# Surgical Freedom in Endoscopic Skull Base Surgery:

## Quantitative Analysis for Endoscopic Approaches

by

Ali Elhadi

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Graduate Supervisory Committee:

Mark Preul, Co-Chair
Bruce Towe, Co-Chair
Andrew Little
Peter Nakaji
Eric Vu

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# ABSTRACT

During the past five decades neurosurgery has made great progress, with marked improvements in patient outcomes. These noticeable improvements of morbidity and mortality can be attributed to the advances in innovative technologies used in neurosurgery. Cutting-edge technologies are essential in most neurosurgical procedures, and there is no doubt that neurosurgery has become heavily technology dependent. With the introduction of any new modalities, surgeons must adapt, train, and become thoroughly familiar with the capabilities and the extent of application of these new innovations. Within the past decade, endoscopy has become more widely used in neurosurgery, and this newly adopted technology is being recognized as the new minimally invasive future of neurosurgery. The use of endoscopy has allowed neurosurgeons to overcome common challenges, such as limited illumination and visualization in a very narrow surgical corridor; however, it introduces other challenges, such as instrument "sword fighting" and limited maneuverability (surgical freedom). The newly introduced concept of surgical freedom is very essential in surgical planning and approach selection and can play a role in determining outcome of the procedure, since limited surgical freedom can cause fatigue or limit the extent of lesion resection. In my thesis, we develop a consistent objective methodology to quantify and evaluate surgical freedom, which has been previously evaluated subjectively, and apply this model to the analysis of various endoscopic techniques. This model is crucial for evaluating different endoscopic surgical approaches before they are applied in a clinical setting, for identifying surgical maneuvers that can improve surgical freedom, and for developing endoscopic training simulators that accurately model the surgical freedom of various approaches. Quantifying the extent of endoscopic surgical freedom will also provide developers with valuable data that will help them design improved endoscopes and endoscopic instrumentation.

# DEDICATION

For my Mother and Father, my greatest role models, thank you for your continuous encouragement, prayers and love.

For my lovely sisters and Yara, thank you for your great love, support and encouragements.

For my professors and mentors, who were always by my side and provided guidance and advice.

For my family and friends, who always kept me in a high spirit throughout this process.

For all neurosurgeons and members of the scientific community who will find this work relevant and apply it for better patient outcomes.

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# INTRODUCTION

Neurosurgical practices may have been performed as early as two millennia B.C. (Elhadi, 2012). As a discipline neurosurgery is based on a long, slow, and deliberate history of important developments (Preul MC et al, 1997). It was not until about 150 years ago, however, that neurosurgery began to be considered as an independent field of medicine. During this period, technology and science allowed and promoted greater “neurosurgical” intervention although outcomes were disastrous with significant mortalities. Some authors consider neurosurgery to be one of the youngest fields in medicine (Barker, 1993), and thus open to significant discoveries and scientific progress. Significant advancements in neurosurgery have been prominent in the 20th century and especially within the last 50 years which have been characterized by the introduction and development of diagnostic modalities, operative techniques, or surgical tools and instruments. Neurosurgery is truly a technologically dependent specialty.

Microscopic procedures have been a hallmark of most modern neurosurgery. The continuous improvements of the surgical microscope and microscopic instruments, as well as development of microsurgical techniques and proper training, have all played an important role in shaping neurosurgery as we know it today. Microscopic procedures made possible operating on lesions or pathologies that were previously deemed challenging (Yasargil, 1999) or inoperable. Such procedures are routinely performed on a daily basis resulting in less morbidity and mortality as a result of the increased scope and application of technology of the procedures performed.

The sensitive and fragile natures of the tissue of the nervous system and the complex network of the associated arteries and veins, mandates precise approaches that can address anatomical targets or lesions within the central nervous system with the least amount of retraction, manipulations and neural or vascular injuries (Rhoton, 2003). The trend in neurosurgery, as with any surgical discipline, is to “minimize” invasion and the extent of the approach. Minimizing the operative extent such as in large craniotomies usually means fewer complications for the patient. There is thus a strong tendency towards development of minimally invasive procedures.

The term minimally invasive is relative. Microscopic neurosurgery was considered minimally invasive when first applied in the early 1960s and 1970s (Yasargil 1970). Dr. Theodore Kurze from the university of Southern California was considered to be the first neurosurgeon to use the microscope in the OR in 1957 (Dounaghy et al, 1979). Today use of the microscope is considered nearly a required technology for the neurosurgical procedure, but is no longer considered necessarily associated with minimal invasion.

The surgical endoscope was introduced to neurosurgery in early 1923 with little success because of technological limitations. Use of the endoscope was significantly expanded in the 1990s when it was first used for diagnostic purposes, and used as an adjunct to the microscope to improve visualization of structures. During the late 1990s and early 2000s neurosurgeons found increased use for the endoscope in removing pituitary adenomas (Prevedello, 2007). Endoscopic use increased to include lesions in the middle and posterior cranial fossae (Little, 2013) and more lateral skull base lesions (Little, 2012). This innovation is due to technological endoscopic improvements, new instrumentations and the development of different endoscopic approaches for different anatomical areas.

Endoscopic neurosurgeons tend to determine their preference towards a certain approach over another for accessing the same anatomical area based on the type of the lesion, extent, surgeon’s training and confidence performing this approach, previous experiences and pre-operative planning. Sometimes a single approach can access several anatomical targets in different surgical planes (Cavallo, 2005), and sometimes several approaches can be used to access a single target or a determined anatomical area (Van Rompaey, 2013).  Several endoscopic approaches and techniques have been described that illustrate maneuvers and anatomical landmarks within different endoscopic approaches. An important factor in determining the right approach for a lesion or an anatomical area is the degree of ease or ability of the surgeon to maneuver different surgical instruments within an endoscopic approach, which is critical in decreasing the surgeons fatigue, frustration and stress. This concept is one of “surgical freedom.” It will also help determine if the surgeon will be capable of removing a lesion completely or no, due to technical difficulties.

In this thesis I expand and assess this new concept of surgical freedom to endoscopic neurosurgery and developed a method to quantify it. Surgical freedom is an important factor and aspect for each endoscopic approach and contributes to surgical planning, decision making, and approach selection.

# BACKGROUND

The nervous system is still mysterious in many ways, and many neuroscience studies still have a lot to discover about this system which mandates continuous and thorough investigations. Neurosurgery is no different from other neuroscience fields and there is yet a lot to be studied in neurosurgery.

As previously mentioned that advancements in neurosurgery are usually marked by improvements in certain aspects like; diagnostics, visualization and illumination, surgical instruments, new surgical techniques, new treatment modalities, and improved neurosurgical training (Powell, 1999). I would like to briefly discuss few examples.

## The role of innovative technologies in neurosurgery

The use of imaging techniques was essential in advancing neurosurgery, the first systematic use of an X-ray was in 1908 by Fedor Krause (Elhadi, 2012), then in 1947 imaging technology advanced to involve the use of radioisotopes in localizing abnormal brain tissue, and in 1950 Angiography became an accepted diagnostic modality to visualize vascular lesions such as aneurysms. During the early 1970, computed tomography (CT) scan was used to localize pathologies in the brain, five years later positron emission tomography (PET) scan was developed which shows different signals for brain cells based on their activity (Xiong, 1997), later in 1980s magnetic resonance imaging (MRI) was regularly used to diagnose pathologies in the CNS. These important evolutions in imaging; technologies, techniques and interpretations played an important role in neurosurgery and its evolution.

Another example is the use of Electro-encephalogram (EEG) which became an acceptable diagnostic tool in epileptic lesions by 1935, and the development of Somato-sensory evoked potential (SSEP) in 1980s which is a way to monitor the integrity of nerves or neural tracts, this monitoring modality have become an important intra-operative tool that may help in preventing nerve injuries, especially during spine procedures.

Basic principles in neurosurgery can change slightly, but a radical change in neurosurgery has been obvious with the introduction of “power tools” that aid in magnification and illumination which make a possible “shrinking” of the surgical working space with sufficient access to the area of interest and minimizing any assault on brain tissue or other delicate structures along the surgical approach or within the working area (Setti, 1994).

### Microscopy and neurosurgery

The surgical microscope was ideal in providing such advantages, the magnification power dramatically increased when compared to previously used magnifying methods. It also provided excellent illumination when compared to older conventional methods. And the illumination is along the line of entry and enables a direct view of the surgeons’ working space (Rand, 1968). These two fundamental aspects that the microscope offered revolutionized and expanded the scope of neurosurgery. It is also notable that continuous innovations in the surgical microscope like; better and lighter microscopes (counter balance microscope), integrated mouth piece to enable hands free maneuver capabilities during most of the operative time, integrated neuro-navigation system, higher magnification and better focus, less heat emitting illumination… etc. all have contributed to better and more efficient procedures (Yasargil, 2006).

A new era of micro-neurosurgery started with new micro-neurosurgical techniques described and used regularly, neuroanatomy has been re-described using the microscope and different microscopic approaches; micro-neuroanatomy, newer micro-surgical instruments have been modified (Yasargil, 2006), it has also become essential to train surgeons and residents on the microscope through micro-neurosurgery laboratories and courses. Even different classifications for tumors and vascular lesions were described based on the microscope usage.

### Endoscopy introduced to the field

Many were mistaken that the degree of visualization offered by the microscope might be the best to be offered to neurosurgery, this idea was then well thought out with the introduction of the endoscope which provides superior visualization, better illumination and even more angular views (Perneczky, 1999).

The endoscope was first used by otolaryngologists in the nasal cavity then neurosurgeons started using the endoscope in the early 1990s as an adjunct to microscopic approaches to provide better view to difficult areas (Perneczky 1998). The endoscope was then used in the removal of pituitary tumors using a trans-shenoidal approach and kept on being limited to sellar lesions during the late 1990s and early 2000s.

The idea of the endoscope goes back to the early19th century when it was first used for hollow organs inspection like the rectum, bladder, nasal cavity, cervix and pharynx. Phillip Bozzini (1773-1809) a German Physician devoted his life to develop this new instrument which was called the Lichtleiter "Light Conductor" which is considered as the very primitive endoscope. He developed the Bozzini Lichtleiter which consists of candlelight as the light source, and a long tube with several lenses for magnification and a number of convex and concave mirrors to reflect light from the source to the distal end of the tube and then back again to the eye piece. Bozzini devoted himself to developing this instrument which was revolutionary at that time. But the endoscope was only a diagnostic tool for the purpose of visualization and curetting or for taking biopsies (Doglietto, 2005).

The early use of the endoscope in neurosurgery was when Walter Dandy used it for ventriculostomy for the treatment of hydrocephalus with little success and this technology was abandoned due to its limited visualization and low magnification, no improvement in outcome, lack of proper instruments (Paine, 1955), relatively large size of the endoscope, and most importantly the availability of an alternative instrument with better outcome which is the microscope.

So although the theoretical idea of the endoscope seemed better, there were technical and logistic limitations and the application of this idea remained difficult and challenging. By the late 1980s, immense advancement in endoscopic technology like the introduction of rod lens, fiber optics, coupled cameras, high definition monitors, malleable scopes (FU, 2007), three dimensional endoscopes and numerous fine endoscopic tools (straight and curved) has made the endoscope a powerful tool in neurosurgery and its used expanded significantly in the last decade.

The common old saying "the eye of the obstetrician should be located in his fingertips" has now changed. In fact, the endoscope today has made possible to have the eye of the surgeon beyond the reach of the tip of his fingers or even beyond the tip of his instruments. Endoscopy has markedly improved visualization to a point that amount of magnification and illumination is not the main catch for an approach but the technique and maneuverability became the main concern in these minimally invasive procedures and how to prevent unwarranted maneuvers (Snyderman, 2009, Kassam, 2008).

### Challenges for endoscopy

With the endoscope being a more reliable tool, neurosurgeons explored its use in various areas of the skull base and numerous new approaches were developed to access unusual areas of the skull base. Endoscopy provides neurosurgeons with a huge advantage by being able to access almost every anatomical target within the realm of neurosurgery.  With this ability, endoscopy is now realized to be the new evolving era in minimally invasive neurosurgery (Oi, 2000).

In contrast to the microscopic techniques (most commonly used magnifying tool in neurosurgery), the endoscopic approaches are characterized by having narrower corridors than that of the microscope and the endoscope makes use of longer instruments (O’Malley, 2008), the endoscope also provides the surgeon with a monocular vision (this has been overcome with the new 3D endoscope). Robust endoscopic anatomical knowledge is very essential in all endoscopic approaches (Cavallo, 2005). Endoscopic surgical training is also significantly different than that of the microscope, and this necessitates proper training facilities and programs to train surgeons on these new innovative techniques (Snyderman, 2007) since there is no correlation between being skilled and experienced in using the microscope and being skilled and experienced in endoscopy.

With these significant differences new endoscopic surgical concepts evolved which need to be further investigated and studied, similar to most diagnostic and operative tools in surgery. The progression of neurosurgical endoscopy is dependent on, technological advancements, development of surgical techniques, sufficient training and robust anatomical knowledge (Hadad, 2006). Technological advancements have been discussed earlier, and sufficient endoscopic training can be acquired through clinical practice and cadaveric dissections, there is also a new trend towards developing endoscopic simulator for training purposes and several projects in our laboratory have been directed to develop and validate such a training modality.

Anatomy has always been the same throughout history; once a certain anatomy was described it stayed the same until today (excluding different anatomical variations and other anomalies). Neuro-anatomy is not any different, but knowing the map is always different than knowing how to navigate through different routes of the city. Thus in neurosurgery with the evolving new visualization tools and unusual positioning of the patient, new anatomical descriptions for different corridors and approaches are essential. This has been performed for microscopic neuro-anatomy and several endoscopic neuro-anatomy studies are out there in the literature which are crucial roadmaps for different approaches.

Endoscopic surgical techniques development can be achieved by either describing new techniques or through mastering existing ones through appreciating anatomy and applying surgical concepts of dissection, suction, cutting and several other maneuvering methods. As I mentioned earlier, endoscopy has brought up new surgical concepts such as “Surgical Freedom” (Wilson, 2013) which is the main focus of my thesis.

Being able to have the surgeon’s “eye” at the anatomical target -where dissection is taking place and where the tip of the instrument is- has several advantages. The operator can precisely observe the minute movements at the distal end of the instrument. Unlike conventional methods, endoscopic surgical corridor does not need to be wider or has a similar area to that of exposed area of interest, so there can be several “pinch points” along the surgical corridor that can be overcome by the leverage movements of the endoscope and endoscopic instruments while enabling the operator to keep track of the distal end of these instruments, these pinch points can significantly limit the view –thus the exposed area- when using a microscope. However, the ability of the operator to keep track of the position of the shaft and the proximal part of the instrument and the endoscope is limited and can produce surgical struggle which can be a source of distraction, frustration and fatigue and may affect the outcome of the procedure (Ramakrishnan, 2013). Therefore proper understanding of the available space for hand movements and endoscopic instruments’ ergonomics are warranted (Paluzzi, 2012), thus surgical freedom studies.

Surgical Freedom can be defined as the area in which the surgeon's hand can freely move while holding the proximal end of a surgical instrument and maneuvering the distal end of this instrument in a given surgical approach. Surgical freedom depends on the type of approach, anatomical target, exposed area (Wilson, 2013) and it also depends on the type and shape of surgical instruments.

Knowing the surgical freedom prior to operating can be very helpful in surgical planning, and although ancillary neuroradiology play an important role in surgical planning and decision making they can only provide the surgeon with the degree of extension of a lesion and the suitable trajectory for this lesion and might be plane limited (Ukimura, 2008). While surgical freedom will provide the surgeon with an estimate of freedom and ease that the surgeon should expect during the procedure which is a vital piece of information in any surgical procedure and can be essential during surgical planning. Several studies have reported certain preference for a particular approach or technique based on the ease and comfort that the surgeon may have while performing this particular approach while other studies may oppose this opinion (Kassam, 2009), this might be due to difference in training among institutions or different endoscopy training schools and experiences, that is why quantifying the surgical freedom can help settle this debate.

Using surgical freedom to compare between different endoscopic approaches that have been developed requires a reliable quantifying method that can measure this virtual area in space, and in my thesis I develop a method to quantify different types of surgical freedom that can be simply applied for almost all endoscopic approaches based on methods previously used in measuring potential space and area in our laboratory.

Surgical freedom, angle of attack and the area of exposure are complimentary surgical concepts that can that can influence approach selection. The angle of attack for a certain anatomical target represents the degree of maneuverability around this target in a certain plane (saggittal, axial, coronal)(Wilson 2013), while the exposed area is the anatomical region that needs to be exposed during the approach.

Another factor that plays a role in determining the surgical freedom is the presence of a pinch point along the surgical corridor, which is important because at this point a reversal of movement of the endoscope or the endoscopic surgical instrument occurs due to pivoting. There can be more than a pinch point along the surgical corridor which can limit the surgical freedom and change the pivot point along the endoscope with different maneuvers. Other factors such as the type of instrument and endoscope, degree of dissection, bone drilling and the presence of vital anatomical structures all can have an effect on the surgical freedom (Fraser, 2010, Kassam, 2011)).

In my thesis, all these factors are taken into consideration in developing this novel method of quantifying the surgical freedom, which by its turn can be a powerful tool for surgical planning and decision making as well as evaluating and comparing different endoscopic surgical approaches.

The following chapters show the application of the surgical freedom quantifying method in different endoscopic approaches and the results were then compared with the literature to validate our methods and to determine the application of knowledge of the surgical freedom.

These chapters have been designed and formatted under the direct supervision of Drs Little, Preul and Nakaji so that these chapters can be presented independently as peer review articles to professional journals and national / international conferences.

# Chapter 1

The following chapter has been presented on February 16th 2013 in the Proffered Papers XII section: Endoscopic Approaches / Anterior Skull Base at the North American Skull Base Society annual meeting 2013, Miami, FL. Also a complete revised manuscript has been accepted for publication at the Endoscopy section of the Skull Base Journal.

# CHAPTER 1

# COMPARISON OF SURGICAL FREEDOM AND AREA OF EXPOSURE IN THREE ENDOSCOPIC TRANSMAXILLARY APPROACHES TO THE ANTEROLATERAL CRANIAL BASE

**Elhadi AM, Mendes GA, Almefty K, Kalani YS, Nakaji P, Dru A, Preul MC, Little AS**

## Abstract

**Objective:** Endoscopic ipsilateral transmaxillary endonasal, contralateral transseptal transmaxillary and endoscopic Caldwell-Luc approaches can access lesions within the retromaxillary space and pterygopalatine fossa. We sought to compare the exposure and surgical freedom of these transmaxillary approaches to assist with surgical decision making.

