, and decrease the need for postoperative nasal packing.[2,7]

The expanded exposure does impose added complexity with regard to reconstruction, particularly with patients with intraoperative CSF leaks. With small sellar openings, it is generally easier to support and buttress fat grafts. The wide drilling of the skull base with EEEA surgeries can be extensive, and therefore it may not be possible to secure bone grafts (or other substitutes) to buttress the fat (or other material) grafts. This had led to the wide use of vascularized, nasoseptal flaps for reconstruction.[75–81]

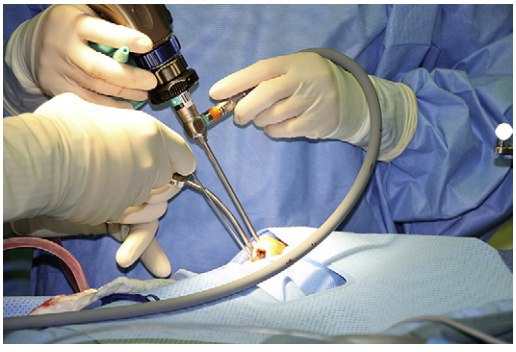

Fig. 1. The dual-surgeon technique maintains constant visualization of the area of dissection, as one surgeon holds the endoscope, constantly moving the endoscope to maintain the surgical field centered and avoiding conflict with the instruments used by the surgeon removing the tumor.

Finally, a rarely mentioned challenge with the use of endoscopes is the fact that blood, running down the endoscope shaft, can intermittently obscure the view. This requires frequent irrigation of the endoscope with saline. For surgeons accustomed to the continuous view afforded by the speculum and surgical microscope, this can be unnerving. For experienced endoscopic surgeons, this is not a serious issue. This issue should not be confused with the ability to control surgical bleeding. Although one might assume that surgical bleeding would be problematic using the endoscope, it is the authors' experience that it is far easier to control and stop bleeding with the use of the dual-surgeon, endoscopic approach. The authors routinely enter the cavernous sinus using this technique; this area is actually much harder to control using a speculum and microscope due to the fact it is not generally in the surgical field of view.

Making the Transition from the Microscope to the Endoscope

An early study by Stankiewicz initially suggested a steep learning curve to endoscopic surgery with a higher complication rate for less experienced surgeons.[82] His experience suggests a learning curve of approximately 90 cases.[83–85] Other studies also suggest a similar number for the learning curve for standardization of this novel approach and for gaining ease and familiarity with endoscopic trans-sphenoidal surgery.[63,64]

More recently, Sonnenburg and colleagues[1] reported their series of the first 45 minimally invasive pituitary cases done at the University of North Carolina by both otolaryngology and neurosurgery in joint cases. In their series, they reported an overall CSF leak rate of approximately 4% and suggested that there is not a steep learning curve to minimally invasive pituitary surgery with the collaboration between otolaryngology and neurosurgery at an academic medical center. In another retrospective analysis of the otolaryngology experience for the endoscopic trans-sphenoidal learning curve, Marks also suggested that the learning curve is not steep and that significant advancement on this curve can be achieved during residency training.[86,87] Other recent reports additionally have suggested that the learning curve to endoscopic surgery is not a steep one and that

significant advancement on this curve can occur during a rigorous residency training program.[86,88,89]

Kabil and colleagues[8] reported on their retrospective analysis of endoscopic and transseptal approaches to pituitary surgery. In their experience, they suggested that the enhanced visualization of the endoscope improves the ability to differentiate normal pituitary from tumor tissue and also permits exceptional visualization of the suprasellar and parasellar regions of pituitary tumor extension. Their series of 300 endoscopic trans-sphenoidal pituitary surgeries reported a CSF leak of less than 2% with improvement as the surgeon advances along the learning curve. Furthermore, their large retrospective analysis suggested that it may be possible to improve tumor resection and reduce complication rates using the enhanced visualization of endoscopy to trans-sphenoidal pituitary surgery.[8] Another recent report by Jarrahy and colleagues[13] in a small series of consecutive patients also suggested that tumor fragments that can only be identified endoscopically may be present in over one-third of pituitary tumor cases. In a recent large cohort, Cappabianca and colleagues[63] reported their postoperative complications in a series of 146 consecutive cases of endoscopic trans-sphenoidal surgery for pituitary adenomas. Their CSF leak rate was only 2%, and their morbidity and mortality rate was comparable to modern microscopic trans-sphenoidal results.[90]

