Endoscopic nasal surgery- a surgical fashion or genuine progress?

Author:
Alexander Yao
Final Year Medical Student (Direct Entry Programme)
Imperial College London

Word count: 2870

Table of Contents

1. Introduction

Improved visualisation afforded by endoscopes has allowed ENT surgeons to perform disease-focused, functional operations, whilst adhering to the minimally invasive surgical ideals of today's society.[1] Endoscopic endonasal surgery utilises the optical qualities of the endoscope to extend beyond the otherwise limiting small aperture of the nostrils to provide panoramic vision of the internal nasal, paranasal and skull base structures (**Figure 1**). The reduction in tissue trauma afforded by this minimally invasive technique offers enhanced post-operative recovery, reduced operative times, and minimised operative costs.[2] Its impact has transformed the practice of rhinology. Endoscopic nasal surgery is now the mainstay of intervention for many sinunasal and skull base conditions,[3] and indeed one of the most frequently performed ENT procedures.[1] Its success has prompted rapid development of innovative techniques and technology over the last two decades,[4] including its extension of application to skull base surgery[5] and orbital procedures.[6]

However, the recent emphasis in medicine towards Evidence Based Medicine (EBM)[7] demands we ask the question: what evidence for the benefit of endoscopic nasal surgery and its associated technologies exists? Do they simply represent a *surgical fashion* without proven benefit or *genuine progress*?

> **Progress**.
> *noun*. (prəʊgrɛs). movement forwards, esp towards a place or objective.
> *verb*. (prə'grɛs). to move forwards or onwards towards a place or objective.
> - *Collins English Dictionary*[8]

According to the definition, one may evaluate progress by reviewing what "movement" has occurred towards our current model of endoscopic nasal surgery, and subsequently, reviewing where efforts are being made to move forward. Although discussion of all the advances within this field lies outside the scope of this essay, major advances and novel developments of interest will be discussed.

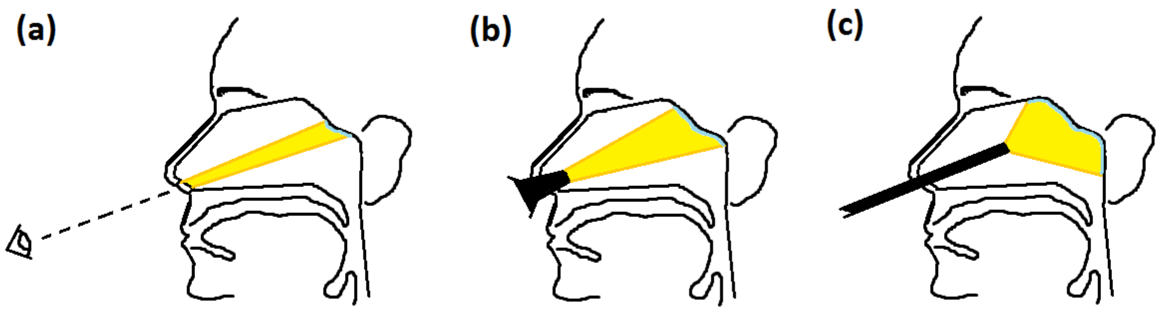

Figure 1. Diagrams indicating the areas of view (in blue) provided by different mechanisms. Conal vision of the nasal cavity and skull base results from the narrow nostril aperture when viewed with the naked eye (a) or during microscope transphenoidal surgery (b). Panoramic vision can be obtained using an endoscope to bypass the narrowest aperture (c). The blue area represents the area of visualisation. (Authors own)

2. Historical progress towards the endoscopic ideal

> "We can chart our future clearly and wisely only when we know the path which has led to the present" - *Adlai E. Stevenson (1900-1965). American politician and United States Ambassador to the United Nations.*

Endoscopic nasal surgery has been the culmination of over two centuries of technological advancement. The most significant historical figures in its development are summarised in **Figure 2.** Despite considerable innovation, early endoscopes remained limited by their poor depth perception, small field of view, and inadequate illumination from flames or small electrical bulbs.

Hopkin's work into optics revolutionised the field of endoscopy, and lay the foundations to modern minimally invasive surgery.[9] Professor Harold Hopkins was a British physicist working as a research fellow at Imperial College London at the time. His novel endoscope employed true optical media using a rigid rod and lens system, instead of conventional fibreoptics.[10] Its double light transmission system allowed shorter and thinner spacer tubes to be used, whilst simultaneously giving a larger and clearer aperture, with better illumination, contrast and depth. Whilst English and American companies showed little interest, the potential of the rigid rod system for use in clinical practice was recognised by Karl Storz, an ENT equipment manufacturer based in Tuttlingen, Germany. Hopkins worked in partnership with Storz to distribute the HOPKINS® rod lens scopes through the 1950s and 60s, with great success. Better definition, contrast, and illumination, with the added availability of angled scopes, gave ENT surgeons an unprecedented view of internal nasal anatomy.[10] Today, Karl Storz is one of the largest manufacturers of rigid and flexible endoscopes for ENT surgery worldwide.[11]