**Design:** Four cadaveric heads were dissected bilaterally using the above three approaches. Prior to dissection, stereotactic CT scans were obtained on each head to obtain anatomic measurements. Surgical freedom and area of exposure were determined by stereotaxis.

**Main Outcome Measures:** Area of exposure was calculated as the extent of the orbital floor, maxillary sinus floor, nasal floor, and mandibular ramus exposed through each approach. Surgical freedom was the area through which the proximal end of the endoscope could be freely moved while moving the tip of the endoscope to the edges of the exposed area.

**Results:** The mean exposed area was similar, 9.9±2.5cm$^2$ (Caldwell-Luc), 10.4±2.6cm$^2$ (ipsilateral endonasal), and 10.1±2.1cm$^2$ (contralateral transseptal) ($p>0.05$). The surgical freedom of the Caldwell-Luc approach (113±7cm$^2$) was greater than for either approaches; 76cm$^2$±15, (p=0.001) (ipsilateral endonasal) and 83 cm$^2$±15, (p=0.003) contralateral transseptal.

**Conclusions:** Our work demonstrates that the Caldwell-Luc approach offers greater surgical freedom than either approach for anterolateral skull base targets. Although these approaches offer similar exposure.

## Introduction

The infratemporal fossa and pterygopalatine fossa are among the most inaccessible areas of the anterolateral skull base. Although open approaches have been used to access these domains,{1, 2, 3} these approaches often require extensive craniofacial resection associated with a high degree of morbidity. Less invasive endoscopic approaches that exploit the maxillary sinus have gradually replaced traditional open approaches for certain anterior and anterolateral skull base lesions.{4, 5, 6, 7, 8, 9, 10} The armamentarium of endoscopic approaches to this region includes the ipsilateral endonasal transmaxillary approach, sublabial transmaxillary approach (Caldwell-Luc), and the contralateral transseptal transmaxillary approach.{8}

The anterolateral skull base is anatomically complex and has been well described.{9, 32, 33} The infratemporal fossa and the pterygopalatine fossa communicate through the pterygomaxillary fissure. They are connected with the orbit through the inferior orbital fissure and with the middle cranial fossa through the foramen spinosum, foramen ovale, and foramen rotundum. The infratemporal fossa and pterygopalatine fossa are bordered superiorly by the squamous temporal bone, the posterior part of the orbital floor, and the inferior surface of the greater wing of the sphenoid. Medially they are bordered by the lateral part of the clivus, first cervical vertebrae, and inferior surface of the petrous bone.

Laterally, these areas are bordered by the zygomatic arch, ascending mandibular ramus, mandibular angle, parotid gland, and masseter and temporalis muscles. Inferiorly, they are connected with the peripharyngeal space and posteriorly they continue as the temporal space and, anteriorly, by the posterior wall of the maxillary sinus.  Proper understanding of the different approaches through this corridor is important for surgical planning, Because of the anatomical relationships of the pterygopalatine fossa and the presence of neurovascular structures such as the maxillary artery, maxillary (V2) and mandibular (V3) nerves, pterygopalatine ganglion, and infraorbital nerve and artery. Anterior endoscopic approaches to the lateral skull base typically cross the pterygopalatine fossa. A transmaxillary corridor has been used to access the infratemporal fossa, parapharyngeal space, middle cranial fossa, and anterolateral skull base.{6, 7, 9} However, detailed anatomical comparisons of endoscopic approaches with anatomical correlations in these areas are lacking but are necessary for selecting the optimal approach.

Surgical freedom and area of exposure are important surgical concepts in skull base surgery that may influence surgical decision making and approach selection. *Surgical freedom* describes the working area for a surgeon's hands and the instruments necessary to complete the operative goals. Greater working area improves the ease of surgery. *Area of exposure* defines the surgical field and what anatomical targets can be reached with a given exposure.

Previously, we developed a model system based on neuronavigation to study the surgical freedom and angle of attack of the ipsilateral endonasal transmaxillary approach and the Caldwell-Luc transmaxillary approach{34} for surgical targets in the anterolateral skull base. In the current study, we extend our previous work by studying the surgical freedom provided by the contralateral endonasal transseptal transmaxillary approach and also by studying the area of exposure.

## Materials and methods

Three endoscopic transmaxillary approaches were performed bilaterally in four fresh silicon-injected heads (Fig. 1.1). Dissections were performed using a 0° endoscope and standard endoscopic techniques, with heads placed in rigid fixation in a supine position. Burrs, dissector blades, and standard endoscopic instruments (Karl Storz, Tuttlingen, Germany) were used. Visualization was supplemented with 30° and 45° endoscopes for lateral visualization. High-resolution computed tomography (CT) scans were performed on each specimen to document the bony facial and cranial anatomy, and the images were uploaded to an image guidance platform (StealthStation Treon Plus with FrameLink Software, Medtronic, Louisville, CO). Image guidance was used to obtain anatomical measurements and to confirm anatomical structures.

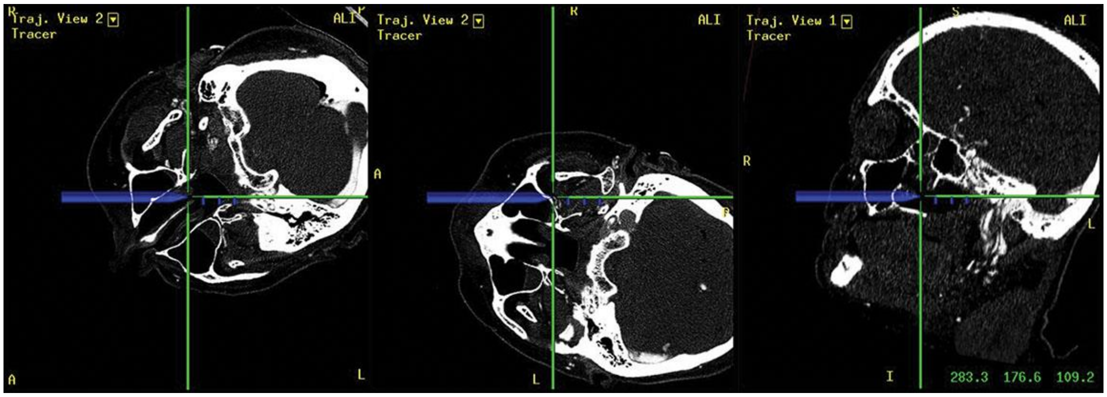

Image guidance still images showing the trajectory, as well as the position of the registered blunt tip when measuring the area of exposure in a Caldwell Luc approach (Right Side).

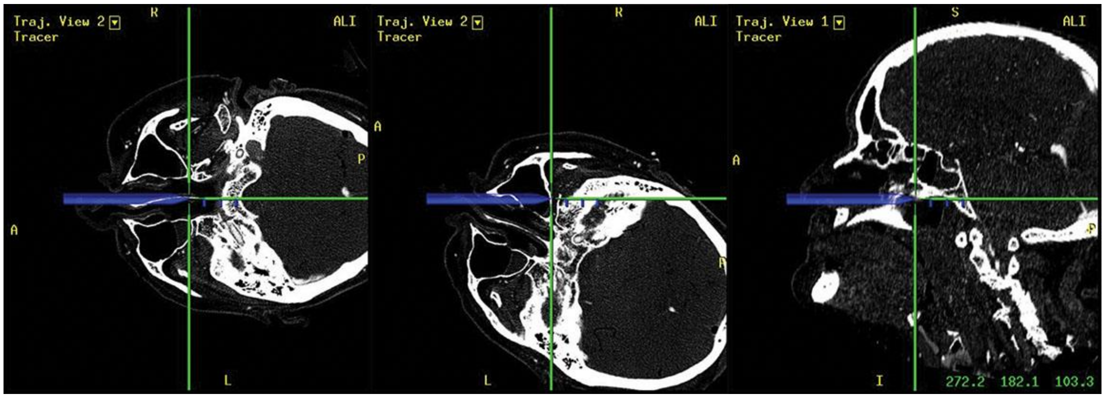

Image guidance still images showing the trajectory, as well as the position of the registered blunt tip when measuring the area of exposure in an Ipsilateral Endonasal approach (Right Side).

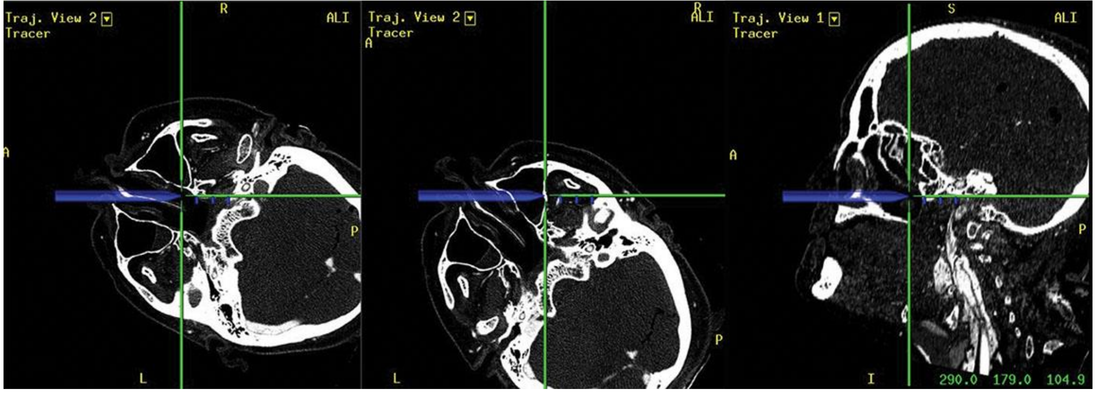

Image guidance still images showing the trajectory, as well as the position of the registered blunt tip when measuring the area of exposure in a Contralateral Transseptal approach (Right Side).

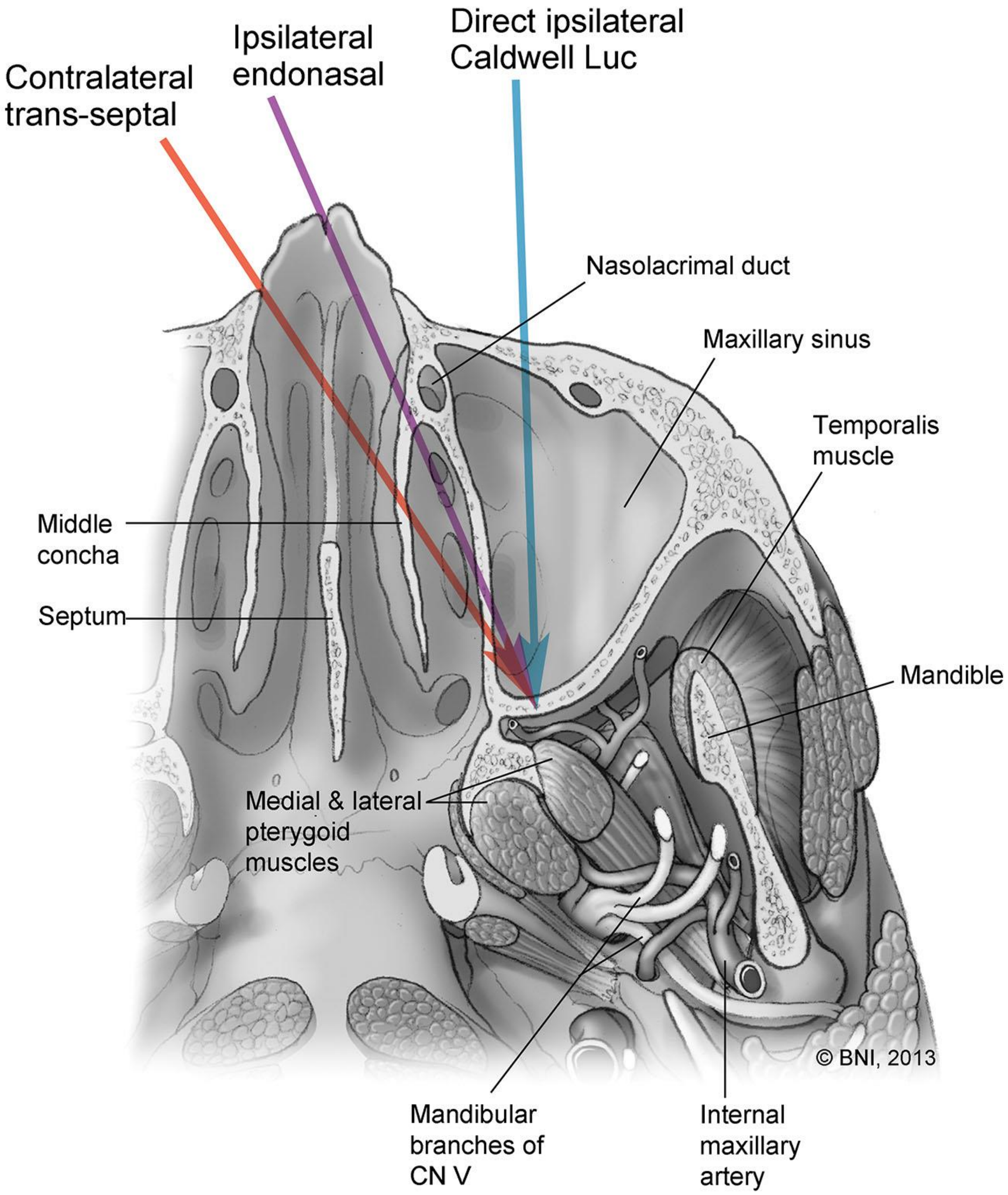

**Figure 1.1**

An illustration showing anatomy of the lateral skull base (inferior image). The arrows show the trajectories used for the three endoscopic approaches. *Used with permission from Barrow Neurological Institute.*

**Ipsilateral sublabial transmaxillary approach:** Similar to techniques described previously,{9, 17, 20, 34} the upper lip is retracted and a transverse incision is made at the buccogingival sulcus just lateral from the canine and extending laterally to the second molar. The incision is made through the mucosa and periosteum. A subperiosteal plane is developed, exposing the anterior wall of the maxilla. Care is taken to protect the infraorbital nerve, which is the superior limitation of the anterior maxillary wall exposure. An osteotome is used to perform an anterior maxillotomy, and the opening is enlarged using Kerrison rongeurs (Integra, Plainsboro, NJ), to create an osteotomy approximately 15 mm wide and 10 mm high. After entering the maxillary sinus, (Fig. 1.2A) the mucosa is peeled away and the infraorbital nerve is identified at the junction between the maxillary roof and posterior wall. A second osteotomy is made in the posterior wall, and the posterior wall is removed using a Kerrison rongeur to expose the periosteum, which is opened to enter the pterygopalatine fossa and expose its contents.

**Ipsilateral endonasal transmaxillary approach:** The endonasal transmaxillary approach has previously been described in detail.{5, 7, 10, 13, 17, 18, 19, 34} In brief, the middle turbinate bone is removed through the ipsilateral nostril, and the inferior turbinate bone is reflected inferiorly or removed, allowing the ethmoid bulla to be identified. An antrostomy is performed using a Kerrison rongeur to allow access to the maxillary sinus (Fig. 1.2B), and the greater palatine nerve and artery are preserved along the junction between the maxillary base and posterior maxillary wall. To increase the intranasal exposure, the ethmoid bulla is removed, exposing the anterior ethmoid artery, and then the sphenopalatine artery is identified and preserved. Next, the infraorbital nerve is identified in the roof of the maxillary sinus, and the posterior maxillary sinus is fractured and carefully removed with Kerrison rongeurs. After removing the posterior maxillary wall, the periosteal membrane is immediately visible and is dissected to expose the contents of the pterygopalatine fossa, which includes the internal maxillary artery and a complex network of its branches. The pterygopalatine ganglion is identified posterior to the sphenopalatine artery and fat tissue; tracing the pterygopalatine ganglion posteriorly and medially can lead to the vidian canal and the vidian nerve. The approach is extended along the course of the vidian canal to the medial portion of the internal carotid artery (ICA) genu by drilling the medial pterygoid plate using a 2-mm diamond bit. The infraorbital nerve is followed posteriorly to the maxillary branch of the trigeminal nerve (V2). The lateral plate of the pterygoid is removed to expose the foramen ovale and the mandibular division of the trigeminal nerve (V3).

**Contralateral endonasal transseptal approach:** The contralateral endonasal transeptal approach provides access to the maxillary sinus through the contralateral nasal cavity {8, 22} with a nasoseptal mucosal flap pedicled posteriorly on the septal branch of the sphenopalatine artery (Fig. 1.2C). An additional ipsilateral flap may also be performed, but was not done in this study. Once access is gained to the ipsilateral nasal cavity, the transmaxillary dissection is performed in a similar manner to the ipsilateral endonasal transmaxillary approach described previously. The endoscope is advanced until it reaches the posterior third of the nasal septum of the contralateral nasal cavity and is then directed through the transseptal window. The endoscope and an instrument are advanced to the maxillary sinus and retromaxillary space.