A recent systematic review of the reported literature on endoscopic trans-sphenoidal pituitary surgery indicates that over 800 patients have now been treated with endoscopic trans-sphenoidal approaches with little morbidity and even less mortality.[9] The overall rate of CSF leak was 6% (the most common complication), and the mortality rate was 0.2% in this data analysis. This large analysis of a pooled cohort of patients suggests that endoscopic trans-sphenoidal pituitary surgery can be performed safely with minimal complications and almost no mortality. In comparison to traditionally reported results from trans-sphenoidal surgery, this meta-analysis suggests that endoscopic trans-sphenoidal surgery is similar in effectiveness and risk as traditional approaches to pituitary surgery.[2,7,9,11,12,21,37,40,90,91] It has been suggested that outcomes with endoscopic trans-sphenoidal pituitary surgery may improve as it becomes widely adopted and neurosurgeons advance along the learning curve and aggregate cumulative experience over time.[9] Among limitations of the literature reporting on endoscopic trans-sphenoidal pituitary surgery are the limited long-term results, as this approach has only been widely employed for the past decade.

Over the past 2 years, the authors have successfully made the transition from microscopic to fully endoscopic pituitary surgery at their institution, having performed over 180 operations in this time. The authors' ability to adopt this approach was facilitated by the fact that both surgeons (MB, MBW) were already adept and highly experienced with endoscopic operations.[92–103] As such, there was virtually no learning curve with respect to the use of an endoscope.

What was required in the authors' case was formal training in the EEEA technique, which they acquired over an intense 4-day hands-on course. Understanding the unique surgical anatomy, surgical techniques, and teamwork training were key to the authors' successful transition. In the authors' opinion, it is not a procedure that should be casually adopted. It requires a dedicated team, including surgical nurses and ancillary personnel familiar with the equipment and procedure.

For their team, the authors incorporated an experienced rhinologic surgeon (MBW) in these cases. Although not necessary for the surgical approach for many routine cases, the rhinologic surgeon can be invaluable for complex or repeat operations. Because the seamless dual-surgeon teamwork is most important for these difficult cases, the authors use the dual-surgeon technique for all cases. Preoperative discussion of the sinonasal sequelae of the surgery by the rhinologic surgeon is also helpful in preparing patients for expectations during the recovery period. Furthermore, they can provide the optimal postoperative care with outpatient endoscopic nasal lavages and surveillance.

One of the suggested disadvantages of the endoscopic approach to the sella is a monocular view instead of the binocular view neurosurgeons have become accustomed to, particularly among neurosurgeons who have received minimal training in the use of the endoscope.[1,2,63] These limitations, however, are mitigated with improving endoscope technologies, significantly larger high-definition visualization video screens, and the increasing incorporation of endoscopic training in neurosurgery residencies.[1,13] Dynamic interaction between the left- and right-handed instruments and coordinated movement of the endoscope give the surgeon visual and tactile clues that help to compensate for the monocular view. The authors have found that a significantly large (50 in or greater size) high-definition screen (**Fig. 2**) can be immersive in its visualization, and can mitigate many of the problems caused by the

Fig. 2. A significantly large (50 in or greater size) high-definition (HD) flat panel screen can be immersive in its visualization and may mitigate many of the problems caused by the monocular view provided by the endoscope.

monocular view provided by the endoscope. The extra space that endoscopic videos and monitors used to take now can be minimized by flat screen high definition visualization technology. Furthermore, digital imaging improvements with dual chips at the tip of the endoscope may permit three-dimensional visualization with technological advancement.[104] Lastly, as the value of endoscopic techniques becomes more apparent, the use of the endoscope during residency training may also improve, and eventually begin to incorporate virtual reality surgery training similar to what pilots use for virtual reality flight simulators in their training.[1,104]