1500

1600

1700

1800

1900

2000

- **1585.** Aranzi used a flask of water to project rays of light into the nasal cavity to aid visualisation.
- **1714.** Dionis described one of the earliest speculums specifically designed for nasal examination
- **1806.** Bozzini, German-born urologist, used his early endoscope, "lichleiter" or "light conductor", to visualise the larynx. He used a wax candle as the light source.
- **1853.** Desormeaux, French surgeon, coined the term "endoscope"
- **1850s.** Czermack, Vienese physiologist, described anterior and posterior rhinoscopy
- **1901.** Hirschmann used Nitze's electric bulb-lit cystoscope for examination of the maxillary sinus via an oroantral fistula.
- **Early 1900s.** Reichert, Sargon, Imhofer used endoscopes therapeutically for treatment of oroantral fisutals.
- **1950s.** Professor Hopkins, physicist and research fellow at Imperial College London, introduced the rigid endoscope. Manufactured by Karl Storz.
- **1978.** Professor Messerklinger and Stammberger published the principles of endoscpic sinus surgery.
- **1980s.** Wigand and Draf pioneered endoscopic endonasal approach to skull base and sinus surgery.
- **1985.** Kennedy coined the term "Functional Endoscopic Sinus Surgery" (FESS).

Figure 2. Summary of the historical landmarks in endoscopic nasal surgery. (Authors own, see Appendix for references)

Modern endoscopic nasal surgery is interventional surgery through a natural orifice using an endoscope.

It is defined by parameters consisting of the endoscope, the instruments, adjunctive radiology, perioperative care and the surgeon. Certainly the former three have seen significant advances and their contribution to progress will be discussed subsequently.

3. Advancement in endoscope components

The endoscope defines the value of endoscopic nasal surgery. It consists of relatively few principle components: a light source, a telescopic component, a camera head, a processor and a monitor.

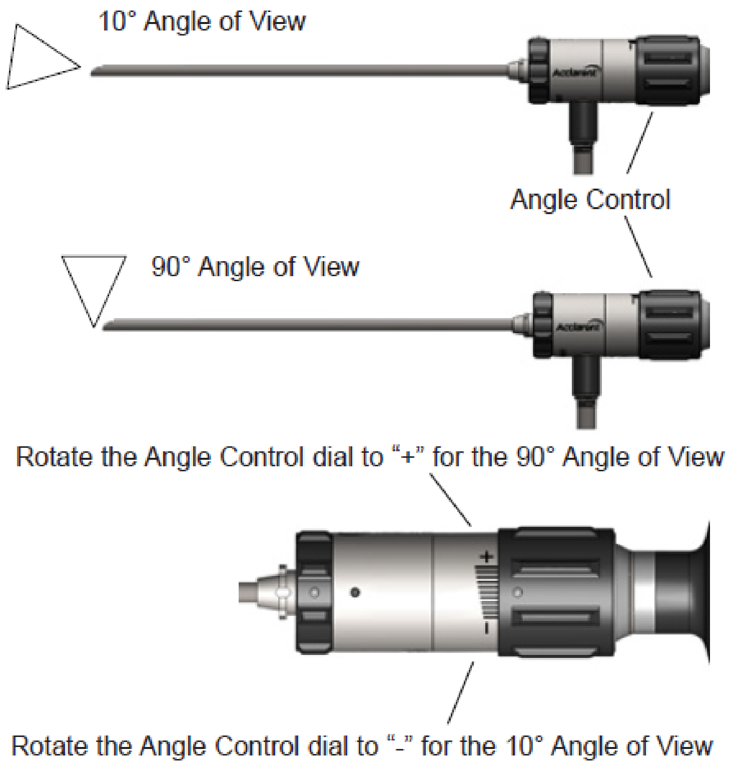

Figure 3. ACCLARENT CYCLOPS™ Multi-angle Endoscope. No change in endoscope is required to alter the angle of view. (Acclarent®, http://www.acclarent.com/solutions/products/acclarent-cyclops-endoscope)

3.1 The xenon light source

It wasn't until 1876 that Nitze used Edison's invention of the light bulb to introduce electricity as a source of illumination for endoscopy.[12] Modern light sources have progressed from using halogen elements to using more durable xenon. Xenon offers numerous advantages including triple the light output compared to standard halogen, and a true white image rather than a yellow hue.[10] Furthermore, xenon has been shown to be more efficient, by consuming less energy, and generating less heat.

3.2 Angled telescopes

The modern selection of endoscopes offers a variety of telescopic angles, allowing views to difficult areas such as around corners or complex anatomy. Access to difficult-to-visualise areas such as the frontal sinus plays a role in reducing recurrence and revision rates of sinunasal pathology.[13] Newer developments include 45^0 wide-angle telescopes which integrate the benefits of the viewing angle of a conventional 70^0 telescope whilst maintaining forward vision, as well as offering improved illumination.[14] The latest single lens, multi-angled angled endoscopes[15] offer telescopic angles between 10^0 and 90^0 integrated into one device, without the need to change endoscopes (**Figure 3**).