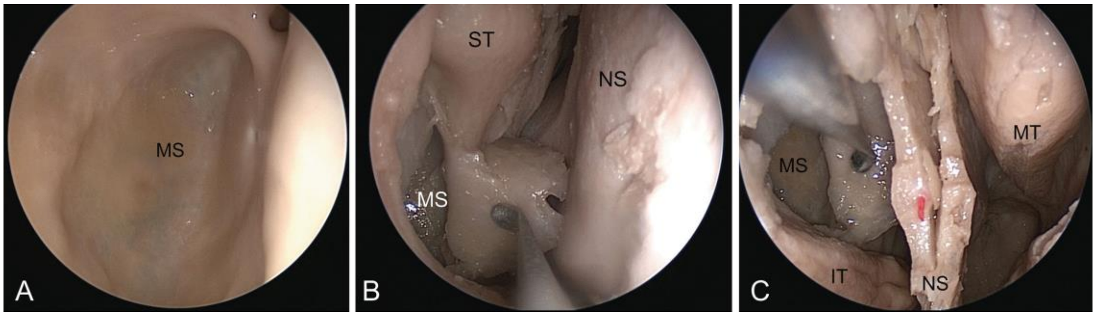

**Figure 1.2**

Images for a 0° endoscope from the right side of cadaveric dissections showing the corridors used to access the maxillary sinus: A) Ipsilateral Caldwell Luc approach, B) ipsilateral endonasal approach, C) contralateral (from left nostril) transseptal approach. MS= maxillary Sinus, ST= superior turbinate, MT= middle turbinate, IT= inferior turbinate, NS= nasal septum. *Used with permission from Barrow Neurological Institute.*

**Area of exposure**

To calculate the area of exposure, four points were identified. The first point (ION) was a fixed anatomical landmark that is the point at which the infraorbital nerve enters the infraorbital canal and is crossed by the infraorbital artery. The other three points were determined relative to the infraorbital nerve: 1) a medial point (MP), which was defined as the point at the junction between the vomer and the sphenoid crest; 2) a lateral point (LP) which was defined as the point directly lateral to the infraorbital nerve after removal of the posterior wall of the maxillary sinus and represented the most lateral point of exposure; and 3) an inferior point (IP) directly inferior to the ION and slightly lateral to the inferior part of the junction between the base of the maxillary sinus and the posterior maxillary wall, just lateral to the greater palatine nerve and vessel.  The MP, LP, and IP were used to determine the medial, lateral and inferior extent of the exposure, respectively. Although the extent of each approach can be increased by using curved instruments and angled endoscopes or using other maneuvers to increase the angle of attack, in our dissections we used only standardized approaches with a standard antrostomy, septectomy or medial maxillotomy.

Three other anatomical landmarks were identified and further dissected for anatomical reference. The first landmark was the Eustachian tube (ET) at the level of the nasopharynx just anterior to the posterior choana.  The second landmark was the second genu of the internal carotid artery (gICA) which was exposed after drilling the sphenoidal wall. The third landmark was the second division of the trigeminal nerve (V2) as it exits the foramen rotundum.

Screen captures from the neuronavigation system were used to measure the area of exposure The area of exposure was identified as the sum of two areas (Fig. 1.3). The first is a rectangular area bounded by a line between the ION and IP laterally, by a line between the ION and MP superiorly, by a line between the the IP and the medial border of the posterior choana inferiorly, and by the junction between the septum and the vomer medially. The second area is a triangular area between the ION, IP, and LP.

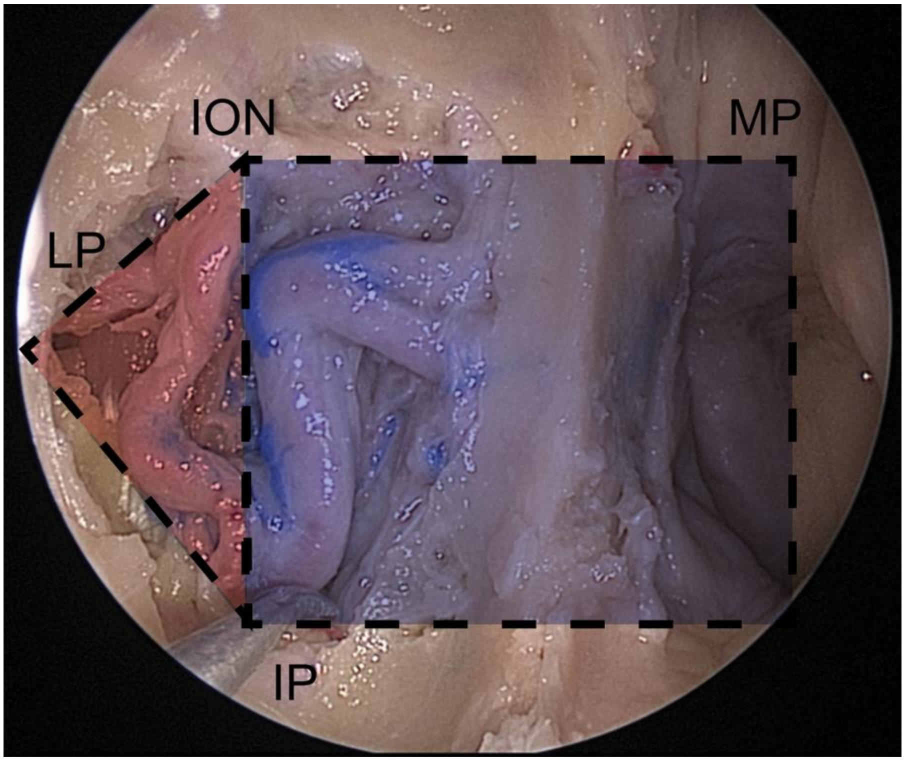

**Figure 1.3**

An endoscopic image form an ipsilateral endonasal (right side) approach showing the area of exposure as the sum of two areas; a rectangular area (highlighted in blue) and a triangular area (highlighted in red). LP: lateral point which represents the lateral extent of a registered blunt tip. IP: inferior point which represents the inferior extent of a registered blunt tip. MP: medial point which represents the medial extent of a registered blunt tip. ION: Infraorbital nerve, as it enters the infraorbital canal. *Used with permission from Barrow Neurological Institute.*

### Surgical freedom

Surgical freedom was defined as the maximal oval area along which the surgical (proximal) end of the endoscope can be freely and easily moved. This area was calculated by measuring the vertical and transverse limits that can be reached by the proximal end of the endoscope (Fig. 1.4A).

The neuro-navigation system was used to measure the transverse limit (Fig. 1.4B-D) which was determined by identifying two points in space. The first point corresponded to the position of the proximal end of the endoscope while placing the distal end of the endoscope as closely as possible to the midpoint of the line between the IP and LP and moving the proximal end of the endoscope as medially as possible, sometimes even crossing the midline. The second point was determined at the proximal end of the endoscope while placing the distal end of the endoscope at the midpoint between the MP and medial border of the posterior choana and moving the endoscope as far laterally as possible.

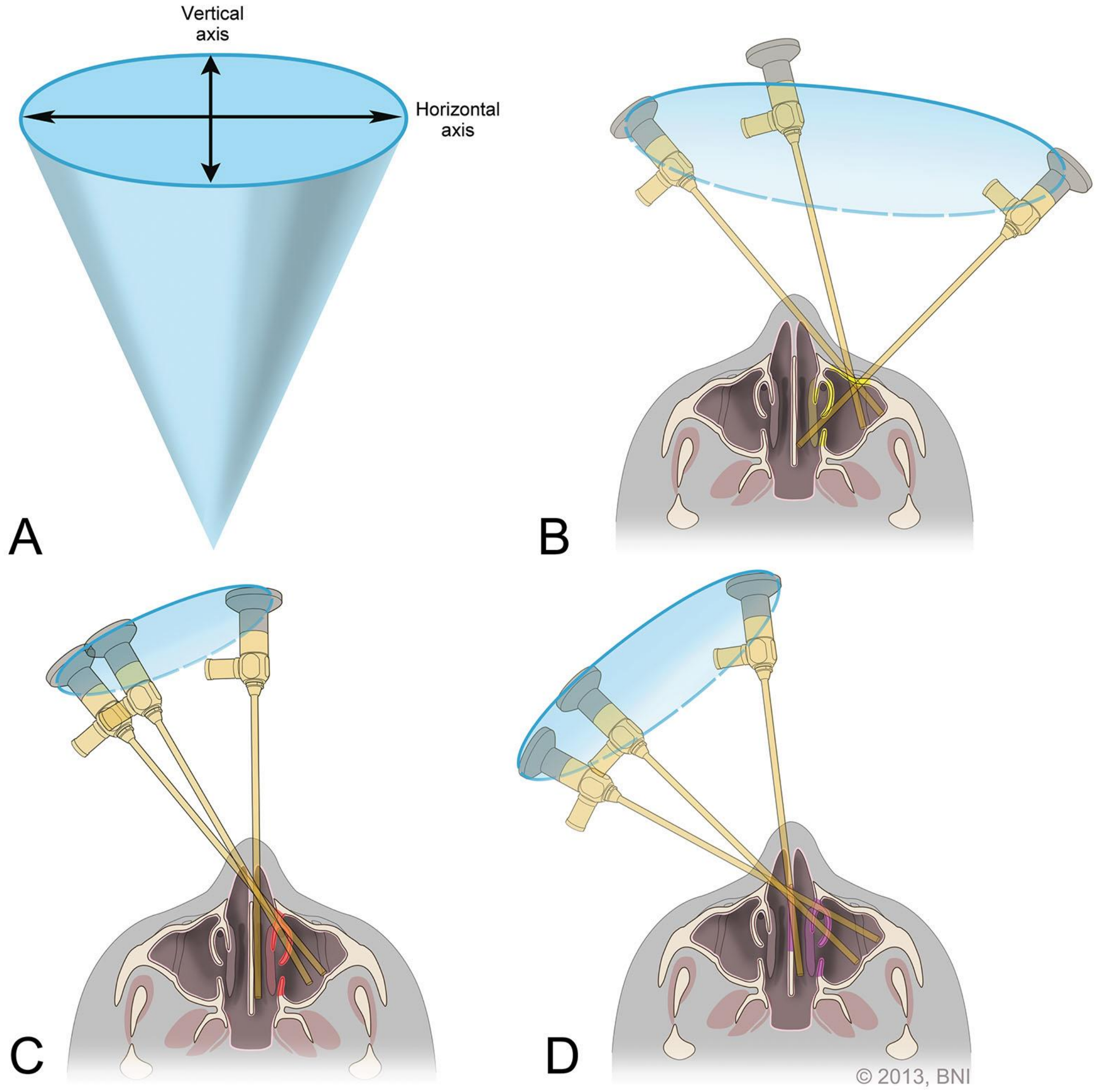

**Figure 1.4**

An illustration demonstrating the method used to calculate the area of surgical freedom. (A) A cone that represents the volume where the endoscope can be freely moved. The oval area at the base of the cone is the area of surgical freedom. for an ipsilateral sublabial approach (B), ipsilateral endonasal approach (C), contralateral transseptal approach (D). *Used with permission from Barrow Neurological Institute.*

In a similar fashion, the vertical limit of the surgical freedom was determined by identifying two points in space. The first point was determined by the position of the proximal end of the endoscope while placing the distal end of the endoscope at a point along the ION and IP as superiorly as possible and moving the proximal end of the endoscope gently as inferiorly as possible. The second point was identified as the position of the proximal end of the endoscope while placing the distal end of the endoscope on a point along the line between the ION and IP as inferiorly as possible while moving the proximal end of the endoscope gently and superiorly. These two points were considered to determine the vertical limit of the surgical freedom. A series of t-tests were used to compare the average means of the surgical freedom and area of exposure for each approach with the other two approaches. Analysis of variance (ANOVA) was also used to compare the surgical freedom between all three approaches.

## **Results**

The mean area of exposure for the three endoscopic approaches was similar (Fig. 1.5, Table 1.1). The sublabial approach had an area of 9.92 ± 2.5 $cm^2$, the endoscopic endonasal approach had an area of 10.47 ± 2.65 $cm^2$, and the transseptal approach had an area of 10.01 ± 2.16 $cm^2$.

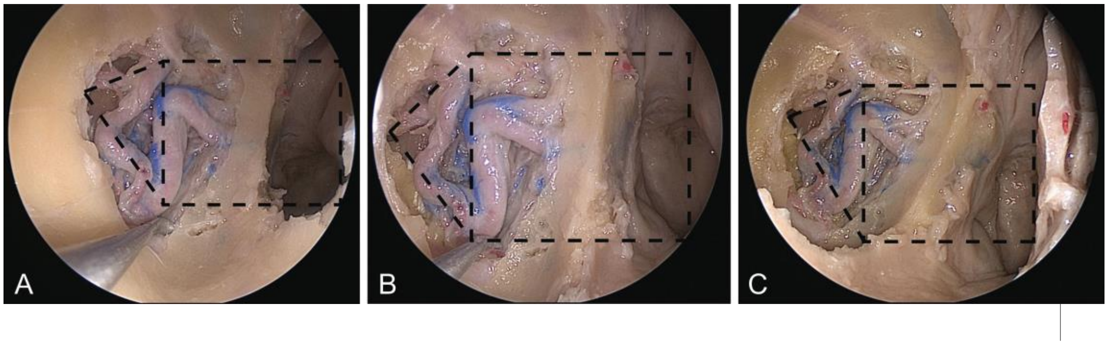

**Figure 1.5**

Endoscopic images using a 0° endoscope for the three different approaches (right side). (A) Sublabial, (B) ipsilateral endonasal and (C) contralateral transseptal. *Used with permission from Barrow Neurological Institute.*

**Table 1.1** Comparison of the area of exposure for the three endoscopic transmaxillary approaches

| | Area mean (mm2) + STDEV | p-value (compared to ipsilateral Caldwell-Luc approach) |
|---|---|---|
| Ipsilateral endonasal | 1047 ± 265 | 0.2 |
| Ipsilateral Caldwell-Luc | 992 ±249 | N/A |
| Contralateral endonasal transseptal | 1001 ± 216 | 0.3 |

When the triangular lateral area of exposure was compared between approaches, the transseptal approach provided approximately 2.7 $cm^2$ of exposure, the endonasal approach provided 2.45 $cm^2$ of exposure, and the sublabial approach provided 2.02 $cm^2$ of exposure. The increase in the lateral area of exposure in the transseptal approach was accompanied by a decrease in medial exposure and vice versa, with the sublabial approach resulting in similar quantities for total area exposed. Anatomical structures limiting exposure were the orbital floor and superior border of the sphenoid sinus superiorly, the nasal floor and maxillary sinus floor inferiorly, the nasal septum medially, and the lateral wall of the maxillary sinus laterally.

The mean areas of surgical freedom were 112.82 ± 7 $cm^2$ for the sublabial approach, 76.3 ± 14.5 $cm^2$ for the ipsilateral endonasal approach, and 83.51 ± 15.13 $cm^2$ for the contralateral transseptal approach. The sublabial approach provided significantly more surgical freedom when compared to the ipsilateral endonasal approach (p <.01) and the transeptal approach (p <.01, Table 1.2). No significant difference was found in the surgical freedom afforded between the endonasal ipsilateral and transeptal approaches (p=0.20). The mean transverse (T) and vertical (V) axis of the three approaches were 12.8 cm ± 1.2(T) and 11 cm ± 0.6 (V) for the sublabial, 8.9 cm ± 1 (T) and 10.5 ± 1.1 (V) for the endoscopic endonasal, and 10.6 cm ± 1.2(T) and 9.7cm ± 1(V) for the transseptal.

**Table 1.2** Comparison of surgical freedom for three endoscopic transmaxillary approaches.

| | Area mean (mm2) + STDEV | p-value (compared to ipsilateral Caldwell-Luc approach) |
|---|---|---|
| Ipsilateral endonasal | 7630 ± 1454 | 0.0005 |
| Ipsilateral Caldwell-Luc | 11282 ± 696 | N/A |
| Contralateral endonasal transseptal | 8351 ± 1513 | 0.001 |

N/A, not applicable

## Discussion

Endonasal endoscopic approaches have been used with good results to access midline lesions of the pituitary, and suprasellar and clival lesions.{16, 23, 24, 25, 26} They have been used widely for benign tumors{17, 28, 29} and have recently been applied to malignant lesions.{17, 30} The morbidity of open surgical approaches to this region have allowed for a natural expansion of the endoscopic technique to the lateral anterior skull base regions.{3, 27} Although they were initially used only for diagnostic and palliative treatment, endoscopic techniques are now routinely being used in the primary treatment of anterolateral skull base lesions such as inverted papillomas and juvenile angiofibromas.{4, 7} The maxillary sinus has been used as a corridor to access the lateral skull base. The sinus is a natural route and its large volume permits a great deal of surgical freedom and access to critical neurovascular structures. Several transmaxillary approaches has been used in the treatment of retromaxillary lesions.{9, 17}

Our data show that the sublabial approach provides the best horizontal working space, while the endonasal approach has the least horizontal working space; therefore, a sublabial approach may be superior in the case of tumors that extend in the same axial plane. In addition, we found that the transseptal approach has the least vertical working space; as a result, it may not be the best option in the case of tumors or lesions that extend in the same sagittal plane. The approaches that we describe in this study have been previously described with a detailed anatomical overview,{9, 22} but an analysis of the exposed working space, including the surgical freedom and the area of exposure, has not been previously described. These concepts are important in planning the appropriate surgical approach for a specific lesion and for understanding the limitations of each of the approaches. Theodospolous et al.{9} concluded in an anatomical study that a combined ipsilateral sublabial and ipsilateral endonasal approach can provide a full exposure to the infratemporal fossa and pterygopalatine fossa, but the lateral aspect of the infratemporal fossa was challenging to access and required traumatic traction to the nose. Eloy et al.{22} demonstrated that the transseptal approach provided more posterolateral exposure for the infratemporal fossa. Our study confirms this: combining any of these approaches with a contralateral endonasal transseptal approach will provide a lateral shift of the area of exposure. This shift in exposure will assist in the removal of lesions that extend as far laterally as the mandibular ramus and temporalis muscle. In our study, the quantitative exposed area for each approach was similar; however, the areas exposed were not the same. Therefore, combining any two approaches will allow for a larger exposure. Combining the ipsilateral sublabial approach with the transseptal approach provides an additional 1.2 $cm^2$ of exposure and adds increased maneuverability, permitting a four-handed technique to be used. Adding an ipsilateral endonasal approach increases the exposed area by 0.6 $cm^2$, which may be of great value in approaching large, challenging lesions.

In their cadaveric study, Harvey et al.{8} determined that surgical access was increased 14.7 ± 2.5 % when a transseptal approach is used compared to ipsilateral approaches. According to our data, the contralateral transseptal exposure will lead to an increase of approximately 12% and 11% in the area of exposure when compared to an ipsilateral endonasal and ipsilateral sublabial approaches, respectively.

In cadaveric studies, Hartnick et al.{31} and Eloy et al.{22} approached the infratemporal fossa via a temporal hairline incision and concluded that it is a limited approach that can be used only for targeted CSF leak treatment or lesion biopsy. Eloy et al. concluded that adding this approach to any of the previously described approaches may lead to an increased surgical freedom to the superior portion of the infratemporal fossa.{22} With the increased experience of the surgical team, the use of angled endoscopes and angled instruments can be helpful in increasing the size of the accessible operative field and leading to improved tumor resections.{35, 36} While these angled instruments and endoscopes would greatly increase the extent and application for each approach, in our comparison we used only straight instruments and a 0° endoscope, so that we could study the approaches in a standard manner.