FUTURE APPLICATIONS OF ENDOSCOPIC TRANS-SPHENOIDAL PITUITARY SURGERY

With increasing cumulative experience with the endoscopic trans-sphenoidal technique for pituitary surgery, the improved visualization and less steep learning curve will facilitate more widespread acceptance of endoscopic pituitary surgery as a valid alternative to the trans-septal trans-sphenoidal microscopic approach to pituitary tumors. If not a complete alternative, endoscopic assisted pituitary surgery will also become more widespread as endoscopy can easily supplement standard microscopic approaches to pituitary tumors. As transnasal endoscopic approaches to the skull base are increasingly refined in technology and skill, additional applications of this technology may permit skull base approaches through the planum sphenoidale and tuberculum sellae for the removal of giant suprasellar macroadenomas, which may otherwise require an open craniotomy for surgical management.[59] This extended endoscopic trans-sphenoidal approach to the skull base may expand the applications of endoscopy technology to skull base surgery.[51,87,105–107] Furthermore, robotic enhancement of endoscopic trans-sphenoidal pituitary surgery may be possible as thoracic and abdominal robotic surgery systems are miniaturized for application in endonasal endoscopic surgery.[49,50] Lastly, integration of improved optical aids and operating instruments as well as constantly improving neuronavigation may also improve the ease with which endoscopic trans-sphenoidal pituitary surgery can be learned.

Future studies should focus on technique refinement, increasing standardization, and the adoption of novel extensions and applications of this technology. The collaboration between otolaryngologists and neurosurgeons is important for further developing successful endoscopic trans-sphenoidal pituitary surgery and improving care for patients.[61–63] Objective evidence is needed to validate whether the improved visualization results in superior patient outcomes and reduced clinical complications, and if this novel technique can be reasonably taught in a controlled, supervised setting in residency training programs. Additional outcomes data are needed to evaluate long-term outcomes and define the boundaries of endoscopic trans-sphenoidal pituitary surgery.

REFERENCES

1. Sonnenburg RE, White D, Ewend MG, et al. The learning curve in minimally invasive pituitary surgery. Am J Rhinol 2004;18(4):259–63.
2. Nasseri SS, McCaffrey TV, Kasperbauer JL, et al. A combined, minimally invasive transnasal approach to the sella turcica. Am J Rhinol 1998; 12(6):409–16.
3. Cho DY, Liau WR. Comparison of endonasal endoscopic surgery and sublabial microsurgery for prolactinomas. Surg Neurol 2002;58(6):371–5 [discussion: 375–6].
4. Jho HD. Endoscopic transsphenoidal surgery. J Neurooncol 2001;54(2):187–95.
5. Jho HD, Alfieri A. Endoscopic endonasal pituitary surgery: evolution of surgical technique and equipment in 150 operations. Minim Invasive Neurosurg 2001;44(1):1–12.
6. Alfieri A, Jho HD. Endoscopic endonasal cavernous sinus surgery: an anatomic study. Neurosurgery 2001;48(4):827–36 [discussion: 836–7].
7. Sonnenburg RE, White D, Ewend MG, et al. Sellar reconstruction: is it necessary? Am J Rhinol 2003; 17(6):343–6.
8. Kabil MS, Eby JB, Shahinian HK. Fully endoscopic endonasal vs transseptal transsphenoidal pituitary surgery. Minim Invasive Neurosurg 2005;48(6): 348–54.