3.3 High definition (HD) monitors

Prior to the use of monitors surgeons would perform endoscopic nasal surgery through the direct vision of the endoscope. The introduction of monitors improved surgery ergonomics,[16] increased theatre staff awareness of the procedure, facilitated image/video capture, and played a role in education. The replacement of one-chip camera processors with three-chip processors (one for each primary colour) significantly improved monitors further by increasing the levels of contrast and balance that could be achieved on the monitor display.[14] Modern monitors potentially offer HD definition (from 640x480 to 1980x1080), wider aspect ratios (from 4:3 to 16:9), and improved refresh rates (from 50Hz to 60Hz). The result of these changes have been improvements in visual acuity, colour, contrast, visualisation of surgical field, less flicker and less eye fatigue.[14]

Overall, few studies have evaluated the effects of these advances on surgical performance or operative outcomes. A systematic review by Ayad et al. into ergonomics of endoscopic endonasal surgery including the use of monitors vs direct visualisation concluded there were no advantages in terms of surgical performance.[16] A limited number of studies indicate that high definition monitors may be of benefit over standard definition monitors in procedures requiring high levels of detail such as diagnostic laryngoscopy[17] and laparoscopic surgical skills.[18] Both studies acknowledge a strong subjective preference for high definition monitor use.

4. Instruments in endoscopic nasal surgery

Early instruments, consisting mainly of simple grasping forceps, used to remove mucosa resulted in excess exposed bone, scarring, chronic inflammation and mucocele formation.[19] To overcome this problem, fine, through-cutting instruments, were adopted to reduce mucosal trauma.

4.1 Microdebriders

Powered, replaceable cutting blades, and concurrent suction capabilities meant microdebriders were able to offer faster, more efficient methods of tissue removal whilst maintaining excellent visualisation, even in the presence of bleeding.[20,21] The impact of the powered microdebrider on rhinology has led some to hail it as one of the four most significant technological advances in the specialty.[22]

4.2 The suction irrigation drill

This device quickly became adopted as an important tool in the removal of thickened osteotic bone found in osseous and fibro-osseous neoplasms, which were otherwise difficult to remove with forceps or the microdebrider.[14]

4.3 Balloon dilatation technology, or balloon sinuplasty

Introduced in 2005, balloon sinuplasty represents an important progression in minimally invasive CRS treatment.[22] The catheter-based system for dilatation of the paranasal sinuses has subsequently been shown to be safe and effective.[23] The CLEAR study by Bolger et al. demonstrated a post-procedure patency rate of 80.5% at 24 weeks follow-up.[24] The indications and applications of balloon sinuplasty as a stand-alone vs adjunctive procedure to FESS have been controversial.

5. Radiology in endoscopic nasal surgery

Operating in close proximity to the paranasal sinuses, orbit and skull base makes endoscopic nasal surgery potentially hazardous.[25] The use of radiological imaging has been a crucial adjunct in its success and safety. Computerised tomography (CT) offers detailed evaluation regarding the anatomy and extent of sinunasal disease, making it the current gold standard.[26] Magnetic resonance imaging (MRI) has a role in soft tissue and skull base pathology including gliomas, meningoceles, meningoencephaloceles, and benign tumours.[14]

Image-guided, or computer-aided, endoscopic nasal surgery uses CT or MRI for anatomical navigation on triplanar radiologic images to create a pre-operative road map. High accuracy within 2mm affords surgeons safe navigation in complex cases such as where anatomical distortion is present secondary to alteration from disease or previous surgery.[1] Fried at al.[27] noted a significant reduction in major complications (from 11% to 1%) in the 97 patients who underwent image-guided surgery compared to those who underwent non-image-guided surgery. Image-guided endoscopic nasal surgery has a foreseeable role in teaching trainees as well as high compatibility with robotic systems.

6. Progress in the management of nasal and paranasal pathology

6.1 Function Endoscopic Sinus Surgery (FESS)

Functional endoscopic sinus surgery (FESS), the archetypal endoscopic nasal procedure, is one of the most performed ENT procedures, and the mainstay of treatment for Chronic rhinosinusitis (CRS) refractory to medical therapy. FESS is an intranasal procedure involving the endoscope to improve ventilation and drainage in addition to polyp removal.[28]

FESS has been shown to be both safe and effective in surgical management of both CRS with nasal polyps (CRSwNP) and without nasal polyps (CRSsNP). A systematic review of 33 articles by Dalziel et al.[28] included three studies comparing FESS with Caldwell Luc or another endonasal procedure (n=240), three non-randomised trials comparing different surgical approaches (n=2699), and 27 case series. Symptom improvement in FESS was “greatly improved” in 75-95%, comparable to traditional procedures. Overall complication rate was low (1.4% for FESS and 0.8% for traditional procedures).