Other maneuvers can be used to increase surgical freedom. For example, in the sublabial approach, the anterior maxillary antrostomy can be widened, but care should be taken with the superior extension of the antrostomy so as not to injure the infraorbital nerve and artery.{9} For the endonasal approach, the medial maxillotomy can be enlarged and the piriform aperture drilled (Denker's approach), but the lacrimal duct should be identified and spared to prevent post-operative complications. For the contralateral endonasal approach, a larger septectomy will allow easier introduction of other endoscopic instruments.{8}

The difference in surgical freedom among the three approaches, with similar exposed areas, is attributed to the pivot point (Pinch point, Fig. 1.6). The pivot point is the fixed point between the tip of the endoscope and the base of the endoscope where the direction of movement is changed. The movement of the proximal end of the endoscope to one direction results in a movement of the distal end to the opposite direction. The pivot point was closer to the tip in the sublabial approach (1-3 cm), thus a larger movement of the proximal end results in a smaller and finer movement at the distal end of the endoscope. The pivot point ranged from 4.5-7 cm in the ipsilateral endonasal approach; thus, a movement of the proximal end would lead to a larger movement of the distal end when compared to the sublabial approach.

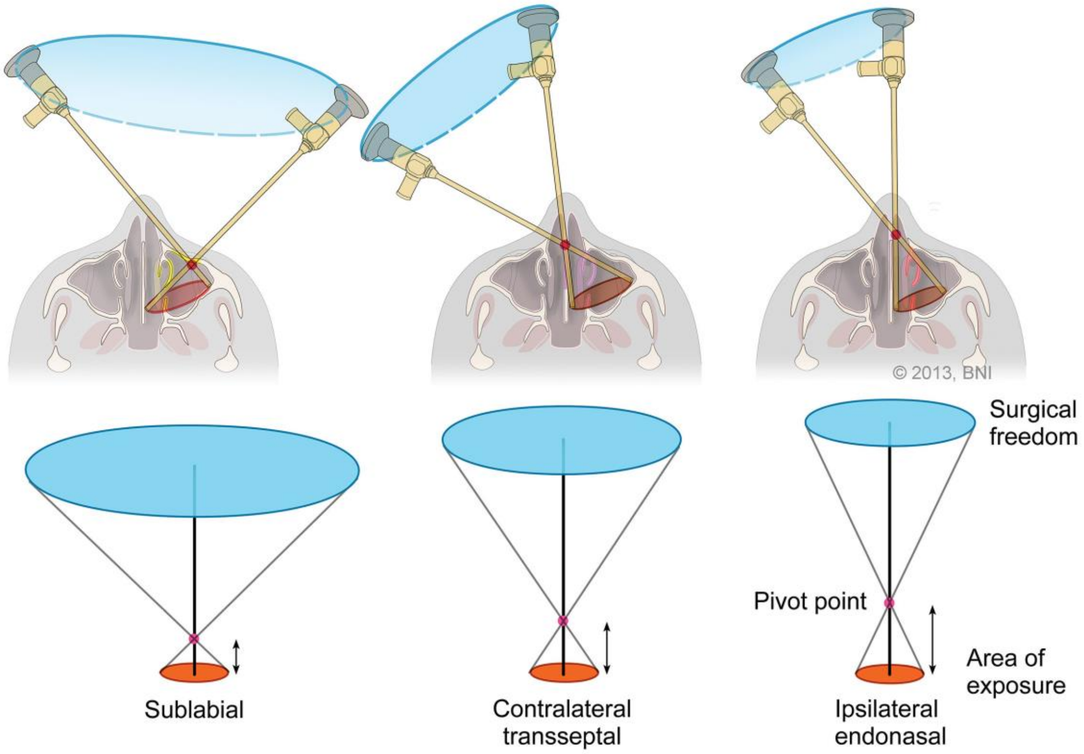

**Figure 1.6**

A diagram showing the importance of the pivot point in the three different approaches, which when changed (depending on the approach) with a fixed area of exposure, affect the degree of surgical freedom. *Used with permission from Barrow Neurological Institute.*

## Conclusion

The sublabial, ipsilateral endonasal, and contralateral transseptal endoscopic transmaxillary approaches provide excellent exposure to the retromaxillary area. The quantity of area exposed is similar for the three approaches, but the transseptal approach offers greater lateral exposure.  Surgical freedom is greatest with the sublabial approach and is least in the ipsilateral endonasal approach. This information may benefit practitioners in surgical planning and decision making for lesions of the infratemporal fossa and pterygopalatine fossa.

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# CHAPTER 2

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The following chapter has been presented on February 15th 2014 in the Proffered Papers IX section: Endonasal approaches 3, at the North American Skull Base Society annual meeting 2014, San Diego, CA. Also a complete and revised manuscript has been submitted for publication at the Journal of Operative Neurosurgery.

# CHAPTER 2

# Evaluation of Surgical Freedom for Microscopic and Endoscopic Transsphenoidal Approaches to the Sella

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**Elhadi AM, Hardesty H, Zaidi H, Kalani YS, Nakaji P, White WL, Preul MC, Little AS.**

## ABSTRACT

**Background.** Microscopic and endoscopic transsphenoidal approaches to the sellar are well-established. Surgical freedom is an important skull base principle that can be measured objectively and compare approaches.

**Objective.** In this study, we compared the surgical freedom of four transsphenoidal approaches to the sella turcica.

**Methods.** Four transsphenoidal approaches to the sella (microscopic sublabial, microscopic endonasal, endoscopic binostril, and endoscopic uninostril) were performed on eight silicon-injected cadaveric heads. Surgical freedom was determined with stereotactic image guidance using previously established techniques. The results are presented as the area of surgical freedom and angular surgical freedom (angle of attack) in the axial and sagittal planes.

**Results.** Mean total exposed area surgical freedom for the microscopic sublabial, endoscopic binostril, endoscopic uninostril, and microscopic endonasal approaches were 102±13cm2, 89±6cm2, 81±4cm2, and 69±10cm2, respectively. The endoscopic binostril approach had the greatest surgical freedom at the pituitary gland, ipsilateral and contralateral ICAs (25.7±5.4, 28.0±4.0, and 23.0±3.0 $cm^2$) compared to microscopic sublabial (21.8±3.5, 21.3±2.4, and 19.5±6.3 $cm^2$), microscopic endonasal (14.2±2.7, 14.1±3.2, and 16.3±4.0 $cm^2$), and endoscopic uninostril (19.7±4.8, 22.4±2.3, and 19.5±2.9 $cm^2$). Axial angle of attack was greatest for the microscopic sublabial approach to the same targets (14.7±1.3, 11.0±1.5, and 11.8±1.1 degrees). For the sagittal angle of attack, the endoscopic binostril approach was superior for all three targets (16.6±1.7, 17.2±0.70, and 15.5±1.2 degrees).

**Conclusions.** The microscopic sublabial and endoscopic binostril approaches provided superior surgical freedom compared to the endonasal microscopic and uninostril endoscopic approaches. This work provides objective, baseline values for the quantification and evaluating future refinements in surgical technique or instrumentation.

## INTRODUCTION

Surgical approaches to sellar region pathology have challenged neurosurgeons since the inception of the field. Microscope-based transsphenoidal approaches using either a sublabial or transnasal passageway are the mainstay of the neurosurgical armamentarium for sellar lesions with excellent results.{6,14,18} In the last two decades, progressive technological advances in the field of neurosurgical endoscopy have ushered in the endoscopic, endonasal, transsphenoidal approach as a viable alternative to microscope-based approaches. Excellent clinical results for a wide variety of sellar pathology have been published using purely endoscopic surgical techniques.{2,4,6,8,12,19} A significant volume of literature has been published regarding the clinical outcomes and complications of microscope- and endoscope-based approaches to the sella. However, there remains a paucity of head-to-head comparisons of the strategies from a technical standpoint. Spencer and colleagues performed a variety of microsurgical and endoscopic transsphenoidal approaches on cadavers and found a significantly improved volume of exposure with endoscopy-based approaches, especially in visualization superiorly (above the dorsum sella) but also in lateral and anterior bony exposure.{20} Catapano and colleagues also demonstrated greater bony exposure using an endoscopic approach compared to a microsurgical approach to the sella.{3} Yet, no anatomical study has examined the surgeon's ability to manipulate instruments at the sella with these approaches, nor determined if one approach provides a superior working corridor. Our laboratory and others have previously established a method of assessing the surgical freedom and angles of attack provided by various microsurgical and endoscopic exposures using stereotaxy.{7,9,17,21} This provides a quantitative analysis of the surgeon's ability to move instruments in space during surgery through the operative corridor, and permits a more rigorous and objective comparison of skull base approaches. Herein we apply the same anatomic analyses to the microscopic and endoscopic transsphenoidal approaches to the sella.

## METHODS

We dissected eight silicon-injected, formalin-fixed cadaveric heads using four transsphenoidal approaches. Two endoscopic approaches were used: a uninostril endonasal transsphenoidal and a binostril endonasal transsphenoidal approach. Two microscopic transsphenoidal approaches were also used: a microscopic endonasal transsphenoidal and a microscopic sublabial transsphenoidal approach. Details of each approach are described below.

Endoscopic approaches were performed using a 0° endoscope and standard endoscopic techniques, burrs, dissector blades, and standard endoscopic instruments

(Karl Storz, Tuttlingen, Germany) with heads placed in rigid fixation in a supine position. Microscopic approaches were performed using a standard surgical microscope (Pentero, Zeiss, Germany) and standard micro-surgical instruments, with the heads placed in rigid fixation in a supine position. High-resolution computed tomography (CT) scans were performed on each specimen to document the bony facial and cranial anatomy, and the images were uploaded to an image guidance platform (StealthStation Treon Plus with FrameLink Software, Medtronic, Louisville, CO). Image guidance was used to obtain anatomical measurements and to confirm anatomical structures. For endoscopic measurements, the endoscope was parked in the superior aspect of the right nares. Statistical analysis was performed by comparing the data collected from the each approach with the other approaches using two-tailed t-tests, and significance was determined when p-value was less than 0.05, and analysis of variance (ANOVA) was used to further compare between the means of surgical freedom and angle of attack for the four different approaches.

### Uninostril endoscopic endonasal transsphenoidal approach

This approach has been described previously.{1} In brief, we used the right nostril to approach the nasal cavity and the middle turbinate was out-fractured. The sphenoid ostia were identified bilaterally and opened widely using a mushroom punch or Kerrison rongeurs. The posterior third of the bony septum was resected along with a piece of the vomer. The sphenoid rostrum was then opened wide using a drill or punch, and bilateral posterior ethmoidectomies were performed. The posterior wall of the sphenoid sinus was then removed to expose the anterior pituitary, the cavernous internal carotid artery (cICA) and a part of the petrous internal carotid artery (pICA). In a unilateral approach, the contralateral nasal mucosa is preserved. For all measurements, the endoscope and the endoscopic dissector instrument were both inserted through the right naris.

### Binostril endoscopic endonasal transsphenoidal approach

In this approach dissections were performed similar to the previous approach but the contralateral posterior septal mucosa was removed and the left middle turbinate outfractured,{13,22} such that the endoscope can be inserted through the right naris and the dissector inserted through the left naris. To remain consistent with the other approaches, the terms ipsilateral and contralateral in reference to the carotid arteries, etc, for this approach are named by the side of endoscope insertion. An advantage to the binostril approach that we did not attempt to quantify in this study is that the dissector can be placed through whichever nares provides the best working angle for the surgeon.

### Microscopic endonasal transsphenoidal approach

The classic approach has been well-described by Griffith in 1987, and several modifications have been reported.{10} The technique was performed as follows. A vertical incision was made at the mucodermal junction of the nasal septum, and the incision was then extended to the nasal floor. The mucosa was then dissected from the septal cartilage and elevated from the nasal floor, whereafter dissection was extended to the anterior wall of the sphenoid sinus. The posterior part of the septal cartilage was disarticulated from the plate of the ethmoid and vomer, and the 80 mm nasal speculum was inserted to retract the mucosa and expose the anterior wall of the sphenoid sinus. The anterior wall of the sphenoid was removed and bilateral ethmoidectomies were performed to expose the clivus and sellar floor. The pituitary gland, cICA, and pICA were exposed by bony removal of the posterior sphenoid wall and the carotid prominence. The right naris was used for all measurements.

### Sublabial microscopic transsphenoidal approach

Similar to the classic technique by Jules Hardy, a horizontal incision was made under the upper lip at the junction of the gum.{11} This incision was made deep enough to incise the periosteum then elevated using a Cushing periosteal elevator to expose the nasal cavum which was enlarged using rongeurs. The mucosal elevator was introduced along the nasal septum to detach the mucosa from the cartilage to the deepest part of the septum to the vomer. A Fukoshima nasal speculum was used to hold the mucosa out of the field, and the nasal cartilage was removed creating a new submucosal cavity. The vomer was detached and further resection of the sphenoid wall performed to expose the whole sphenoid sinus cavity. The sphenoid mucosa was removed, exposing the sellar floor along with the carotid prominence on both sides.

### Exposed area surgical freedom

This variable is calculated using four points in space and represents the available area of maneuverability that can be offered for the proximal (surgeon’s) end of an endoscopic instrument (2 mm dissector, 23 cm in length) while moving the distal end of this instrument along the borders of the exposed area (holding the endoscope within the nasal vestibule, in the endoscopic approaches). The four points were determined using the neuro-navigation system. Each point corresponded to the position (outside the patient) of the proximal end of the dissector while placing the distal end of the dissector at an anatomic target. The four anatomic targets for the distal dissector were as follows: first point, contralateral cICA with the proximal dissector as inferior and lateral as possible; second point, ipsilateral pICA with the proximal dissector as superior and medial as possible; third point, ipsilateral cICA with the proximal dissector as inferior and medial as possible; fourth point, contralateral pICA with the proximal dissector superior and lateral as possible (Fig. 2.1). In case of microscopic approaches, the surgical freedom was measured after placing the nasal speculum and measuring the freedom of the dissector in a similar fashion (Fig. 2.2). With these four points measured, three vectors were calculated which represent two juxtaposed triangles and the surgical freedom is the sum of the area of these two triangles. {7,9,17,21}

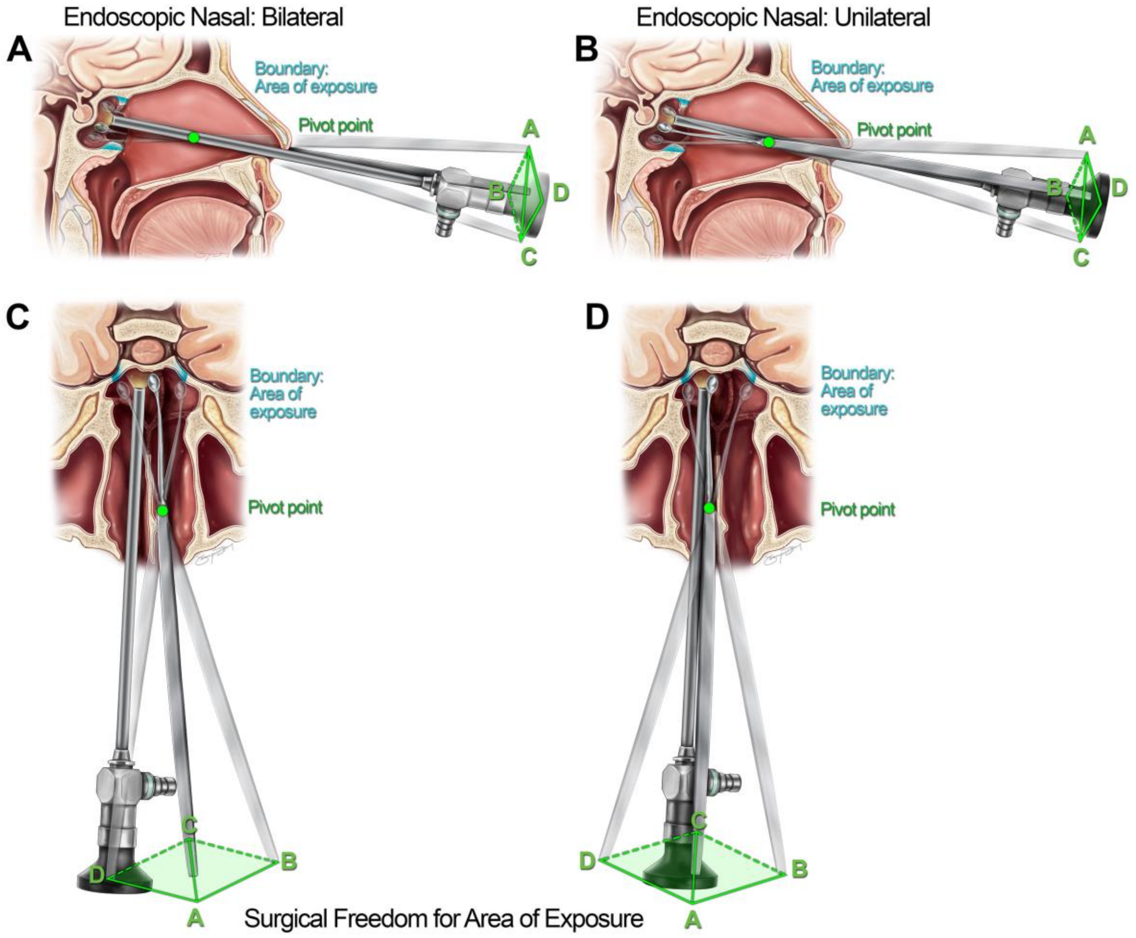

**Figure 2.1**

An illustration showing the exposed area surgical freedom for the two endoscopic approaches; Endoscopic Endonasal Binostril approach (A) sagittal, (C) axial, and the Endoscopic Endonasal Uninostril approach (B) sagittal, (D) axial.