9. Tabaee A, Anand VK, Barron Y, et al. Endoscopic pituitary surgery: a systematic review and meta-analysis. J Neurosurg 2009;111(3):545–54.
10. Horsley V. Disease of the pituitary gland. Br Med J 1906;1:323.
11. Dew LA, Haller JR, Major S. Transnasal transsphenoidal hypophysectomy: choice of approach for the otolaryngologist. Otolaryngol Head Neck Surg 1999;120(6):824–7.
12. Ciric I, Ragin A, Baumgartner C, et al. Complications of trans-sphenoidal surgery: results of a national survey, review of the literature, and personal experience. Neurosurgery 1997;40(2): 225–36 [discussion: 236–7].
13. Jarrahy R, Berci G, Shahinian HK. Assessment of the efficacy of endoscopy in pituitary adenoma resection. Arch Otolaryngol Head Neck Surg 2000;126(12):1487–90.
14. Welbourn RB. The evolution of transsphenoidal pituitary microsurgery. Surgery 1986;100(6): 1185–90.
15. Hardy J, Wigser SM. Trans-sphenoidal surgery of pituitary fossa tumors with televised radiofluoroscopic control. J Neurosurg 1965;23(6): 612–9.
16. Hardy J. Transphenoidal microsurgery of the normal and pathological pituitary. Clin Neurosurg 1969;16:185–217.
17. Hardy J. Excision of pituitary adenomas by transsphenoidal approach. Union Med Can 1962;91: 933–45.
18. Hardy J, Vezina JL. Transsphenoidal neurosurgery of intracranial neoplasm. Adv Neurol 1976;15: 261–73.
19. Ross DA, Wilson CB. Results of transsphenoidal microsurgery for growth hormone-secreting pituitary adenoma in a series of 214 patients. J Neurosurg 1988;68(6):854–67.
20. Jane JA Jr, Laws ER Jr. The surgical management of pituitary adenomas in a series of 3093 patients. J Am Coll Surg 2001;193(6):651–9.
21. Barker FG 2nd, Klibanski A, Swearingen B. Transsphenoidal surgery for pituitary tumors in the United States, 1996–2000: mortality, morbidity, and the effects of hospital and surgeon volume. J Clin Endocrinol Metab 2003;88(10):4709–19.
22. Ciric I, Mikhael M, Stafford T, et al. Trans-sphenoidal microsurgery of pituitary macroadenomas with long-term follow-up results. J Neurosurg 1983;59(3):395–401.
23. Charpentier G, de Plunkett T, Jedynak P, et al. Surgical treatment of prolactinomas. Short- and long-term results, prognostic factors. Horm Res 1985;22(3):222–7.
24. Chandler WF, Schteingart DE, Lloyd RV, et al. Surgical treatment of Cushing's disease. J Neurosurg 1987;66(2):204–12.
25. Maira G, Anile C, De Marinis L, et al. Prolactin-secreting adenomas: surgical results and long-term follow-up. Neurosurgery 1989;24(5):736–43.
26. Mampalam TJ, Tyrrell JB, Wilson CB. Trans-sphenoidal microsurgery for Cushing disease. A report of 216 cases. Ann Intern Med 1988;109(6):487–93.
27. Tyrrell JB, Lamborn KR, Hannegan LT, et al. Transsphenoidal microsurgical therapy of prolactinomas: initial outcomes and long-term results. Neurosurgery 1999;44(2):254–61 [discussion: 261–3].
28. Guidetti B, Fraioli B, Cantore GP. Results of surgical management of 319 pituitary adenomas. Acta Neurochir (Wien) 1987;85:117–24.
29. Fahlbusch R, Buchfelder M. Present status of neurosurgery in the treatment of prolactinomas. Neurosurg Rev 1985;8:195–205.
30. Fahlbusch R, Buchfelder M, Muller OA. Transsphenoidal surgery for Cushing's disease. J R Soc Med 1986;79(5):262–9.
31. Yang SY, Zhu T, Zhang JN, et al. Trans-sphenoidal microsurgical management of pituitary adenomas. Microsurgery 1994;15(11):754–9.
32. Guilhaume B, Bertagna X, Thomsen M, et al. Transsphenoidal pituitary surgery for the treatment of Cushing's disease: results in 64 patients and long-term follow-up studies. J Clin Endocrinol Metab 1988;66(5):1056–64.
33. Boggan JE, Tyrrell JB, Wilson CB. Trans-sphenoidal microsurgical management of Cushing's disease. Report of 100 cases. J Neurosurg 1983; 59(2):195–200.
34. Davis DH, Laws ER Jr, Ilstrup DM, et al. Results of surgical treatment for growth hormone-secreting pituitary adenomas. J Neurosurg 1993;79(1):70–5.
35. Hammer GD, Tyrrell JB, Lamborn KR, et al. Transsphenoidal microsurgery for Cushing's disease: initial outcome and long-term results. J Clin Endocrinol Metab 2004;89(12):6348–57.
36. Abosch A, Tyrrell JB, Lamborn KR, et al. Transsphenoidal microsurgery for growth hormone-secreting pituitary adenomas: initial outcome and long-term results. J Clin Endocrinol Metab 1998; 83(10):3411–8.
37. Black PM, Zervas NT, Candia GL. Incidence and management of complications of trans-sphenoidal operation for pituitary adenomas. Neurosurgery 1987;20(6):920–4.
38. Tindall GT, Oyesiku NM, Watts NB, et al. Transsphenoidal adenomectomy for growth hormone-secreting pituitary adenomas in acromegaly: outcome analysis and determinants of failure. J Neurosurg 1993;78(2):205–15.
39. Tindall GT, Herring CJ, Clark RV, et al. Cushing's disease: results of trans-sphenoidal microsurgery with emphasis on surgical failures. J Neurosurg 1990;72(3):363–9.