Most patients with CRS seek treatment when the burden of symptoms negatively impacts on their quality of life. Therefore the degree to which the quality of life improves after sinus surgery is a critical indicator of surgical success. A systemic review of 289 studies by Chester et al. found Endoscopic sinus surgery was particularly effective in CRSsNP in relieving subjective symptoms of nasal obstruction, facial pain, and post-nasal discharge.[29] Similarly in CRSwNP, the National Comparative Audit of Surgery for Nasal Polyposis and Chronic Rhinosinusitis reported a high level of patient satisfaction with the surgery, and clinically significant improvement in SNOT-22 scores at 3, 12, 36, 60 months post-operatively.[30]

Studies have shown endoscopic sinus surgery to be at least as effect as medical therapy in treating CRS. A randomised controlled trial by Raghab et al. comparing long term antibiotics with endoscopic sinus surgery in CRSwNP management found both to be equally effective in significantly improving objective and subjective measures of CRS ($p<0.01$).[31] No significant difference was found between quality of life measures when CRSwNP was treated surgical vs medically.[32]

There is also evidence to suggest FESS is superior to conventional non-endoscopic or open surgical approaches in the treatment of CRS, except for sphenoethmoidectomy where no studies have yet been conducted.[3,33–35]

6.2 Septoplasty

Septoplasty is a common procedure used to treat nasal obstruction secondary to nasal septal deviation.[36] Good intra-operative visualisation is crucial to minimising complications and achieving functional airway. A study of 2,730 patients undergoing power-assisted endoscopic septoplasties demonstrated a role in minimise flap tears, and addressing septal spurs.[37] Endoscopic septoplasty may better address discrete, localised lesions such isolated deflection, spurs, perforations, contact points compared to traditional headlight septoplasty.[38] Symptomatic outcomes also compare favourably to traditional techniques. A retrospective review of 160 patients undergoing endoscopic septoplasty for nasal airway obstruction demonstrated 70% resolution, and 20% improvement on symptoms after a 13 month mean follow-up.[39]

6.3 Rhinoplasty

Rhinoplasty is an increasingly popular procedure, restoring form and function in nasal deformity. Rhinoplasty can be extremely challenging,[40] and parts of the procedure which are not in direct vision of the surgeon, or poorly visualised, may benefit from endoscopic assistance.[41] However, the evidence for its use has largely been limited to case series, usually with small numbers and short follow-up. Data have suggested that the endoscope may reduce secondary revisions and precision contouring of the bony nasal dorsum.[42,43]

6.4 Skull base surgery

The whole ventral skull base can be approached endonasally, via open craniotomy or via a transphenoidal microscopic approach.[5] In addition to benefitting from a greatly improved view (**Figure 1**), endoscopic approaches avoid the need for extensive bone drilling, brain retraction, and nerve manipulation that is sometimes required in transcranial approaches.[44]

Endoscopic repair is now generally regarded as the procedure of choice for cerebral spinal fluid (CSF) leak repair.[45] By approaching the anterior skull base endonasally, one can minimise complications such as anosmia, intracranial haemorrhage or oedema, seizures, and changes in memory and behaviour.[46] A systematic review including 55 studies by Psaltis et al.[47] demonstrated endoscope repair was effective, with a 90% overall success rate for primary repairs, and 97% for secondary repairs. It is also regarded as safe with a low complication rate of <0.03%. No studies have compared open invasive intracranial approaches with the endonasal approach.

Tumours such as craniopharyngiomas, clivalchordomas, and meningiomas may also be resected endoscopically with equivalent or greater rates of gross total resection compared to traditional open approaches.[44] Similarly, rates of post-operative complications are at least comparable with traditional approaches. However, CSF leak still remains a problem.

6.5 Orbital surgery

Grave's ophthalmopathy without decompression can lead to permanent loss of vision. Enhanced visualisation of key anatomical features of the medial wall and floor of the orbit has allowed for safe and effective surgical decompression of the orbit.[48] Lund et al. studied a cohort of 33 patients who underwent either an external Patterson approach or endonasal endoscopic approach for thyroid eye disease.[49] The endoscopic approach demonstrated greater improvement in proptosis, visual acuity, colour vision and rates of complications.

Endoscopy has also been applied to dacrocystorhinostomy (DCR), a minimally invasive procedure to unblock the nasolacrimal duct using instruments or laser. Its advantages over the standard external DCR approach are summarised in **Box 1**.[50]

Box 1. Potential advantages of Endoscopic DCR over the standard external DCR approach. (adapted from NICE guidelines Endoscopic dacrocystorhinostomy (IPG113))

- No facial cosmetic scars
- Local anaesthetic can be used
- Reduced trauma preserves the canthal anatomy and reduces angular vein damage
- Diagnosis and/or management of of predisposing or concomitant nasal and paranasal disorders.
- Bilateral cases are performed simultaneously
- Immediate mistakes revised at surgery
- Active dacryocystitis (nasal infection) is not a contraindication as with external approach
- The possibility of failures being endoscopically investigated
- Reduced operating time
- Reduced intraoperative bleeding
- Reduced morbidity
- Performed as an outpatient, day surgery basis
- Improved cost-effectiveness

7. The future of endoscopic nasal surgery

Kupferman[51] stated that the ideal surgical technique should offer the surgeon the distinct advantage of 3D vision and bimanual surgical dissection, possibly guided by a navigation system.