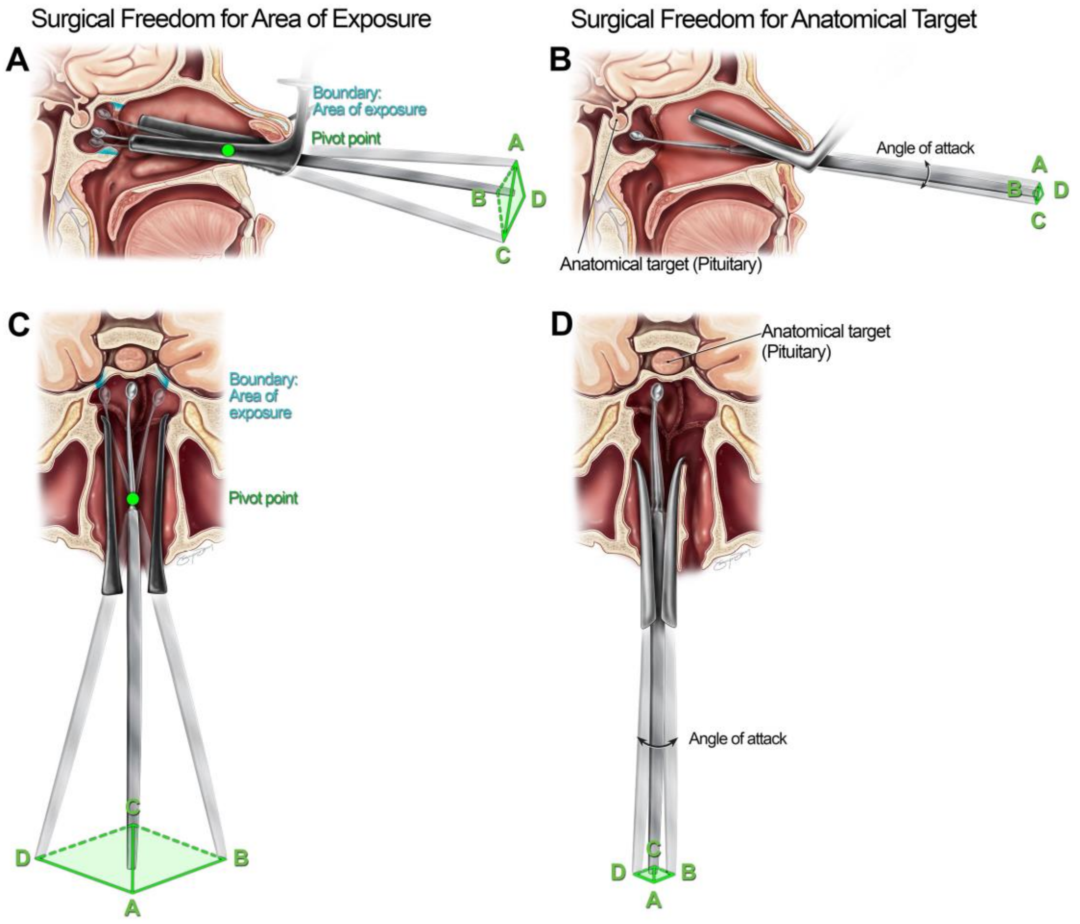

**Figure 2.2**

An illustration showing the exposed area surgical freedom for the two microscopic approaches; microscopic sublabial approach (using a fukushima retractor) (A) sagittal, (C) axial, and the microscopic endonasal approach (B) sagittal, (D) axial.

### Anatomic target surgical freedom

This variable represents the maneuverability of the proximal end of the dissector while fixing the distal end of the dissector on a specific anatomic target and the endoscope placed within the vestibule (in case of endoscopic approaches), or after placing the nasal speculum in case of the microscopic approaches.

Four points were again determined using the neuro-navigation system, which represent the four positions of the proximal end of the dissector outside the patient while fixing the distal end on an anatomical target and placing the proximal end as inferiorly, superiorly, medially and laterally as possible. As above, after these four points are calculated three vectors can be measured which represent two juxtaposed triangles and the surgical freedom is the sum of the area of these two triangles(Fig. 2.3, 2.4). We measured anatomic target surgical freedom for the center of the pituitary gland and the two cavernous ICAs.

### Angle of attack

The angular surgical freedom ("angles of attack") in two planes was determined for three targets: the pituitary gland and both cICAs. This was measured, as we have described previously, by fixing the distal end of the dissector on the anatomic target and moving the proximal end of the dissector as far left and right as possible to determine the maximum angle of attack within the axial plane.{21}(Fig. 2.3) The angle of attack in the sagittal plane was calculated by measuring the maximum angle of movement when fixing the distal end of the dissector on the anatomic target and moving the proximal end as superior and inferior as possible (Fig. 2.4). These measurements were taken while positioning the endoscope against the nasal vestibule and providing a full view of the exposed area for the endoscopic techniques, and after placing the microscopic nasal speculum in case of the microscopic approaches.

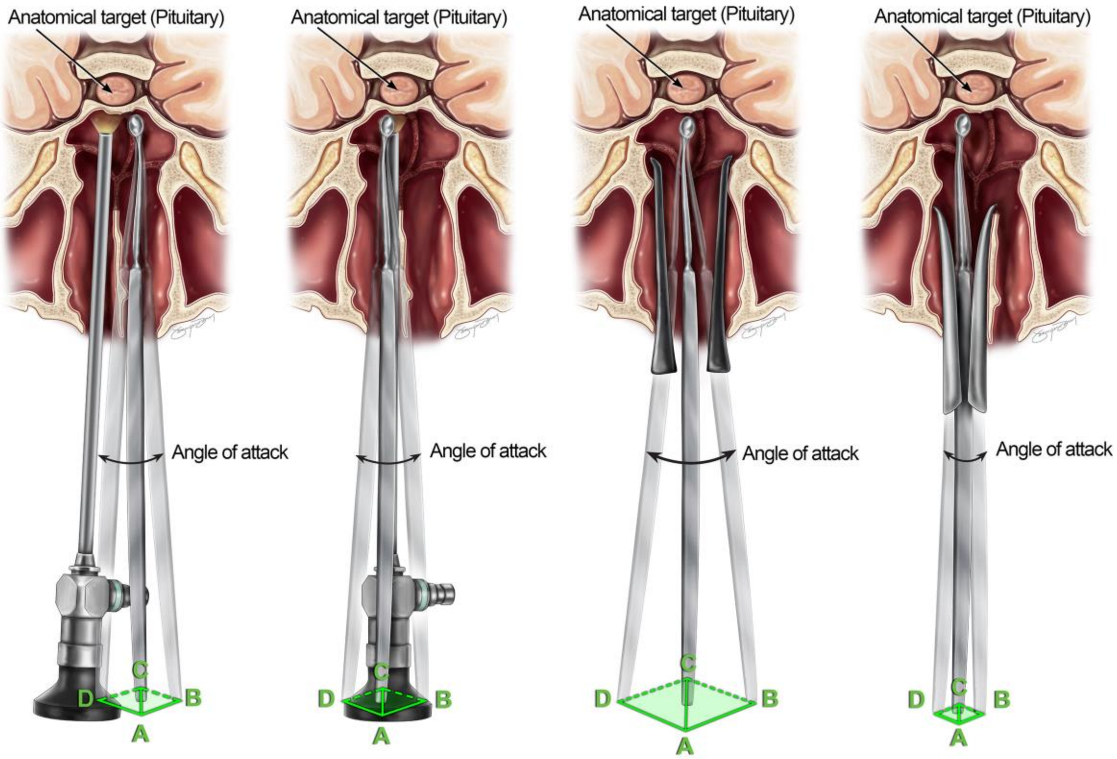

**Figure 2.3**

Illustration showing the point anatomical target surgical freedom and angle of attack for the pituitary gland in the axial plane for the endoscopic endonasal binostril approach (A), endoscopic endonasal uninostril approach (B), microscopic sublabial approach (C), microscopic endonasal approach (D).

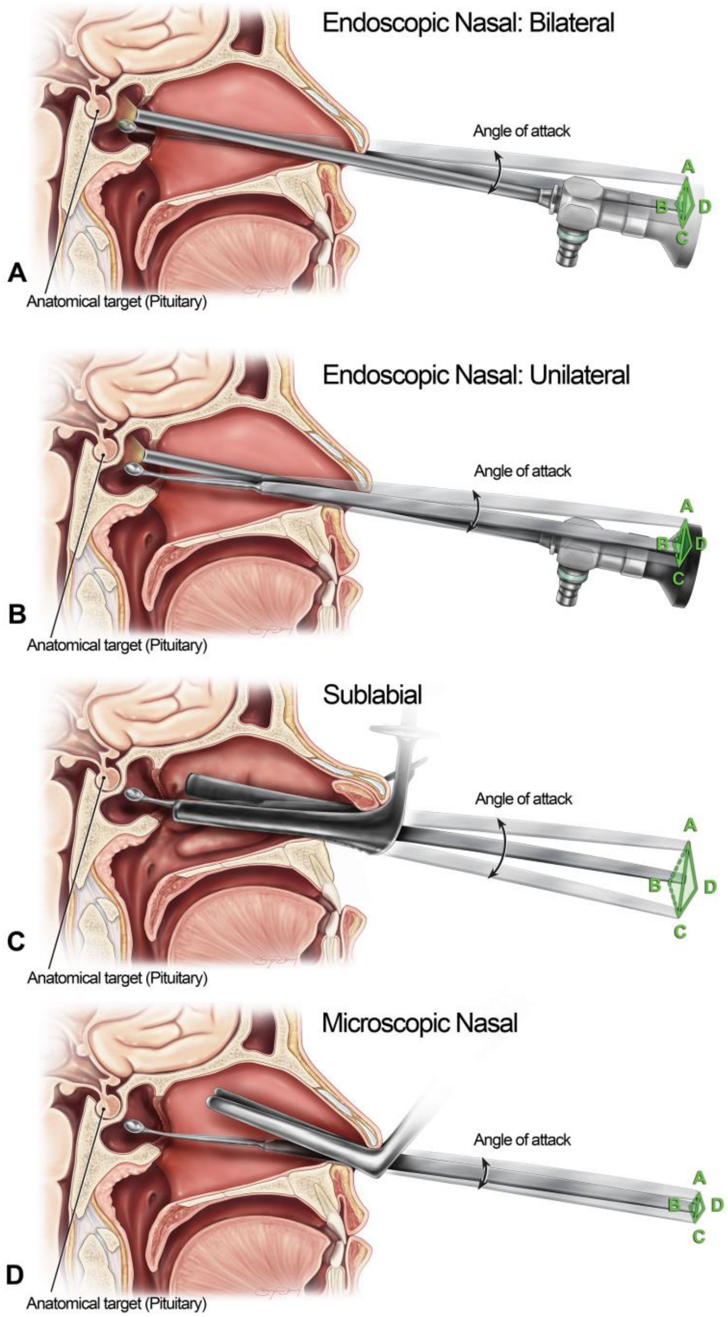

**Figure 2.4**

Illustration showing the point anatomical target surgical freedom and angle of attack for the pituitary gland in the sagittal plan for the endoscopic endonasal binostril approach

(A), endoscopic endonasal uninostril approach (B), microscopic sublabial approach (C), microscopic endonasal approach (D).

## RESULTS

### Exposed area surgical freedom

The microscopic sublabial approach provided the greatest exposed area surgical freedom (102.3 ± 12.6 $cm^2$, Fig. 2.5), followed by the endoscopic binostril approach (88.9 ± 5.5 $cm^2$; two-tailed t-test compared to microscopic sublabial, p=0.02), the endoscopic uninostril approach (80.9 ± 4.5 $cm^2$; two-tailed t-test compared to microscopic sublabial, p=0.004), and the least exposed area surgical freedom was provided by the microscopic endonasal approach (68.7 ±9.6 $cm^2$; two-tailed t-test compared to microscopic sublabial, p=0.0008). Statistical significance of each approach compared to every other approach is summarized in Table 2.1.

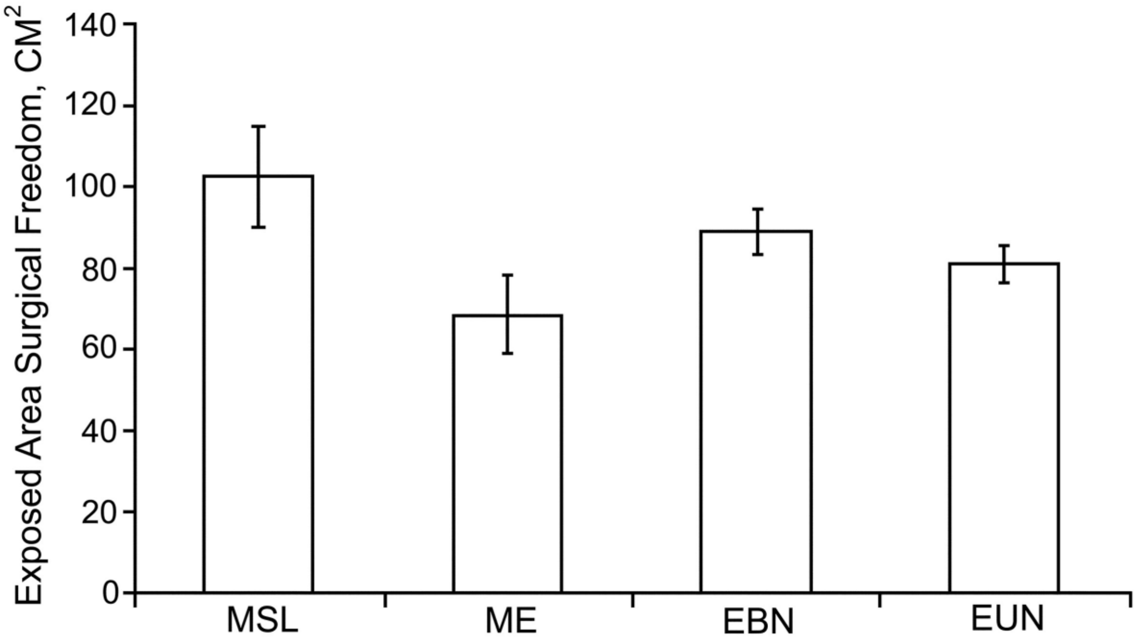

**Figure 2.5**

Total exposed area surgical freedom by approach. MSL, microscopic sublabial. ME, microscopic endonasal. EBN, endoscopic binostril. EUN, endoscopic uninostril. Every measurement reported is statistically significant when compared to all other values by two-tailed t-test.

**Table 2.1**

Two-tailed t-test p values for each approach compared to A) Microscopic Sublabial Approach, B) Endoscopc Binostril Approach, C) Microscopic Endonasal Approach, D) Endoscopic Uninostril approach.

Table 2.1-a

| **Microscopic Sublabial Approach** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Surgical approach** | **Angle of Attack** | | | | | | **Surgical freedom** | | | |
| | **Axial** | | | **Sagittal** | | | **Anatomic target** | | | **Exposed area** |
| | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | |
| **ME** | 0.0002** | 0.2 | 0.001** | 0.008** | 0.005** | 0.06 | 0.005** | 0.001** | 0.08** | 0.0008** |
| **EBN** | 0.02** | 0.02** | 0.04** | 0.03* | 0.005* | 0.2 | 0.01* | 0.003* | 0.3 | 0.02** |
| **EUN** | 0.001** | 0.007** | 0.02** | 0.8 | 0.5 | 0.9 | 0.1 | 0.4 | 1 | 0.004** |

Table 2.1-b

| **Endoscopic Binostril Approach** | | |
|---|---|---|
| **Surgical approach** | **Angle of Attack** | **Surgical freedom** |

| | **Axial** | | | **Sagittal** | | | **Anatomic target** | | | **Exposed area** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | |
| **MSL** | 0.02* | 0.02* | 0.04* | 0.03** | 0.005** | 0.2 | 0.01** | 0.003** | 0.3 | 0.02* |
| **ME** | 0.002** | 0.6 | 0.6 | 0.002** | 0.00007** | 0.01** | 0.001** | 0.00004** | 0.01** | 0.0009** |
| **EUN** | 0.003** | 0.09 | 0.3 | 0.0003** | 0.0000003** | 0.002** | 0.003** | 0.002** | 0.02** | 0.0002** |

Table 2.1-c

| **Microscopic Endonasal Approach** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Surgical approach** | **Angle of Attack** | | | | | | **Surgical freedom** | | | |
| | **Axial** | | | **Sagittal** | | | **Anatomic target** | | | **Exposed area** |
| | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | |
| **MSL** | 0.0002* | 0.2 | 0.001* | 0.008* | 0.005* | 0.06 | 0.005* | 0.001* | 0.08* | 0.0008* |
| **EBN** | 0.002* | 0.6 | 0.6 | 0.002* | 0.00007** | 0.01** | 0.001* | 0.00004* | 0.01* | 0.0009* |
| **EUN** | 0.7 | 0.08 | 0.2 | 0.02* | 0.004* | 0.08* | 0.03* | 0.001* | 0.03* | 0.009* |

Table 2.1-d

| **Endoscopic Uninostril Approach** |
|---|

| **Surgical approach** | **Angle of Attack** | | | | | | **Surgical freedom** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Axial** | | | **Sagittal** | | | **Anatomic target** | | | **Exposed area** |
| | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | **Pit** | **I-cICA** | **C-cICA** | |
| **MSL** | 0.001* | 0.007* | 0.02* | 0.8 | 0.5 | 0.9 | 0.1 | 0.4 | 1 | 0.004* |
| **ME** | 0.7 | 0.08 | 0.2 | 0.02** | 0.004** | 0.08 | 0.03* | 0.001** | 0.03** | 0.009** |
| **EBN** | 0.003* | 0.09 | 0.3 | 0.0003** | 0.0000003* | 0.002* | 0.0003* | 0.002* | 0.02* | 0.0002* |

(**) represent a statisically significant superiority. (*) represent a statistically significant inferiority.

MSL, microscopic sublabial
ME, microscopic endonasal
EBN, endoscopic binostril
EUN, endoscopic uninostril
Pit, pituitary gland
I-cICA Ipsilateral cavernous internal carotid artery
C-cICA Contralateral cavernous internal carotid artery

### Anatomic target surgical freedom

The largest anatomic target surgical freedom for the pituitary gland was provided by the endoscopic binostril approach (27.7 ± 5.4 $cm^2$) followed by the microscopic sublabial approach (21.8 ± 3.5 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.01), the endoscopic uninostril approach (19.7 ± 4.8 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.0002), and the least surgical freedom was provided by the microscopic endonasal approach (14.1 ± 2.7 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.001, Fig. 2.6). The surgical freedom for the ipsilateral cICA (right cICA) was greatest using the endoscopic binostril approach (27.0 ± 4.0 $cm^2$), followed by the endoscopic uninostril approach (22.4 ± 2.32 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.002), the microscopic sublabial approach (21.3 ± 2.4 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.01) and the microscopic endonasal approach (14.1 ±3.17 $cm^2$; two-tailed t-test compared to endoscopic binostril, p = 0.0004). For the contralateral cICA (left cICA) the endoscopic binostril approach had the greatest anatomic target surgical freedom (23.0 ± 3 $cm^2$), followed by the endoscopic uninostril approach (19.5 ± 2.9 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.014), the microscopic sublabial approach (19.5 ± 6.2 $cm^2$; two-tailed t-test compared to endoscopic binostril, p>0.05, non-significant), and lastly the microscopic endonasal approach (16.3 ± 4.0 $cm^2$; two-tailed t-test compared to endoscopic binostril, p=0.02). Statistical significance of each approach compared to every other approach is summarized in Table 2.1.