40. Semple PL, Laws ER Jr. Complications in a contemporary series of patients who underwent transsphenoidal surgery for Cushing's disease. J Neurosurg 1999;91(2):175–9.
41. Ebersold MJ, Quast LM, Laws ER Jr, et al. Long-term results in trans-sphenoidal removal of nonfunctioning pituitary adenomas. J Neurosurg 1986;64(5):713–9.
42. Fatemi N, Dusick JR, de Paiva Neto MA, et al. The endonasal microscopic approach for pituitary adenomas and other parasellar tumors: a 10-year experience. Neurosurgery 2008;63:244–56 [discussion: 256].
43. Dusick JR, Fatemi N, Mattozo C, et al. Pituitary function after endonasal surgery for nonadenomatous parasellar tumors: Rathke's cleft cysts, craniopharyngiomas, and meningiomas. Surg Neurol 2008;70(5):482–90 [discussion: 490–1].
44. Fatemi N, Dusick JR, Gorgulho AA, et al. Endonasal microscopic removal of clival chordomas. Surg Neurol 2008;69(4):331–8.
45. Abe T, Ludecke DK. Recent primary transnasal surgical outcomes associated with intraoperative growth hormone measurement in acromegaly. Clin Endocrinol (Oxf) 1999;50(1):27–35.
46. Abe T, Ludecke DK. Recent results of secondary transnasal surgery for residual or recurring acromegaly. Neurosurgery 1998;42(5):1013–21 [discussion: 1021–2].
47. Abe T, Ludecke DK. Recent results of primary transnasal surgery for infradiaphragmatic craniopharyngioma. Neurosurg Focus 1997;3(6):e4.
48. Abe T, Ludecke DK. Transnasal surgery for prolactin-secreting pituitary adenomas in childhood and adolescence. Surg Neurol 2002;57(6):369–78 [discussion: 378–9].
49. O'Malley BW Jr, Weinstein GS. Robotic skull base surgery: preclinical investigations to human clinical application. Arch Otolaryngol Head Neck Surg 2007;133(12):1215–9.
50. Hanna EY, Holsinger C, DeMonte F, et al. Robotic endoscopic surgery of the skull base: a novel surgical approach. Arch Otolaryngol Head Neck Surg 2007;133(12):1209–14.
51. Lee SC, Senior BA. Endoscopic skull base surgery. Clin Exp Otorhinolaryngol 2008;1(2):53–62.
52. Kassam AB, Gardner PA, Snyderman CH, et al. Expanded endonasal approach, a fully endoscopic transnasal approach for the resection of midline suprasellar craniopharyngiomas: a new classification based on the infundibulum. J Neurosurg 2008;108(4):715–28.
53. Kassam A, Thomas AJ, Snyderman C, et al. Fully endoscopic expanded endonasal approach treating skull base lesions in pediatric patients. J Neurosurg 2007;106(Suppl 2):75–86.
54. Jankowski R, Auque J, Simon C, et al. Endoscopic pituitary tumor surgery. Laryngoscope 1992;102(2):198–202.
55. Cappabianca P, Cavallo LM, de Divitiis E. Endoscopic endonasal trans-sphenoidal surgery. Neurosurgery 2004;55(4):933–40 [discussion 940–1].
56. Gamea A, Fathi M, el-Guindy A. The use of the rigid endoscope in trans-sphenoidal pituitary surgery. J Laryngol Otol 1994;108(1):19–22.
57. Sethi DS, Pillay PK. Endoscopic management of lesions of the sella turcica. J Laryngol Otol 1995;109(10):956–62.
58. Helal MZ. Combined microendoscopic transsphenoid excisions of pituitary macroadenomas. Eur Arch Otorhinolaryngol 1995;252(3):186–9.
59. Schwartz TH, Stieg PE, Anand VK. Endoscopic transsphenoidal pituitary surgery with intraoperative magnetic resonance imaging. Neurosurgery 2006;58(Suppl 1):ONS44–51 [discussion: ONS44–51].
60. White DR, Sonnenburg RE, Ewend MG, et al. Safety of minimally invasive pituitary surgery (MIPS) compared with a traditional approach. Laryngoscope 2004;114(11):1945–8.
61. Cappabianca P, Alfieri A, Colao A, et al. Endoscopic endonasal trans-sphenoidal approach: an additional reason in support of surgery in the management of pituitary lesions. Skull Base Surg 1999;9(2):109–17.
62. Cappabianca P, Alfieri A, Colao A, et al. Endoscopic endonasal trans-sphenoidal surgery in recurrent and residual pituitary adenomas: technical note. Minim Invasive Neurosurg 2000;43(1):38–43.
63. Cappabianca P, Cavallo LM, Colao A, et al. Surgical complications associated with the endoscopic endonasal trans-sphenoidal approach for pituitary adenomas. J Neurosurg 2002;97(2):293–8.
64. Cappabianca P, Cavallo LM, de Divitiis E. Collagen sponge repair of small cerebrospinal fluid leaks obviates tissue grafts and cerebrospinal fluid diversion after pituitary surgery. Neurosurgery 2002;50(5):1173–4 [author reply 1174].
65. Jho HD, Carrau RL, Ko Y, et al. Endoscopic pituitary surgery: an early experience. Surg Neurol 1997;47(3):213–22 [discussion 222–3].
66. Esposito F, Cappabianca P, Del Basso De Caro M, et al. Endoscopic endonasal trans-sphenoidal removal of an intra-suprasellar schwannoma mimicking a pituitary adenoma. Minim Invasive Neurosurg 2004;47(4):230–4.
67. Cavallo LM, Briganti F, Cappabianca P, et al. Hemorrhagic vascular complications of endoscopic trans-sphenoidal surgery. Minim Invasive Neurosurg 2004;47(3):145–50.