7.1 3D endoscopes and monitors

Traditionally, 2D endoscopes and monitors have been limited by their lack of field of depth, somewhat mitigated by scope movement. Evaluation of the use of 3D endoscopes have reported significant advantages including improved depth perception and enhanced surgical precision,[52] although evidence for this has been largely anecdotal. Data comparing operative outcomes of 2D vs 3D endoscopes is notably lacking. One study by Kari et al. compared peri- and post-operative outcomes in a retrospective review of 58 patients who underwent endoscopic pituitary surgery with 2D or 3D endoscopes.[53] There was no significant difference between 2D and 3D endoscopes found in operative time, estimated blood loss, CSF leak rate, endocrine complications, length of hospital stay or readmission rates. 3D endoscopes possess significant disadvantages including their limited use to 40 cases before replacement, the lack of 70 degree telescopes, and the learning curve required for use.[52]

7.2 Robotic systems

Just as endoscopes have transformed rhinology and skull base surgery, robotic systems potentially represent the next stage in the evolution process. Robotic systems have the capacity to both assist and perform endoscopic nasal surgery via a master-slave interface. Robotic master-slave systems offer advantages of high dexterity and precision, tremor elimination, combined with an excellent field of view afforded by endoscopes. Recent attempts to utilise this technology endonasally have seen mixed results. Several difficulties have been noted concerning the most popular model (da Vinci Surgical System by Intuitive Surgical Inc.) including; size and number of instruments fitting through the nose, difficulty in instrument exchange, and paucity of haptic feedback.[54]

Prototype robots have been developed to overcome these issues. Some models have the capacity to handle the endoscope autonomously via speech commands from the surgeon, freeing the surgeon to operate bimanually with traditional instruments.[55] The active bending endoscope robot system's circumvents the limitation of the single pivot point at the nostril by offering angles of view up to 180 degrees on the same endoscope [**figure**]. Schneider et al. describe a three-concentric tube continuum robot with integrated instrument and telescope canals that also offers a bending component.[54]

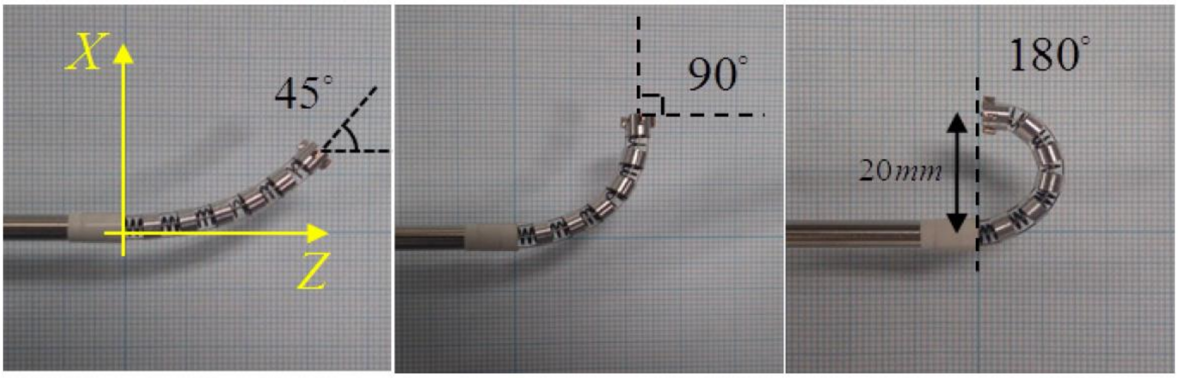

Figure 4. Active Bending Endoscope Robot System. The end of the scope stands a continuum module consisting of a spring backbone providing 0-180° of flexion in a 2 cm arc. The endoscope itself is 4mm wide. (Yoon et al. 2011)

7.3 Intra-operative imaging

Navigational enhancement is being developed using landmarks in augmented reality endoscopic systems, adding further levels of image-guidance.[56] However, pre-operative image based guided systems do not render the anatomical changes that occur during procedures.

More recently, small studies have investigated the role of intra-operative CT and MRI imaging. Intra-operatively CT scans can be loaded to image-guided systems within minutes. New information obtained in intra-operative CT resulted in alteration of surgical plan in 30% of patients.[57] Considerable disadvantages lie in the cost, and space required, radiation exposure, increased operation length.[58]

8. Conclusion

Advances in technology over the last two centuries have seen the progression of Bozzini's wax candle[59] into the modern endoscope, potentiating minimally invasive diagnosis and surgical intervention on sinunasal pathology.[60] Heinz Stammberger, one of the pioneers of endoscopic nasal surgery said, "To put it bluntly, the endoscope emerged as the instrument that helped avoid unnecessary and unnecessarily radical surgery"[61]

"Fashion is very important. If is life-enhancing, like everything that gives pleasure, it is worth doing well."

- Vivienne Westwood. English fashion designer.

Unfortunately, rigorous objective evaluation of the progress in endoscopic nasal surgery remains limited by the lack of high quality comparative studies and objective outcome measures in many areas. Insufficient robust evidence fails to provide a clear guide to policies on behalf of the NHS[28] and makes informed decisions concerning commissioning particularly difficult.