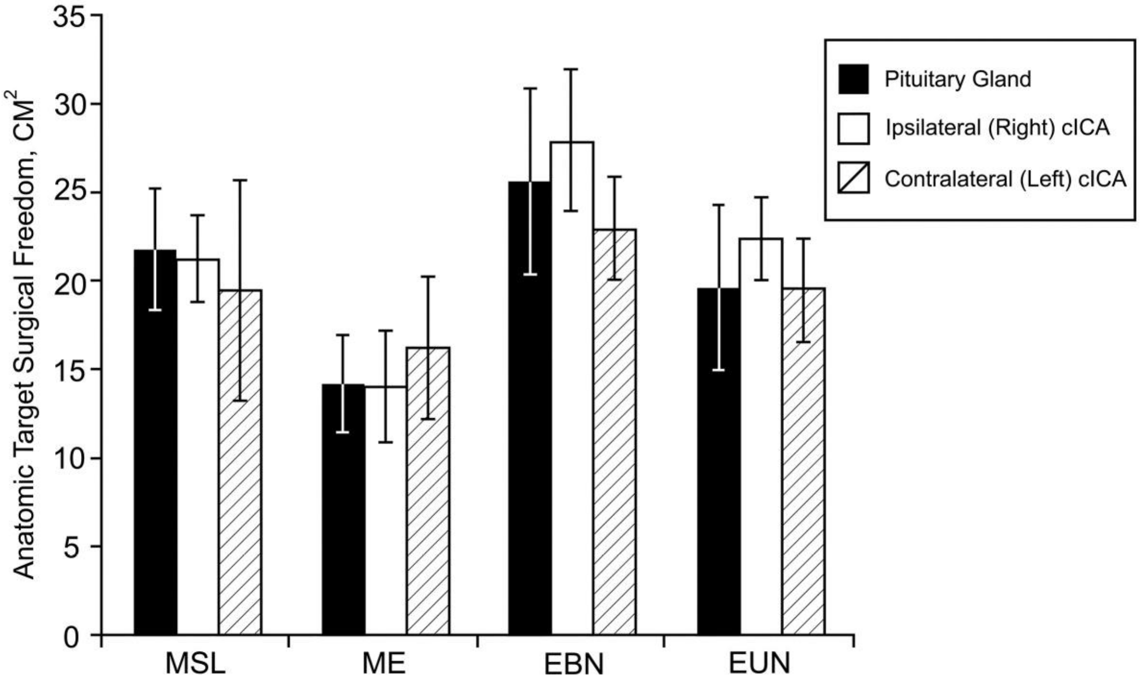

**Figure 2.6**

Anatomic target surgical freedom by approach. MSL, microscopic sublabial. ME, microscopic endonasal. EBN, endoscopic binostril. EUN, endoscopic uninostril. Statistical comparisons are reported separately in Table 2.1.

**Angle of attack**

The axial plane angle of attack for the pituitary gland was greatest for the microscopic sublabial approach (14.7° ± 1.3, Fig. 2.7), followed by the endoscopic binostril approach (12.8° ± 1.7; two-tailed t-test compared to microscopic sublabial, p=0.02), the microscopic endonasal approach (9.5° ± 1; two-tailed t-test compared to microscopic sublabial, p=0.0002), and the endonasal uninostril approach (9.2° ± 2; two-tailed t-test compared to microscopic sublabial, p=0.001). The angle of attack for the pituitary gland in the sagittal plane was greatest for the endoscopic binostril approach (16.5° ± 1.7, Fig. 2.8), followed by the microscopic sublabial approach (14.9° ±1.9; two-tailed t-test compared to endoscopic binostril, p=0.03), the endoscopic uninostril approach (14.7°

±1.3; two-tailed t-test compared to endoscopic binostril, p=0.0003), and the microscopic endonasal approach (12.4° ± 2; two-tailed t-test compared to endoscopic binostril, p=0.002). The axial and sagittal plane angles of attack for the ipsilateral (right) and contralateral (left) cICAs by approach are summarized in Figures 2.7 and 2.8; in short, the microscopic sublabial approach had the greatest axial angle of attack for both cICAs, while the endoscopic binostril approach had the greatest sagittal angle of attack for both cICAs. Statistical significance of each approach compared to every other approach is summarized in Table 2.1.

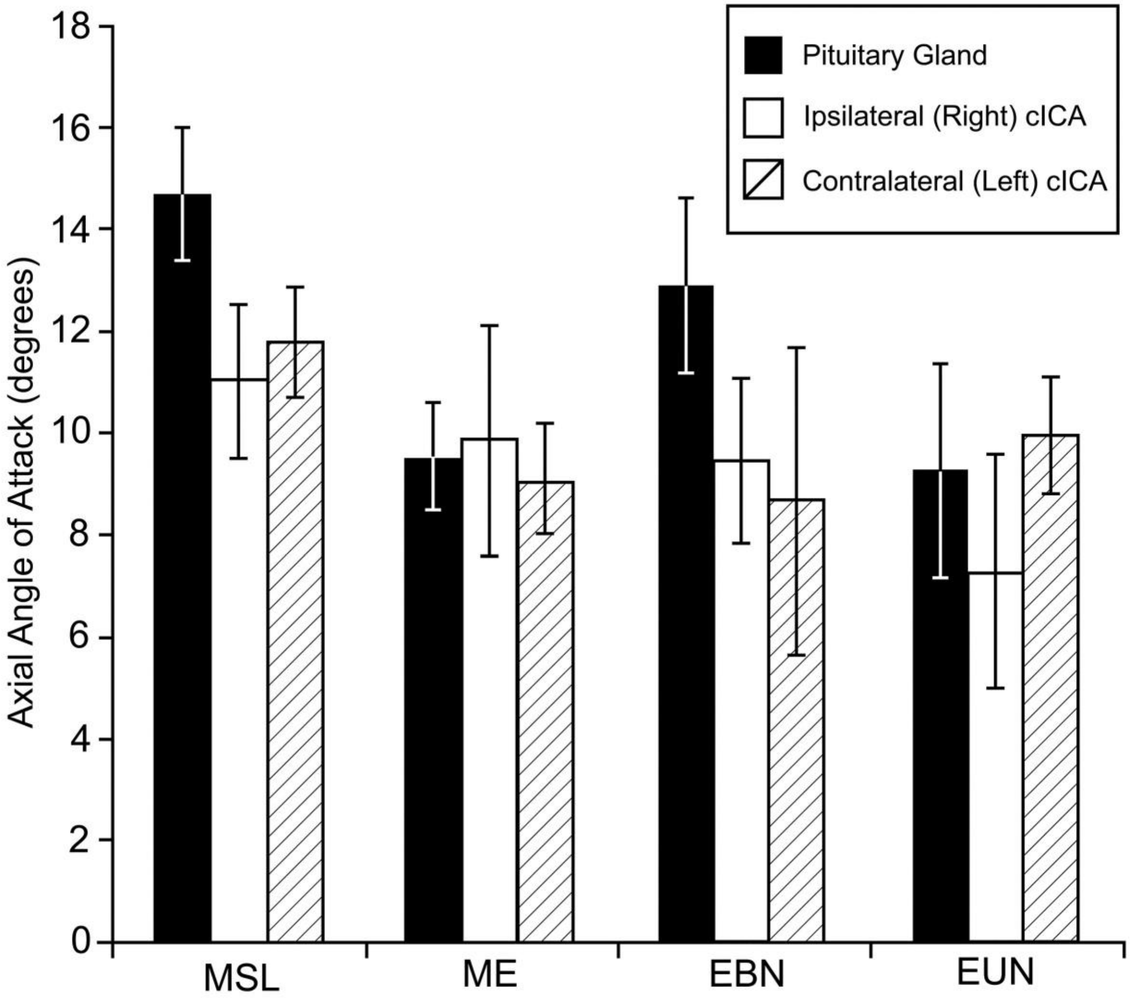

**Figure 2.7**

Axial angle of attack by approach. MSL, microscopic sublabial. ME, microscopic endonasal. EBN, endoscopic binostril. EUN, endoscopic uninostril. Statistical comparisons are reported separately in Table 2.1.

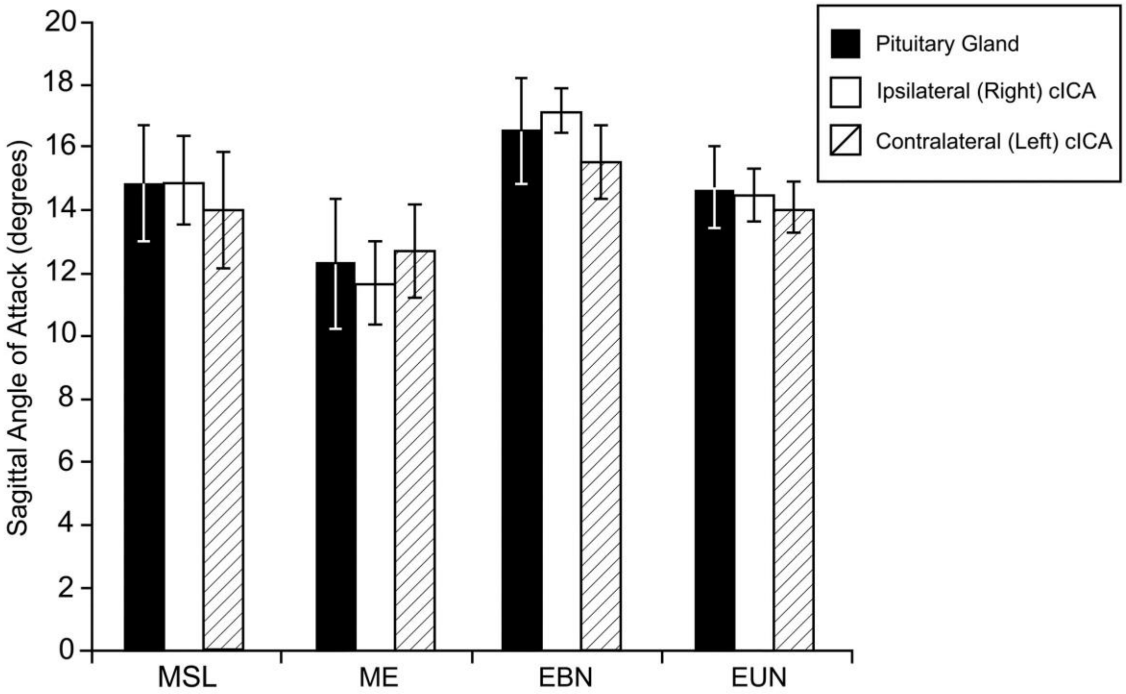

**Figure 2.8**

**.** Sagittal angle of attack by approach. MSL, microscopic sublabial. ME, microscopic endonasal. EBN, endoscopic binostril. EUN, endoscopic uninostril. Statistical comparisons are reported separately in Table 2.1.

## DISCUSSION

Microscopic transsphenoidal surgery represents the gold-standard for addressing lesions of the sella turcica.{6,14,18} The two most commonly used microsurgical approaches applied in practice are the uninostril direct endonasal approach and the sublabial transsphenoidal approach, but recent endoscopic technological advances and the development of effective closure techniques have led to the adoption of purely endoscopic, endonasal approaches to the sella.{2,4,5,8,12,19} The two most commonly applied endoscopic approaches are uninostril and binostril transsphenoidal techniques. While most recent literature has focused on the technical nuances of individual approaches and preliminary patient outcomes, few objective technical comparisons of the approaches exist. Surgical freedom is an important skull base principle that describes the extent to which a surgeon can moves his hands in the operative field. Increased surgical freedom and angle of attack limit sword fighting and instrument collisions, reduce surgeon frustration, improve delicate microdissection, and improve target visualization. Numerous impediments to surgical freedom in the crowded nasal corridor exist, such as the nasal septum, turbinates, nares, sphenoid sinus bone, endoscope, and retractors. In this study, we present the first objective comparison of surgical freedom of the four most commonly performed transsphenoidal approaches as one might use to remove a pituitary tumor. We estimated surgical freedom using four measurements (exposed are surgical freedom, target surgical freedom, axial angular freedom, sagittal angular freedom). These complementary measurements allow us to determine not only the total area of freedom, but also in which plane one approach may be superior to another.

We demonstrated that the sublabial microscopic and the binostril endoscopic approaches were superior to the uninostril microscopic and uninostril endoscopic approaches in the examined variables. The sublabial approach provided the greatest surgical freedom in the exposed area and axial angular freedom, whereas the endoscopic binostril approach provided the greatest target surgical freedom and sagittal angular freedom. The microscopic endonasal approach provided the least surgical freedom in three of the four measurements in our model. The surgical freedom results can be explained by the anatomical structures that limit movement in each approach. For example, in the sublabial approach, the retractor is placed in a horizontal plane thus providing a wide but short orifice at the distal end of the exposure. In contrast, in the endoscopic approaches, the axial angular freedom is limited by the nares, nasal septum, middle turbinate and maxillary sinus wall. However, sagittal angular freedom is excellent because one can elevate the soft tissue of the nares to generate more freedom. The uninostril microscopic approach provided the least surgical freedom because axial plane freedom was limited by the nasal speculum, and the sagittal freedom was reduced by the skin and cartilage of the nares made tight by the expanded retractor. The other interesting observation was the noted superiority of the binostril endoscopic approach compared to uninostril approach. This confirms our clinical impression. The uninostril approach surgical freedom was more impacted by the presence of the endoscope and the conflicts between the endoscope and dissecting instruments. In a standard binostril approach, the endoscope is parked in the right nostril, and the dissectors are placed in the left nostril thus limiting collisions.

These results provide practical information for surgeons choosing a surgical approach and help quantify clinical impressions. For example, the senior author *[author name blinded for review]* will choose a sublabial microscopic approach over a microscopic uninostril approach for complex sellar tumors, such as craniopharyngioma, because of the greater ease of dissection and shorter operative distance. Regarding the endoscopic approaches, the authors now utilize an exclusively binostril approach instead of a uninostril approach for all sellar lesions. This improves the ease of tumor dissection, limits endoscope-instrument conflict, and significantly eases the hassle of sellar reconstruction. However, surgical freedom is only one of several factors that a surgeon considers when choosing an approach. Other factors include approach-related morbidity{15} and surgeon experience/preference.

Our study utilized cadaveric heads fixed in standard preservatives, and this process decreases the elasticity of tissue. This is a drawback inherent to any anatomical study performed in cadavers, but naturally should still be considered a limitation to the present study. We tried to address this variable by performing the measurements in the same specimens for all four approaches, thus having each specimen serve as its own internal control.  To standardize the methodology, we chose to use only straight instruments and 0 degree endoscopes. Different surgical freedom areas could have been obtained with angled instruments or endoscopes. Lastly, our study examines a standardized dissection using each approach. Individual patient anatomy and surgical pathology is highly variable and each surgical approach in the living patient is tailored to that unique anatomy. Therefore, surgical freedom and angles of attack may differ somewhat when these approaches are used in the operating room.

The choice to approach a lesion from either an endoscopic, microscopic, or combined approach has many deciding factors and can yield excellent clinical results. We view the present results not as an unqualified endorsement of the endoscopic binostril approach or sublabial approach, but more as the early steps towards a rigorous and objective anatomical comparison of surgical approaches in sellar surgery. With these baselines now established for routine approaches, we can utilize the same principles to evaluate expanded exposures, new instrumentation, and other technical modifications. Innovations in surgical approach will in the future have standardized quantitative, rather than simply qualitative, data to support their adoption.

## CONCLUSIONS

The microscopic, sublabial approach to the sella provides the greatest surgical freedom in the axial plane, and the greatest total surgical area freedom. The endoscopic, binostril approach provides the greatest degree of sagittal surgical freedom and freedom at common anatomic targets within the sella. Microscopic endonasal and endoscopic uninostril approaches yielded significantly less surgical freedom in most examined variables. This research provides a foundation for the quantitative measurement of endoscopic skull base approaches.

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# CHAPTER 3

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The following chapter has been presented on February 14th 2014 at the Proffered Papers III section: Innovative Technology, at the North American Skull Base Society annual meeting 2014, San Diego, CA. Also a complete and revised manuscript has been accepted for publication in the Journal of Operative Neurosurgery.

# CHAPTER 3:

# MALLEABLE ENDOSCOPE INCREASES SURGICAL FREEDOM WHEN COMPARED TO A RIGID ENDOSCOPE IN ENDOSCOPIC ENDONASAL APPROACHES TO THE PARASELLAR REGION

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**Elhadi AM, Zaidi H, Hardesty H, Cavallo C, Preul MC, Nakaji P, Little AS.**

## ABSTRACT

**Background:** One challenge performing endoscopic endonasal approaches is the surgical conflict that occurs between the surgical instruments and endoscope in the crowded nasal corridor. This conflict decreases surgical freedom, increases surgeon frustration, and lengthens the learning curve for trainees.

**Objective**: In this study, we evaluated the impact a malleable endoscope has on surgical freedom for endoscopic approaches to the parasellar region.

**Methods:** Uninostril and binostril endoscopic transsphenoidal approaches to the pituitary gland and cavernous carotid arteries were performed on eight silicon-injected, formalin-fixed cadaveric heads using both rigid and flexible 3D endoscopes. Surgical freedom to targets in the parasellar region was assessed using an established technique based on image guidance. Results are presented as three measurements: area of surgical freedom for a point target, area for the surgical field (cavernous carotids and sella), and angular surgical freedom (angle of attack).

**Results:** Point target surgical freedom, exposed area surgical freedom, and angle of attack were all significantly greater in approaches using the malleable endoscope compared to the rigid endoscope (p values 0.06 to <0.001) between 17 and 28%. The improved surgical freedom noted with the malleable endoscope was due to the minimization of instrument-endoscope conflict at the back-end (camera) and front-end (tip) of the endoscope.