68. Cappabianca P, Cavallo LM, Valente V, et al. Sellar repair with fibrin sealant and collagen fleece after endoscopic endonasal trans-sphenoidal surgery. Surg Neurol 2004;62(3):227–33 [discussion 233].
69. Cappabianca P, Cavallo LM, Esposito F, et al. Endoscopic endonasal trans-sphenoidal surgery: procedure, endoscopic equipment, and instrumentation. Childs Nerv Syst 2004;20:796–801.
70. Carrau RL, Jho HD, Ko Y. Transnasal–trans-sphenoidal endoscopic surgery of the pituitary gland. Laryngoscope 1996;106(7):914–8.
71. Jho HD, Carrau RL. Endoscopy assisted transsphenoidal surgery for pituitary adenoma. Technical note. Acta Neurochir (Wien) 1996;138(12): 1416–25.
72. Heilman CB, Shucart WA, Rebeiz EE. Endoscopic sphenoidotomy approach to the sella. Neurosurgery 1997;41(3):602–7.
73. Sethi DS, Stanley RE, Pillay PK. Endoscopic anatomy of the sphenoid sinus and sella turcica. J Laryngol Otol 1995;109(10):951–5.
74. Ogawa T, Matsumoto K, Nakashima T, et al. Hypophysis surgery with or without endoscopy. Auris Nasus Larynx 2001;28(2):143–9.
75. Caicedo-Granados E, Carrau R, Snyderman CH, et al. Reverse rotation flap for reconstruction of donor site after vascular pedicled nasoseptal flap in skull base surgery. Laryngoscope 2010;120(8): 1550–2.
76. Nyquist GG, Anand VK, Singh A, et al. Janus flap: bilateral nasoseptal flaps for anterior skull base reconstruction. Otolaryngol Head Neck Surg 2010;142(3):327–31.
77. Zanation AM, Carrau RL, Snyderman CH, et al. Nasoseptal flap reconstruction of high flow intraoperative cerebral spinal fluid leaks during endoscopic skull base surgery. Am J Rhinol Allergy 2009;23(5):518–21.
78. Kang MD, Escott E, Thomas AJ, et al. The MR imaging appearance of the vascular pedicle nasoseptal flap. AJNR Am J Neuroradiol 2009;30(4): 781–6.
79. Kassam AB, Thomas A, Carrau RL, et al. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. Neurosurgery 2008; 63(Suppl 1):ONS44–52 [discussion ONS52–3].
80. Pinheiro-Neto CD, Prevedello DM, Carrau RL, et al. Improving the design of the pedicled nasoseptal flap for skull base reconstruction: a radioanatomic study. Laryngoscope 2007;117(9):1560–9.
81. Hadad G, Bassagasteguy L, Carrau L, et al. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. Laryngoscope 2006;116(10):1882–6.
82. Stankiewicz JA. Complications of endoscopic intranasal ethmoidectomy. Laryngoscope 1987;97(11): 1270–3.
83. Stankiewicz JA. Complications of endoscopic sinus surgery. Otolaryngol Clin North Am 1989;22(4): 749–58.
84. Stankiewicz JA. Complications in endoscopic intranasal ethmoidectomy: an update. Laryngoscope 1989;99:686–90.
85. Stankiewicz JA. The endoscopic approach to the sphenoid sinus. Laryngoscope 1989;99(2): 218–21.
86. Marks SC. Learning curve in endoscopic sinus surgery. Otolaryngol Head Neck Surg 1999;120(2): 215–8.
87. Kuppersmith RB, Alford EL, Patrinely JR, et al. Combined transconjunctival/intranasal endoscopic approach to the optic canal in traumatic optic neuropathy. Laryngoscope 1997;107(3):311–5.
88. Kinsella JB, Calhoun KH, Bradfield JJ, et al. Complications of endoscopic sinus surgery in a residency training program. Laryngoscope 1995;105(10):1029–32.
89. Vleming M, Middelweerd RJ, de Vries N. Complications of endoscopic sinus surgery. Arch Otolaryngol Head Neck Surg 1992;118(6):617–23.
90. Laufer I, Anand VN, Schwartz TH. Endoscopic, endonasal extended trans-sphenoidal, transplanum transtuberculum approach for resection of suprasellar lesions. J Neurosurg 2007;106(3):400–6.
91. Carrau RL, Kassam AB, Snyderman CH. Pituitary surgery. Otolaryngol Clin North Am 2001;34(6): 1143–55.
92. Bergsneider M. Endoscopic removal of cysticercal cysts within the fourth ventricle: technique and results. Neurosurg Focus 1999;6(4):e8.
93. Bergsneider M. Endoscopic removal of cysticercal cysts within the fourth ventricle. Technical note. J Neurosurg 1999;91(2):340–5.
94. Bergsneider M. Complete microsurgical resection of colloid cysts with a dual-port endoscopic technique. Neurosurgery 2007;60:ONS33–42 [discussion ONS42–3].
95. Bergsneider M, Holly LT, Lee JH, et al. Endoscopic management of cysticercal cysts within the lateral and third ventricles. Neurosurg Focus 1999;6(4):e7.
96. Bergsneider M, Holly LT, Lee JH, et al. Endoscopic management of cysticercal cysts within the lateral and third ventricles. J Neurosurg 2000;92(1): 14–23.
97. Dusick JR, McArthur DL, Bergsneider M. Success and complication rates of endoscopic third ventriculostomy for adult hydrocephalus: a series of 108 patients. Surg Neurol 2008;69(1):5–15.
98. Frazee JG, King WA, De Salles AA, et al. Endoscopic-assisted clipping of cerebral aneurysms. J Stroke Cerebrovasc Dis 1997;6(4):240–1.
99. Gravori T, Steineke T, Bergsneider M. Endoscopic removal of cisternal neurocysticercal cysts. Technical note. Neurosurg Focus 2002;12(6):e7.