However, it is important to recognise a lack of level 1a evidence for effectiveness does not automatically warrant a label of ineffectiveness or dismissal as surgical fashion. Indeed, the parachute has never been subjected to such rigorous evaluation.[62] Evidently, robust observational data can be extremely valuable.

Further research is required to evaluate merits, limitations and costs of expensive new technologies such as 3D endoscopes, intra-operative imaging, and robotic systems. Many current procedures require further clarification in regards to indications, and optimising patient selection.[28]

Overall, it remains undeniable that endoscopic nasal surgery represents *genuine progress*. The field of endoscopic surgery is constantly evolving, and the future seems extremely promising to patient and surgeon alike.

9. References

1. Wise SK, DelGaudio JM. Computer-aided surgery of the paranasal sinuses and skull base. Expert review of medical devices. 2005. 2(4):395–408.

2. Welch KC, Stankiewicz JA. Application of minimally invasive endoscopic sinus surgery techniques. Otolaryngologic clinics of North America. 2010. 43(3):565–78, ix.

3. Fokkens WJ, Lund VJ, Mullol J, Bachert C, Alobid I, Baroody F, et al. European Position Paper on Rhinosinusitis and Nasal Polyps 2012. Rhinology. Supplement. 2012.(23):3, 1–298.

4. Kennedy DW. Technical innovations and the evolution of endoscopic sinus surgery. The Annals of otology, rhinology & laryngology. Supplement. 2006. 196:3–12.

5. Paluzzi A, Gardner P, Fernandez-Miranda JC, Snyderman C. The expanding role of endoscopic skull base surgery. British journal of neurosurgery. 2012. 26(5):649–61.

6. Metson R, Pletcher SD. Endoscopic Orbital and Optic Nerve Decompression. Otolaryngologic Clinics of North America. 2006 Jun;39(3):551–61.

7. Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. Evidence based medicine: what it is and what it isn't. BMJ. 1996.312(7023):71–2.

8. Collins Dictionary. Definition of "Progress". 2013. Available at http://www.collinsdictionary.com/dictionary/english/progress?showCookiePolicy=true Last Accessed 2013 Aug 4.

9. Jennings CR. Harold Hopkins. Archives of Otolaryngology–Head & Neck Surgery. 1998 Sep 1;124(9):1042.

10. Chandra RK, Conley DB, Kern RC. Evolution of the endoscope and endoscopic sinus surgery. Otolaryngologic clinics of North America. 2009.42(5):747–52, vii.

11. Storz: Karl Storz Endoskope. Ear, Nose, Throat. Website. 2013. Website available from: https://www.karlstorz.com/cps/rde/xchg/SID-E1C8421C-D260A1DB/karlstorz-en/hs.xsl/45.htm. Last Accessed: 2013 Aug 31

12. Mouton WG, Bessell JR, Maddern GJ. Looking back to the advent of modern endoscopy: 150th birthday of Maximilian Nitze. World journal of surgery. 1998. 22(12):1256–8.

13. Gore MR, Ebert CS, Zanation AM, Senior BA. Beyond the "central sinus": radiographic findings in patients undergoing revision functional endoscopic sinus surgery. International forum of allergy & rhinology. 2013. 3(2):139–46.

14. Govindaraj S, Adappa ND, Kennedy DW. Endoscopic sinus surgery: evolution and technical innovations. The Journal of laryngology and otology. 2010. 124(3):242–50.

15. Acclarent. ACCLARENT CYCLOPS™ Multi-angle Endoscope. 2013. Website available from: http://www.acclarent.com/solutions/products/acclarent-cyclops-endoscope. Last Accessed: 2013 Aug 31

16. Ayad T, Péloquin L, Prince F. Ergonomics in endoscopic sinus surgery: systematic review of the literature. The Journal of otolaryngology. 200. 34(5):333–40.

17. Otto KJ, Hapner ER, Baker M, Johns MM. Blinded evaluation of the effects of high definition and magnification on perceived image quality in laryngeal imaging. The Annals of otology, rhinology, and laryngology. 2006. 115(2):110–3.

18. Hagiike M, Phillips EH, Berci G. Performance differences in laparoscopic surgical skills between true high-definition and three-chip CCD video systems. Surgical endoscopy. 2007. 21(10):1849–54.

19. Kennedy DW. Diseases of the Sinuses: Diagnosis and Management. Ontario: BC Decker; 2000.

20. Parsons DS. Rhinologic uses of powered instrumentation in children beyond sinus surgery. Otolaryngologic clinics of North America . 1996. 29(1):105–14.

21. Setliff RC. The hummer: a remedy for apprehension in functional endoscopic sinus surgery. Otolaryngologic clinics of North America. 1996. 29(1):95–104.

22. Catalano PJ. Balloon dilation technology: let the truth be told. Current allergy and asthma reports . 2013. 13(2):250–4.

23. Levine HL, Sertich AP, Hoisington DR, Weiss RL, Pritikin J. Multicenter registry of balloon catheter sinusotomy outcomes for 1,036 patients. The Annals of otology, rhinology, and laryngology. 2008. 117(4):263–70.