**Conclusions:** This study demonstrates that application of a malleable endoscope to transsphenoidal approaches to the parasellar region decreases instrument-endoscope conflict and improves surgical freedom.

## INTRODUCTION

Endoscopic transsphenoidal surgery is an increasingly popular surgical technique to address pituitary and parasellar lesions.{15,16,17,18,19} The approach presents a technical challenge and causes surgeon frustration because the long, crowded, narrow working corridor promotes instrument collisions and “sword fighting”. Instrument conflict occurs at several locations within the operative corridor. At the back-end of the endoscope, the camera and cable interfere with the surgeon’s hands on the dissection instruments and suction. The movement of the endoscope shaft and instruments can be limited by the nasal vestibule, middle turbinate, and amount of boney removal of the sphenoid ostium, posterior ethmoids, and nasal septum.{20} Finally, the tip of the endoscope can interfere with dissection instruments and scissors because the endoscope takes up valuable space near the surgical target. To date, the standard endoscopic approach is performed with a rigid endoscope, which contributes to the difficulty by redirecting or impeding instruments with which it interacts.

Surgical freedom is an important topic in skull base surgery and describes the ease and extent the surgeon can move his/her hands in the operative field.  Limited surgical freedom causes increased surgeon frustration, lengthens the learning curve for trainees, increases operative time, and impairs the ease and perhaps the safety of conducting delicate dissections. Surgical freedom is one factor that a surgeon may consider when choosing a surgical approach. We have modeled surgical freedom in various open and endoscopic skull base approaches and demonstrated that it can be a useful objective measure to compare approaches.{3,7,8,9} This concept is brought into sharp relief in endoscopic endonasal surgery because of the tight anatomical corridor puts a premium on space.{3,21}

One possible solution to improving instrument conflict in endoscopic endonasal surgery is the development of a malleable endoscope that can be contoured to minimize endoscope-instrument collisions. In this study, we compare the surgical freedom attained in endoscopic transsphenoidal approaches to the parasellar region using a rigid 3D endoscope and a malleable 3D endoscope

## METHODS

### Endoscopes

Two 3D endoscopes manufactured by Visionsense (Petach Tikva, Israel) were utilized in this study. The rigid endoscope (VSII, 4.9 mm diameter and 180 mm length) is commercially available, while the malleable endoscope (Cobra, 4.7 mm diameter and 180 mm length) is not yet available (Fig 3.1). The malleable endoscope retains its shape after it is bent. Both endoscopes provide high-quality standard definition images. According to the manufacturer, the malleable and rigid 3D endoscopes use the same optic technology and software. Therefore, the luminosity and image quality are identical (Fig 3.2). Both endoscopes also provide a 70 degree field of view. The malleable endoscope has a rigid portion about 1 cm long at the tip. The malleable endoscope is not available in angled or fisheye lenses.

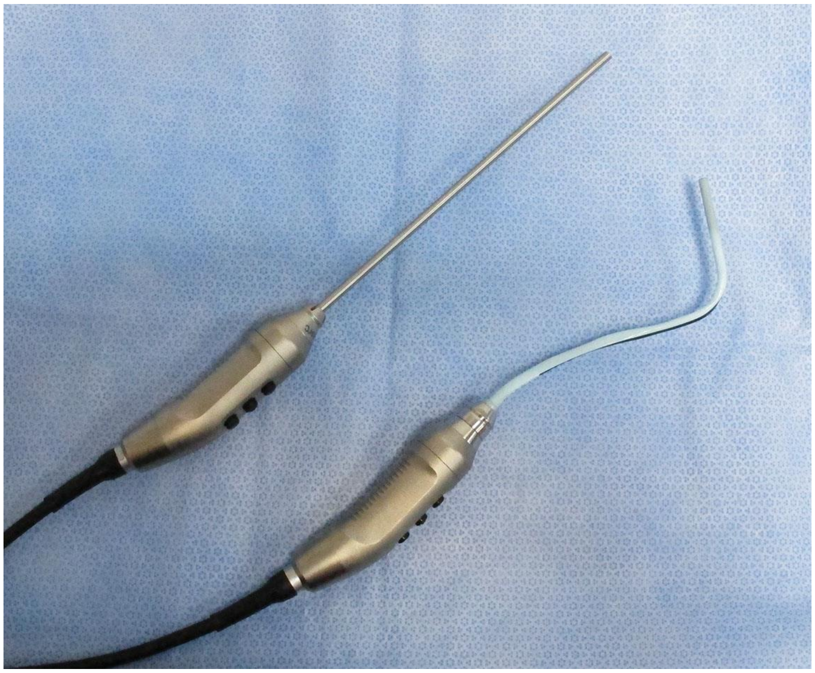


**Figure 3.1**
Image showing the malleable 3D endoscope and the rigid 3D endoscope developed by Visionsense. The malleable endoscope (Cobra) is not yet cleared for use in the United States

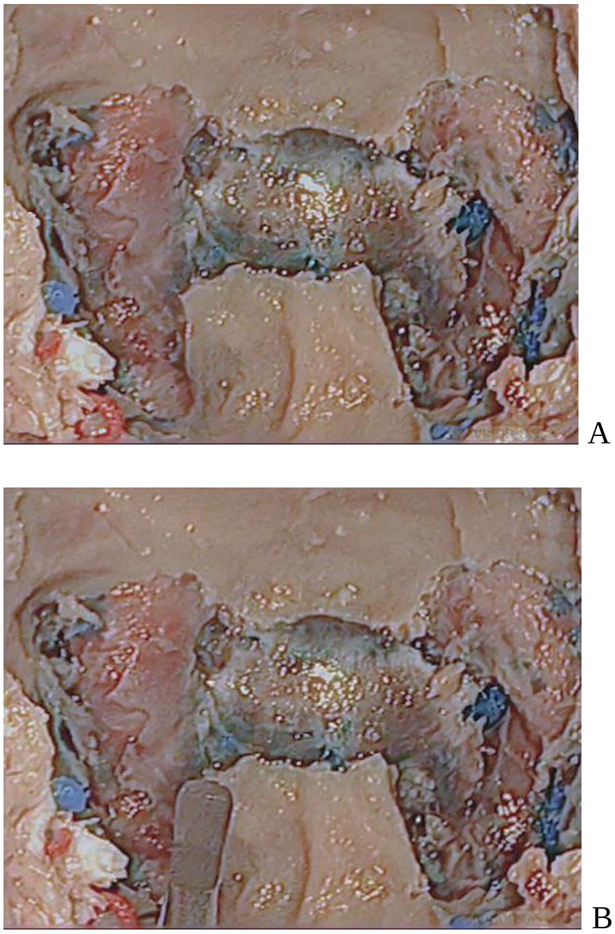


**Figure 3.2**
Representative images taken from the malleable (A) and rigid 3D (B) endoscopes used in this study. According to the manufacturer, the image definition and luminosity are the same.

### Anatomical Dissections

Uninostril endonasal transsphenoidal approaches and binostril endonasal transsphenoidal approaches were performed on eight silicone-injected, formalin-fixed cadaveric heads. Dissections were performed using a single-surgeon technique with a rigid 3D 0-degree endoscope. Once the surgical corridor was exposed, the endoscope's position (either rigid or malleable) was fixed using an endoscope holder (Karl, Storzz, Germany) against the nasal vestibule. Right-sided unilateral transsphenoidal approaches were performed using established techniques according to the method published by Berhouma et al.,{4} In brief, this included out-fracture of the right middle turbinate, wide bilateral sphenoidotomies, posterior septectomy, and removal of the sellar bone to expose the pituitary gland and cavernous internal carotid arteries (ICA). In the binostril approach, the left middle turbinate was out-fractured and the contralateral posterior septal mucosa was removed as described by Kassam.{5}

Prior to dissection, stereotactic imaging using high resolution computed tomography (CT) scans were performed on each head to document bone and cranial anatomy. Images were uploaded to an image guidance platform (StealthStation Treon Plus with FrameLink Software, Medtronic, Minneapolis, MN). Image guidance was then used to obtain anatomical measurements and confirm anatomical structures, and assist with anatomical dissections.

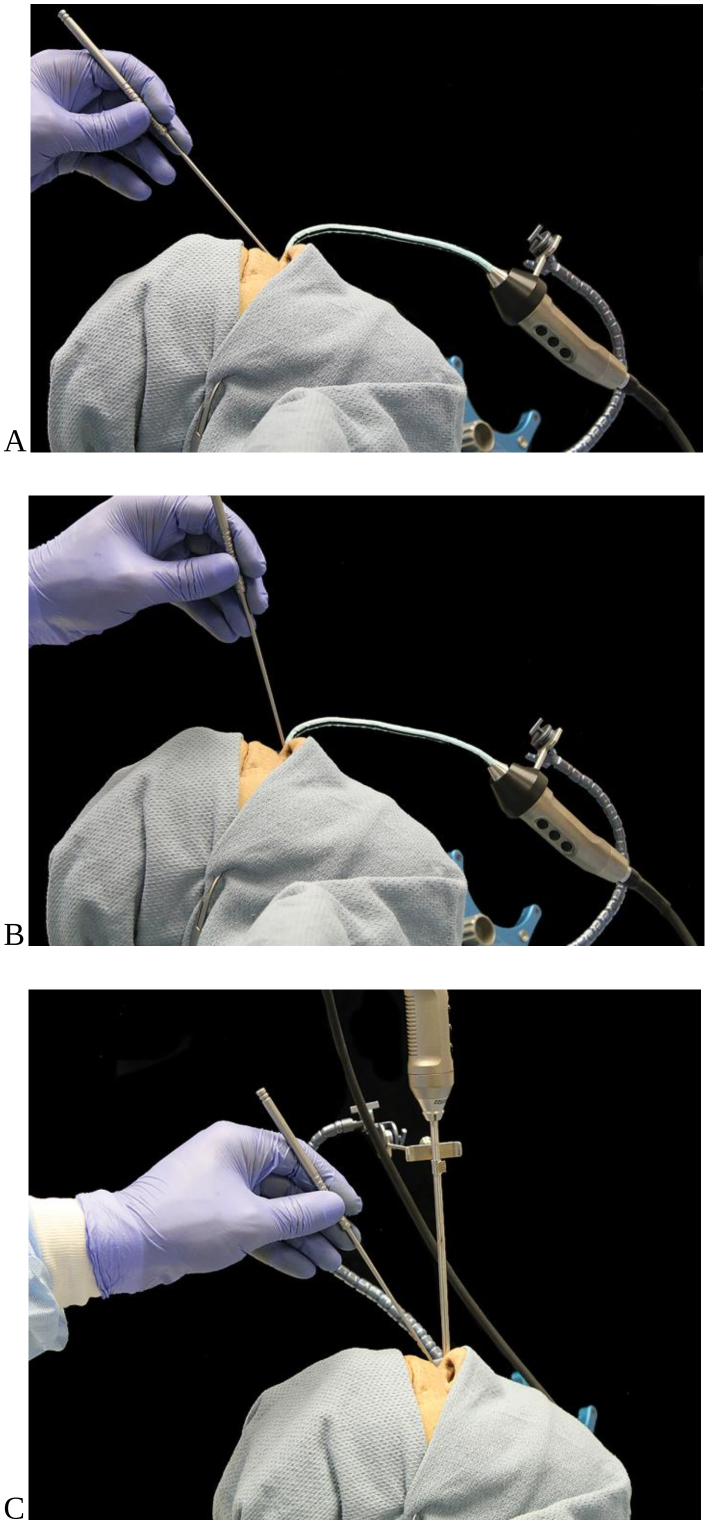
### Surgical Freedom

Surgical freedom was defined as the maximum allowable working area or angle at the proximal (surgeon's) end of a 23 cm endonasal dissecting instrument.{3} This definition was chosen to reflect the working space available at the level of the surgeon's hand while holding an instrument. In this study, surgical freedom was estimated using three measurements. First, we measured the maximum area through which a surgeon could move his hand holding a 2 mm tip dissector with the tip of the instrument held on a designated surgical target ("point target surgical freedom"). We chose the center of the anterior face of the pituitary gland and bilateral midsegment cavernous ICAs as the targets. To estimate surgical freedom for point anatomical targets, the area between four points representing the extreme positions (i.e., as far medially, superiorly, inferiorly, and laterally as possible) of the proximal end of the dissector was calculated using the vector cross-product method.{3,9,6,8} The spatial coordinates of the four points were determined using neuronavigation (Stealth System, Medtronic, Minneapolis, MN).

Next, we measured the maximal area through which a surgeon could move his hand holding a dissector while moving the distal end (tip) of the instrument along the borders of the surgical field ("exposed area surgical freedom"). This area was calculated by identifying four points in space that represents the position of the proximal end of the dissector. The first point represents the position of the proximal end of the dissector while placing the distal end at the contralateral cavernous ICA and moving the proximal end as inferiorly and laterally as possible. The second point was represents the proximal end of the dissector while placing the distal end at the ipsilateral cavernous ICA and moving the dissector as superiorly and medially as possible. The third point represents the proximal end of the dissector while placing the distal end at the ipsilateral cavernous ICA and placing the proximal end as inferiorly and medially as possible. The fourth point represents the proximal end of the dissector while placing the distal end at the contralateral cavernous ICA and placing the proximal end as superiorly and laterally as possible.

Third, we measured the angle through which the surgeon could move his hands while holding a dissector (angular surgical freedom or "angle of attack"). The angle of attack was determined for the center of the anterior face of the pituitary gland. The axial angle of attack was measured by fixing the distal end of the dissector on the target and moving the proximal end of the dissector as far left and right as possible. The angle of attack on the sagittal plane was calculated by measuring the maximum angle of movement when fixing the distal end of the dissector on the anatomical target and moving the proximal end as superiorly and inferiorly as possible.

To standardize the procedure, the endoscopes were placed in the superior aspect of the right nares and positioned with an endoscope holder (Karl Storz, Germany) to see the entire surgical target (bilateral cavernous ICA and pituitary fossa. The malleable endoscope was contoured such that the proximal camera end moved away from the operative corridor (Fig. 3.3). Spatial coordinates were obtained on the proximal end of the dissector placed in the right nostril for the uninostril approach and in the left nostril for the binostril approach. Measurements for the uninostril and binostril technique were made on the same eight specimens to eliminate the extent of boney removal as a confounding variable and so the specimens could serve as their own internal controls. Surgical freedom data were calculated for both binostril and uninostril approaches using both a rigid and malleable endoscope. Statistical analysis was performed using paired, independent t-tests and analysis of variance (ANOVA) was used to compare the surgical freedom and angle of attack for the two approaches using the two different systems. A p value of less than 0.05 was considered significant.


A
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C

D

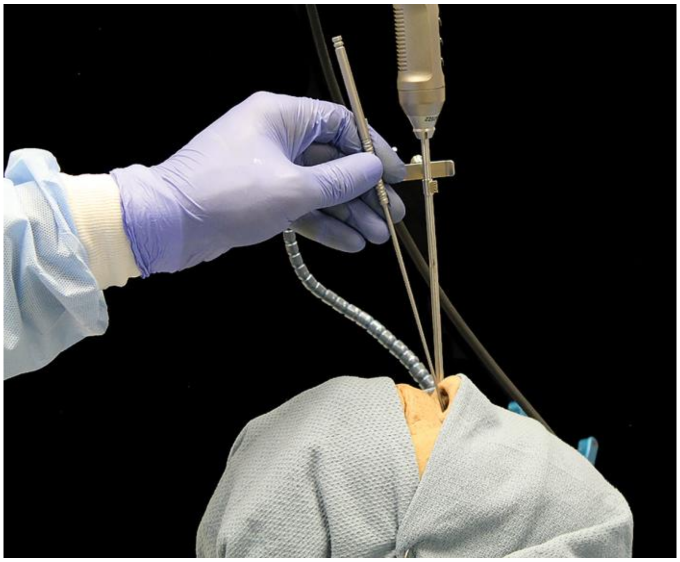

**Figure 3.3**

A series of photographs demonstrating the position of the dissector and endoscope during the acquisition of spatial coordinates. **(A)** and **(B)** illustrate how the camera of the malleable endoscope has been contoured out of the operative corridor and the dissector is moved **(A)** inferiorly and **(B)** superiorly. **(C)** and **(D)** demonstrate the position of the rigid endoscope as the dissector is moved **(C)** inferiorly and **(D)** superiorly, where it collides with the endoscope camera restricting surgical freedom.

## RESULTS

In all three estimates of surgical freedom, use of the malleable endoscope was superior to the rigid endoscope for parasellar targets (Tables 3.1, 3.2, and 3.3). For example, in the uninostril approach, use of the malleable endoscope improved surgical field freedom by 17% (91.85 ± vs 107.84 ±, $p < 0.001$) and by 17% in the binostril approach (115.46 ± vs 135.00 ± , $p<0.001$) (Table 3.1). When surgical freedom was calculated to point anatomical targets such as the center of the face of the pituitary gland and cavernous carotid arteries (Table 3.2), use of the malleable endoscope improved surgical freedom by 26% in the uninostril approach (21.7 ± vs 27.4 ±, $p = 0.02$) and by 28% in the binostril approach (26.72 ± vs 34.56 ±, $p = 0.001$). Use of the malleable endoscope also improved the angular surgical freedom to the pituitary gland (angle of attack) in the axial plane for the binostril approach (13.34 ± vs 18.1 ±, $p < 0.001$) and in the sagittal plane in both the uninostril (16.34 ± vs 18.9 ±, $p = 0.001$) and binostril approaches (17.51 ± vs. 20.25 ±, $p = 0.002$) (Table 3). There was a trend towards improved surgical freedom in axial angular freedom in the uninostril approach (p=0.06).