100. Joo D, Chhetri DK, Wang MB. Endoscopic removal of juvenile nasopharyngeal angiofibromas: a video presentation. Laryngoscope 2008;118(6):e1–3.
101. King WA, Ullman JS, Frazee JG, et al. Endoscopic resection of colloid cysts: surgical considerations using the rigid endoscope. Neurosurgery 1999; 44(5):1103–9 [discussion 1109–11].
102. Sung A, Bergsneider M, Wang MB. Transnasal endoscopic surgery of the cavernous sinus for tissue diagnosis. Laryngoscope 2010;120(2):282–4.
103. Upchurch K, Raifu M, Bergsneider M. Endoscope-assisted placement of a multiperforated shunt catheter into the fourth ventricle via a frontal transventricular approach. Neurosurg Focus 2007;22(4):E8.
104. Levy ML, Nguyen A, Aryan H, et al. Robotic virtual endoscopy: development of a multidirectional rigid endoscope. Neurosurgery 2006;59(Suppl 1): ONS134–41 [discussion ONS134–41].
105. Jho HD. The expanding role of endoscopy in skull-base surgery. Indications and instruments. Clin Neurosurg 2001;48:287–305.
106. Casler JD, Doolittle AM, Mair EA. Endoscopic surgery of the anterior skull base. Laryngoscope 2005;115(1):16–24.
107. Li KK, Teknos TN, Lai A, et al. Traumatic optic neuropathy: result in 45 consecutive surgically treated patients. Otolaryngol Head Neck Surg 1999;120(1):5–11.