24. Bolger WE, Brown CL, Church CA, Goldberg AN, Karanfilov B, Kuhn FA, et al. Safety and outcomes of balloon catheter sinusotomy: a multicenter 24-week analysis in 115 patients. Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery. 2007. 137(1):10–20.

25. Lynn-Macrae AG, Lynn-Macrae RA, Emani J, Kern RC, Conley DB. Medicolegal analysis of injury during endoscopic sinus surgery. The Laryngoscope. 2004. 114(8):1492–5.

26. Lund VJ, Savy L, Lloyd G. Imaging for endoscopic sinus surgery in adults. The Journal of laryngology and otology. 2000. 114(5):395–7.

27. Fried MP, Moharir VM, Shin J, Taylor-Becker M, Morrison P. Comparison of endoscopic sinus surgery with and without image guidance. American journal of rhinology. 2002. 16(4):193–7.

28. Dalziel K, Stein K, Round A, Garside R, Royle P. Systematic review of endoscopic sinus surgery for nasal polyps. Health technology assessment (Winchester, England). 2003. 7(17):iii, 1–159.

29. Chester AC, Antisdel JL, Sindwani R. Symptom-specific outcomes of endoscopic sinus surgery: a systematic review. Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery. 2009. 140(5):633–9.

30. Browne J, Hopkins C, Slack R, Jan van der M, Lund V, Topham J, et al. The National Comparative Audit of Surgery for Nasal Polyposis and Chronic Rhinosinusitis. 2003.

31. Ragab SM, Lund VJ, Scadding G. Evaluation of the medical and surgical treatment of chronic rhinosinusitis: a prospective, randomised, controlled trial. The Laryngoscope. 2004. 114(5):923–30.

32. Alobid I, Benítez P, Bernal-Sprekelsen M, Roca J, Alonso J, Picado C, et al. Nasal polyposis and its impact on quality of life: comparison between the effects of medical and surgical treatments. Allergy. 2005. 60(4):452–8.

33. Lund VJ. The results of inferior and middle meatal antrostomy under endoscopic control. Acta oto-rhino-laryngologica Belgica. 1993.47(1):65–71.

34. Penttilä MA, Rautiainen ME, Pukander JS, Karma PH. Endoscopic versus Caldwell-Luc approach in chronic maxillary sinusitis: comparison of symptoms at one-year follow-up. Rhinology. 1994 Dec. 32(4):161–5.

35. Venkatachalam VP, Jain A. Comparative evaluation of functional endoscopic sinus surgery and conventional surgery in the management of chronic sinusitis. Journal of the Indian Medical Association. 2002. 100(2):78–9, 82–3.

36. Ketcham AS, Han JK. Complications and management of septoplasty. Otolaryngologic clinics of North America. 2010. 43(4):897–904.

37. Sousa A de, Iniciarte L, Levine H. Powered Endoscopic Nasal Septal Surgery. Acta médica portuguesa. 18(4):249–55.

38. Getz AE, Hwang PH. Endoscopic septoplasty. Current opinion in otolaryngology & head and neck surgery. 2008. 16(1):26–31.

39. Chung BJ, Batra PS, Citardi MJ, Lanza DC. Endoscopic septoplasty: revisitation of the technique, indications, and outcomes. American journal of rhinology. 21(3):307–11.

40. Tasman A-J. Rhinoplasty - indications and techniques. GMS current topics in otorhinolaryngology, head and neck surgery. 2007.

41. Tasca I. Endoscopy-Assisted Rhinoplasty. Archives of Facial Plastic Surgery. 2002. 4(3):190–3.

42. Mitz V. Endoscopic control during rhinoplasty. Aesthetic plastic surgery. 1994. 18(2):153–6.

43. Krouse JH. Endoscopic-powered rhinoplasty. The Journal of otolaryngology . 1999. 28(5):282–4.

44. Raper DMS, Komotar RJ, Starke RM, Anand VK, Schwartz TH. Endoscopic versus open approaches to the skull base: A comprehensive literature review. Operative Techniques in Otolaryngology-Head and Neck Surgery . 2011. 22(4):302–7.

45. Martin TJ, Loehrl TA. Endoscopic CSF leak repair. Current opinion in otolaryngology & head and neck surgery . 2007. 15(1):35–9.

46. Daele JJM, Goffart Y, Machiels S. Traumatic, iatrogenic, and spontaneous cerebrospinal fluid (CSF) leak: endoscopic repair. B-ENT . 2011. 7 Suppl 17:47–60.

47. Psaltis AJ, Schlosser RJ, Banks CA, Yawn J, Soler ZM. A systematic review of the endoscopic repair of cerebrospinal fluid leaks. Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery . 2012. 147(2):196–203.

48. Pletcher SD, Sindwani R, Metson R. Endoscopic orbital and optic nerve decompression. Otolaryngologic clinics of North America . 2006 Oct. 39(5):943–58, vi.

49. Lund VJ, Larkin G, Fells P, Adams G. Orbital decompression for thyroid eye disease: a comparison of external and endoscopic techniques. The Journal of laryngology and otology . 1997. 111(11):1051–5.