**Table 3.1**

Comparison of mean area of surgical freedom (cm2) for the operative field (including parasellar carotid ICA and sella turcica) for a rigid endoscope and malleable endoscope.

| | Surgical Freedom ($cm^2$) | | |
|---|---|---|---|
| | Rigid Endoscope (SD) | Malleable endoscope (SD) | p-value |
| Uninostril Transsphenoidal | 91.9 (6.2) | 107.8 (7.3) | 0.0003 |
| Binostril Transsphenoidal | 115.5 (10.4) | 135.0 (2.7) | 0.0001 |

SD, standard deviation

**Table 3.2**

Comparison of mean area of surgical freedom ($cm^2$) for parasellar targets for a rigid endoscope and malleable endoscope.

| | | Surgical Freedom ($cm^2$) | | |
|---|---|---|---|---|
| Endoscopic approach | Anatomical target | Rigid Endoscope (SD) | Malleable endoscope (SD) | p-value |
| Uninostril Transsphenoidal | Pituitary gland | 21.7 (4.9) | 27.4 (5.3) | 0.02 |
| | Ipsilateral ICA | 24.3 (2.5) | 30.4 (2.5) | 0.0001 |
| | Contralateral | 20.7 (3.5) | 26.1 (4.2) | 0.007 |

| | | | | |
|---|---|---|---|---|
| | ICA | | | |
| Binostril Transsphenoidal | Pituitary gland | 29.3 (5.8) | 37.5 (5.9) | 0.007 |
| | Ipsilateral ICA | 31.9 (4.6) | 39.8 (4.8) | 0.004 |
| | Contralateral ICA | 26.7 (4.0) | 34.6 (4.8) | 0.001 |

ICA, internal carotid artery; SD, standard deviation

**Table 3.3**
Comparison of angle of attack to the pituitary gland in the axial and sagittal planes using a rigid and malleable endoscope.

| | | Angle of attack for the pituitary gland (degrees) (SD) | | |
|---|---|---|---|---|
| Surgical plane | Endoscopic approach | Rigid Endoscope (SD) | Malleable endoscope (SD) | p-value |
| Axial | Uninostril Transsphenoidal | 9.2 (1.7) | 10.6 (1.7) | 0.06 |
| | Binostril Transsphenoidal | 13.3 (2.2) | 18.1 (1.7) | 0.0001 |
| Sagittal | Uninostril Transsphenoidal | 16.3 (1.5) | 18.9 (1.2) | 0.001 |
| | Binostril Transsphenoidal | 17.5 (1.7) | 20.3 (1.6) | 0.002 |

SD, standard deviation

Experimental observations revealed that the malleable endoscope decreased endoscope-instrument collisions at two locations. First, there was less conflict at the back-end of the endoscope where a surgeon’s hands holding a dissector would collide with the endoscope camera and cords. The malleable endoscope camera could be positioned out of the operative corridor to avoid this conflict (Fig. 3.3). The second location was at the tip of the endoscope because the malleable nature of the scope allowed for the dissectors to easily push the tip out of the way to reach the surgical target. Because of the memory properties of the malleable endoscope, the tip returned to its original position after the dissectors were moved.

## DISCUSSION

Improvements in endoscopic endonasal surgery are in part driven by technological advancements. Pioneers in the 1990's adopted the rigid endoscope since it provided superior image quality, illumination, and magnification when compared to the malleable fiberoptic endoscope.{11} The rigid endoscope was originally developed for general surgery, and was ideally suited for abdominal pathology: a $CO_2$ insufflated abdominal cavity allows for a large working space to navigate rigid instruments. However, when applied to endonasal neurosurgical procedures, frequent instrument conflict in a narrow nasal corridor during delicate microsurgical dissection steepens the learning curve and increases surgeon frustration. Recent technological advances in digital optics have created a new generation of endoscopes which permit for malleability without compromising image quality or illumination. In this cadaveric model of an endoscopic transsphenoidal approach to the sella turcica, we demonstrate that using a malleable 3D endoscope improves surgical ergonomics and reduces instrument conflict when compared to a rigid 3D endoscope. Experimental observations suggest that this is because of decreased instrument conflict at the both the front-end (endoscope tip) and back-end (endoscope camera) of the malleable endoscope. The malleable nature of the endoscope allows the camera to be positioned away from the surgical corridor and allows the tip that is obstructing access to the surgical target to be temporarily displaced by dissecting instruments as they approach the target. One limitation we noted with the malleable endoscope was in conducting the initial dissection of the nasal cavity. The malleable endoscope was more difficult to navigate through the nasal cavity because precise movements with the surgeon’s hand did not always translate directly into tip movement. However, once the sphenoid sinus was opened, the advantage of being able to contour the back-end out of the operative field became apparent.

In addition to using a malleable endoscope, there are other techniques that can be used to improve surgical freedom in an endonasal exposure. These include increasing the amount of tissue removal in the nasal cavity, such as resecting the middle turbinate or widening the posterior septectomy, ethmoidectomy, or sphenoidotomy. The choice of surgical approach can also make a difference as demonstrated in other endoscopic approaches.{3,12} The data presented here along with clinical observations suggests that a binostril approach offers improved freedom compared to a uninostril approach because of the increase number of potential instrument corridors. Next, smaller endoscopes may be of benefit, as they occupy less space in the surgical field. In our study, the endoscope diameters differed by 0.2 mm, so we hypothesized that the impact of this difference was negligible. However, a rigorous analysis of endoscope diameter on surgical freedom is an intriguing future direction. For example, the influence of smaller diameter endoscopes, such as pediatric endonasal scopes, may be a useful next step. Finally, in order to standardize the study methodology we affixed the endoscopes with a holder in the upper aspect of the right nostril, which is the most common location to park an endoscope.{2} However, in two-handed team endoscopic surgery, an experienced endoscopist can continuously move the endoscope to maximize visualization and limit instrument conflict.{1}

Given the minimal access nature of endonasal surgery which puts a premium on optimizing surgical ergonomics in a narrow corridor, the development of standardized models to objectively compare technologies may be beneficial. In order to compare surgical freedom between various endoscopic procedures, other investigators have analyzed computer tomography (CT) scans to calculate angle of exposure,{12} millimeter scale rulers to measure area of exposure,{22} performed 3D virtual dissection studies,{14} or simply compared subjective data.{13} As an alternative objective approach to analyzing degree of freedom, our group previously described a method of using stereotaxy to measure surgical freedom and angle of attack for both traditional cranial approaches.{7} as well as extended endonasal approaches.{3} This model provides rigorous, quantitative, and practical data to compare surgical methodologies, and establishes a framework by which surgeons can study the merits of new tools and approaches.

The study methodology also deserves further discussion. First, the study was conducted in cadaveric specimens, which have decreased tissue elasticity compared to living specimens. Therefore, the data presented herein likely represent an underestimate of the surgical freedom obtainable in a living specimen. Second, uninostril and binostril measurements were made in the same specimens, and, therefore, each specimen served as its own control for tissue elasticity and degree of boney removal, thus limiting the impact of these potential confounders on the results. Third, our study does not address how much surgical freedom a surgeon actually needs to successfully carry out a procedure, which may depend on surgeon experience. We propose that, in general, more surgical freedom is better in order to minimize surgeon struggle and fatigue, but whether the additional surgical freedom provided by the malleable endoscope is beneficial will be up to the surgeon. Finally, the purpose of our study was not to evaluate the benefits and disadvantages of a 3D imaging platform, nor to compare image quality with currently available 2D platforms.

## CONCLUSIONS

In this study, we performed an analysis of endoscopic surgical freedom comparing the use of a rigid and malleable 3D endoscope for approaches to the parasellar region. We used three measurements of surgical freedom and found that the application of a malleable endoscope significantly improved surgical freedom in all three measures from 17% to 29%. The improvement in surgical freedom was a result of limiting endoscope-instrument conflicts that occur at the front-end (tip) and back-end (camera) of the endoscope.

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# CONCLUSIONS

## Clinical decision making

Appropriate clinical decision making and proper approach selection are key in endoscopic neurosurgery, and have a great role in surgical outcome. Depending on the type of the lesion, site of the lesion, its extent and its relation to the surrounding anatomical structures, surgeons evaluate their patients clinically and select the approach that may seem appropriate, which can significantly vary for individual cases.

The literature is replete with articles describing the angle of attack or surgical trajectories based on imaging, or other descriptive articles (qualitative) without quantitative data, while our methods provided both quantitative data as well as quantitated surgical trajectory description. Surgeons mainly depend on neuro-imaging in determining the trajectory for the approach to be used, without addressing the degree of maneuverability and ability to manipulate certain anatomical targets. The surgical freedom data from the studies in this thesis, which is based on comparative analyses between approaches, provided a more realistic evaluation for the degree of maneuverability that can be offered in a certain approach rather than just determining a simple or mere surgical trajectory. Knowing the surgical freedom that is offered by different endoscopes or using different instruments can be important even within the surgical procedure itself Aa surgeon can then easily change to an endoscope or an endoscopic instrument with a better surgical freedom which enables the operator to perform with less struggle.

Our data suggest technical maneuvers that may increase the surgical freedom. For example in the first chapter; a sublabial transmaxillary approach can have a rather larger surgical freedom when the anterior maxillary antrostomy is increased in size while trying not to injure other structures like the infra-orbital nerve and artery. The concept of the pivot point is also an interesting point, our data shows that the more the pivot point is closer to the distal end of the endoscope or endoscopic instrument the larger the surgical freedom can be provided. So if there is a struggle in the endoscopic field the surgeon can simply pull the endoscope slightly outwards and increase the magnification power, this will move the distal end of the endoscope closer to the pivot point while maintaining the view of the surgical field using the increased magnification.

In the second chapter our data showed that the microscopic sublabial approach has the greatest surgical freedom for the exposed area when compared to the other approaches, while the bilateral endoscopic endonasal approach provided the greatest surgical freedom for the anatomical target. These fundamental differences may explain why this particular endoscopic approach is more widely used, in addition to other factors related to the latter being less invasive and affording better visualization.

These studies are different from previous studies in that most of the articles in the literature provide subjective opinions for different endoscopic approaches based on either anatomical description, surgeons opinion (Domenico Catapano et al, 2006, Pillai, P. et al , 2009), or comparisons of clinical outcomes for different approaches ( Sheehan, MT et al, 1999., Cho, DY et al, 2002., Kawamata, T et al, 2002).  While many descriptions of new approaches or maneuvers claim to increase the surgical freedom, there have been no quantitive comparisons or evaluations of this crucial aspect of neurosurgical endoscopy.

The quantifying method used for the studies in this thesis can provide a numerical value for changes in the operative approach that in turn alter surgical freedom. Only in this way can reliable comparisons be made employing validated data resulting in objective assessments of surgical maneuvers.

### Approach selection

A better understanding of the surgical freedom for a given approach can greatly influence approach selection, for example; if there is a large lesion that needs to be ressected, an approach with a larger surgical freedom for this anatomical area would be preferred than other approaches with less surgical freedom. On the other hand, if there is a rather smaller lesion that compresses on a vital neural or vascular structure, an approach with a larger surgical freedom for this anatomical target will be warranted since this means that this approach provides better maneuverability around this anatomical target which enables better dissection between the lesion and the anatomical structure.

Although our data is based on comparing approaches, the absolute surgical freedom value will be more and more appreciated with the increased application of this quantifying method to different surgical approaches (both endoscopic and microscopic) enabling surgeons to determine their ability to operate within a given surgical freedom limits. So as the surgeon’s experience increase along with his surgical skills he will be able to better operate within approaches that have less surgical freedom.

Our data is also important in the assessments of uncommon approaches amenable to endoscopy these approaches may be unfamiliar (chapter one). A newly described approach should be evaluated for its surgical freedom in addition to its anatomical and technical description, this evaluation should be done before applying this new approach clinically. The surgical freedom evaluation is not only for the approach by itself it can be applied for different instruments that may aid in changing an approach from being with a limited surgical freedom to being an approach with adequate surgical freedom (discussed later).

Since most newly introduced spine instrumentations are evaluated biomechanically, I believe that all newly introduced endoscopic kits, instruments, approaches and maneuvers should be evaluated for the surgical freedom provided by them.

### Training application

Although not mentioned in my thesis, I believe that the series of studies that were performed can be a valuable tool in residents training, in our laboratory we have been working on developing and endoscopic simulator that may help improve surgical skills for novices, with the surgical freedom data in hand a more accurate and significant system can be designed. And when designing a simulator with surgical freedom in mind we can have a simulator the has a certain surgical freedom which can be manipulated, then novices can be scored and evaluated with different surgical freedom provided, we can even monitor the progress of surgical skills acquisition through providing the same endoscopic tasks and gradually restricting the surgical freedom.

Cadaveric dissections that are performed during these studies are very crucial and can provide an excellent material for training for young residents, so the expanding of these studies and its application on a wider scale will enable not only anatomical appreciation during cadaveric dissections but a more in-depth analysis and understanding for the whole surgical corridor and awareness to the surrounding anatomical structures, not only to prevent injury to these structures but to realize maneuvers that can be performed to avoid vital structures and increase surgical freedom as well.

Pre-operative imaging which is the main measure used by surgeons in providing the appropriate trajectory and determining the surgical approach cannot give an idea about the surgical freedom that will be provided because the surgical freedom estimates the available space within the whole approach in all dimensions. While imaging would only provide a certain anatomical cut in a given plane (sagittal, coronal, axial), which is not adequate to provide information on the degree of freedom available. And with data like this available for more and more endoscopic approaches immediate and more accurate surgical planning and decision making can be obtained.

### Effect on endoscopic and endoscopic instruments design

In the first chapter of my thesis I was able to determine that the difference in the approach itself can lead to a 25-30% change in the surgical freedom, the second and third chapters, in addition to comparing the type of approach, addressed the effect of difference in instruments and type of the endoscope.

During my dissection work I noticed that most of the limitations and struggle that arise -and may affect the surgical freedom- usually comes from the shaft, proximal and distal ends of the endoscope and the instruments while they “sword” against each other. The type of instruments used as well as type of the endoscope also played an important role and our results showed that these factors if optimized will have an effect on surgical freedom to a point that will shape a new era of endoscopy in neurosurgery (which is actually taking place every day with new innovative technologies).

The results shown from these studies enables developers to focus on certain aspects that directly influence surgical freedom so if I was to submit a design for an endoscope I would think about the length, diameter, material, shape, malleability or flexibility and the tip of the endoscope. The length of the endoscope will depend on the purpose for which the endoscope is used, deeper structures will need longer endoscopes, but I think that 18-22 cm is a reasonable length, most importantly that the longer the endoscope the better it is for the surgical freedom because it keeps the camera along with the other cables away from the surgical field, but the control of a longer endoscope is more challenging due to amplification of the movement at the distal end.

The diameter of the endoscope would also matter, right now the common diameters of the endoscopes range between 4-5 mm with 2-3 mm more when an irrigation sheath is added to the endoscope increasing the endoscope’s diameter to around 7-8 mm, and this can be significant especially for narrow corridors that may have pinch points to almost 1-3 cm2. (The thinner the better).

The images in the endoscopic telescope is usually transmitted through a series of glass rod lenses, which mandated the endoscope to be rigid, less durable and limited to the power of these lenses, although this is the most commonly used system until today, but this system is being replaced by a new technology in which the image is transmitted digitally from an minute chip at the distal tip of the endoscopic telescope through fiber optics and this made a malleable endoscope possible. This can also make a thinner endoscope possible, I think that a flexible endoscope is a great advancements in endoscopic neurosurgery, it takes away the whole proximal end of the endoscope out of the surgeon’s working space and enables better surgical freedom, I doubt that a malleable endoscope can be used in the initial phase of an endoscopic procedure, I think a rigid endoscope will be better used in this phase followed by a malleable endoscope during tissue manipulation or resection. That is why it will be interesting to have an endoscope that is flexible and can be locked in a certain position similar to the Mizuho self-retaining retractor (Hongo Buykyo-ku, Japan).

Also one of the advantages of the endoscope is that its ability to look around the corners using 30, 40, 70 degrees endoscopes. With the new technology, I believe that it is possible to have the distal chip placed on a rotator head that can be controlled from a control unit placed next to the camera so that the distal end can be moved to get angled views without having to change the endoscopic telescope, or maybe have a rather half sphere lens at the tip of the endoscope that can give a “peephole” effect.

The increase in the viewing ability of the endoscope without having to move the endoscope itself or by having the camera and cables all the way out of the surgical field will improve the surgical freedom for the other instruments used. I also think that a flexible device that goes through a rather rigid catheter and then becomes directable can be a practical solution because I would assume that it will be easier to sterilize.

Manipulating the shapes of the endoscopic instruments will greatly influence the surgical freedom, and this may be tested using our methods. Curved instruments with 30 or 45 degrees at the distal end enables the surgeon to operate without having to be in line with the endoscope, also bent instruments at the proximal end enables the operator’s hands to be away from each other, thus a larger surgical freedom (chapter three).

# LIMITATIONS

Dissections are performed on chemically fixed heads which change the properties of the tissue when compared to tissue in vivo.

The studies are performed on specimens without intracranial pathologies, some lesions may displace normal anatomical structures and distort normal anatomical relationships.

In a clinical setting, hemostasis is an important issue and can be time consuming; this cannot be replicated in a cadaveric study.

# BROADER IMPACT AND FUTURE STUDIES

Applying this methodology for measuring the surgical freedom can greatly impact the future of endoscopic neurosurgery. It provides a powerful tool in comparing different endoscopic approaches which is very essential for surgeons for surgical planning and understanding the working space limitations which can be expected during the procedure.

Certain endoscopic maneuvers that have been described to increase the exposed area or the working space, these maneuvers can be tested to quantify exactly what is the rate of increase of surgical freedom.

Surgical freedom can also be as important to endoscopic instruments developers, and by measuring the newly introduced instruments or endoscopes a better evaluation for these tools can be achieved.

With surgical freedom better evaluated, endoscopic approaches can be optimized as well as endoscopic instruments leading to better steady fast improvement of endoscopy in neurosurgery.

Minimally invasive procedures have shown better outcome clinically, and the main limiting factor was the visual limitation due to smaller incisions or smaller surgical corridors as well as limited working space. Surgical freedom studies can help provide minimally invasive procedures with better working space while preserving other minimally invasive characters.

## Future studies

Being able to quantify the novel concept of surgical freedom will open a new realm of studies for evaluating neurosurgical endoscopy.

Evaluation of surgical freedom for other commonly used endoscopic approaches like: extended trans-sphenoidal approaches, interventricular approaches, transcribriform, transclival, transodontoid… etc

Comparing different endoscopic approaches that can be used to access similar anatomical targets.

Evaluating surgical freedom for newly evolving endoscopic techniques that may replace microscopic procedures.

Determining the least surgical freedom that can be sufficient for removal of certain lesions with specific dimensions.

Evaluating surgical freedom for endoscopic instruments that can be used for the same purpose but may have different surgical freedom.

Evaluating newly advanced technologies that may affect the surgical freedom like, decreased number of cables, longer endoscopic telescope, slimmer cameras…etc.

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