50. National Institute of Clinical Excellence (NICE). Endoscopic dacrocystorhinostomy (IPG113) . 2005;Available from: http://guidance.nice.org.uk/IPG113

51. Kupferman M, Demonte F, Holsinger FC, Hanna E. Transantral robotic access to the pituitary gland. Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery . 2009. 141(3):413–5.

52. Manes RP, Barnett S, Batra PS. Utility of novel 3-dimensional stereoscopic vision system for endoscopic sinonasal and skull-base surgery. International forum of allergy & rhinology. 2011. 1(3):191–7.

53. Kari E, Oyesiku NM, Dadashev V, Wise SK. Comparison of traditional 2-dimensional endoscopic pituitary surgery with new 3-dimensional endoscopic technology: intraoperative and early postoperative factors. International forum of allergy & rhinology. 2012. 2(1):2–8.

54. Schneider JS, Burgner J, Webster RJ, Russell PT. Robotic surgery for the sinuses and skull base: what are the possibilities and what are the obstacles? Current opinion in otolaryngology & head and neck surgery . 2013 Mar. 21(1):11–6.

55. Rilk M, Kubus D, Wahl FM, Eichhorn KWG, Wagner I, Bootz F. Demonstration of a prototype for robot assisted Endoscopic Sinus Surgery . In: 2010 IEEE International Conference on Robotics and Automation. IEEE; 2010. p. 1090–1.

56. Thoranaghatte RU, Giraldez JG, Zheng G. Landmark based augmented reality endoscope system for sinus and skull-base surgeries. Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference . 2008. 2008:74–7.

57. Jackman AH, Palmer JN, Chiu AG, Kennedy DW. Use of intraoperative CT scanning in endoscopic sinus surgery: a preliminary report. American journal of rhinology. 2008. 22(2):170–4.

58. Cartellieri M, Vorbeck F. Endoscopic sinus surgery using intraoperative computed tomography imaging for updating a three-dimensional navigation system. The Laryngoscope. 2000. 110(2 Pt 1):292–6.

59. Verger-Kuhnke AB, Reuter MA, Beccaria ML. [Biography of Phillip Bozzini (1773-1809) an idealist of the endoscopy]. Actas urologicas españolas . 2007. 31(5):437–44.

60. Linder TE, Simmen D, Stool SE. Revolutionary Inventions in the 20th Century: The History of Endoscopy. Archives of Otolaryngology - Head and Neck Surgery . 1997. 123(11):1161–3.

61. Stammberger H. The evolution of functional endoscopic sinus surgery. Ear, nose, & throat journal . 1994. 73(7):451, 454–5.

62. Smith GCS, Pell JP. Parachute use to prevent death and major trauma related to gravitational challenge: systematic review of randomised controlled trials. BMJ (Clinical research ed.) . 2003. 327(7429):1459–61.

10. Appendix- References for Figure 1

References for Figure 1. Summary of the historical landmarks in endoscopic nasal surgery.

1. Essentials of Pediatric Endoscopic Surgery. Springer; 2008.

2. Verger-Kuhnke AB, Reuter MA, Beccaria ML. [Biography of Phillip Bozzini (1773-1809) an idealist of the endoscopy]. Actas urologicas españolas. 2007 May 4;31(5):437–44.

3. Garcia M. Observations on the Human Voice. Proceedings of the Royal Society of London (1854-1905). 1854;7:399–410.

4. Czermak J. Der Kehlkopspiegel und seine Verwerthung fur Physiologie und Medicin. 2nd ed. Leipzig: Engelmann; 1893.

5. Howard DJ, Lund VJ. Endoscopic surgery in otolaryngology. Br. Med. Bull. 1986 Jan 1;42(3):234–9.

6. Killian G. Uber Rhinoskopia media. Munchen Med Wochenschr. 1896;33.

7. Hirschmann A. Uber Endoskopie der Nase und deren Nebenhohlen. Arch Laryngol Rhinol. 1903;14:195–202.

8. Reichert M. Über eine neue Unterscuhungsmethode der Oberkieferhöhle mittels des Antroskops. Berl klin Wochenschr. 1902;401:478.

9. Mouton WG, Bessell JR, Maddern GJ. Looking back to the advent of modern endoscopy: 150th birthday of Maximilian Nitze. World journal of surgery. 1998 Dec;22(12):1256–8.

10. Chandra RK, Conley DB, Kern RC. Evolution of the endoscope and endoscopic sinus surgery. Otolaryngologic clinics of North America. 2009 Oct;42(5):747–52, vii.

11. Govindaraj S, Adappa ND, Kennedy DW. Endoscopic sinus surgery: evolution and technical innovations. The Journal of laryngology and otology. 2010 Mar;124(3):242–50.

12. Messerklinger W. Endoscopy of the Nose. Baltimore, Maryland: Urban & Schwarzenberg; 1978.

13. Kennedy DW. Functional endoscopic sinus surgery: Technique. Archives of otolaryngology. 1985 Oct.111(10):643–9.