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Virtual Endoscopy is a Useful Device for Training and Preoperative Planning of Transsphenoidal Endoscopic Pituitary Surgery

Original Paper

Stefan Wolfsberger, MD[a,b], Marie-Therese Forster, MD[a], Markus Donat, MD[a],

André Neubauer, MSc[c], Katja Bühler, PhD[c], Rainer Wegenkittl, PhD[d],

Thomas Czech, MD[a], Johannes A. Hainfellner, MD[b], and Engelbert Knosp, MD[a]

[a]Department of Neurosurgery, Medical University Vienna, Vienna, Austria

[b]Institute of Neurology, Medical University Vienna, Vienna, Austria

[c]VRVIS Zentrum für Virtual Reality und Visualisierung ForschungsGmbH, Vienna, Austria

[d]TIANI Medgraph AG, Brunn/Gebirge, Austria

Corresponding author

Stefan Wolfsberger, MD; Department of Neurosurgery, Medical University Vienna,

General Hospital (AKH), Waehringer Guertel 18-20, A-1097 Vienna, Austria

phone +43/1/40400-4565

fax +43/1/40400-4566

email stefan.wolfsberger@akh-wien.ac.at

Abbreviations (in alphabetical order)

3-D	three-dimensional
CD-R	recordable compact disc
CT	computed tomography
ICA	internal carotid artery
MRA	magnetic resonance angiography
MRI	magnetic resonance imaging
PACS	picture archiving and communications system
PC	personal computer
VE	virtual endoscopy

Abstract

Objective: Virtual endoscopy (vE) allows simulated three-dimensional (3-D) visualization of anatomical structures by computerized reconstruction of radiological images. The aim of this study was to evaluate the feasibility of vE and its potential benefits for endoscopic transsphenoidal pituitary surgery.

Patients and methods: vE was realized using a commercially available ray-casting software plugin of a picture archiving and communications system (PACS). For this study, the vE system was enhanced with volume segmentation, transparency and cutting tools. The data for vE were derived from high resolution computed tomography (CT) scans of 22 patients with pituitary pathology (20 pituitary adenomas, 2 Rathke's cleft cysts) preoperatively. Anatomical structures were identified on vE images and compared with the intraoperative endoscopic view.

Results: The simulated 3-D vE images were found comparable to the intraoperative endoscopic anatomy in terms of distortion and angle of view. vE was found particularly useful for the preoperative depiction of 1) the nasal anatomy and its variations for choosing the side of the approach, 2) the sphenoid sinus septae and chambers for improved intraoperative orientation, 3) the transparent 3-D simulated visualization of the pituitary gland, tumor and adjacent anatomic structures in relation to the sphenoid sinus landmarks for planning the opening of the sellar floor.

We conclude that vE harbours the potential to become a valuable tool in endoscopic pituitary surgery for training purposes and preoperative planning. Furthermore, vE may add to the safety of interventions in case of anatomical variations.

Key words

virtual endoscopy · pituitary · endoscopic transsphenoidal surgery

Introduction

Pursuing the goal of minimal invasiveness, endoscopy has recently been introduced in neurosurgery as a further refinement of the transnasal transsphenoidal approach to sellar lesions [4, 13]. As the tip of the optic device is close to the surgical target, endoscopes offer the advantage of high magnification, large field of view and different viewing angles, making views “around the corner” possible through a keyhole approach. Modern rod-lens based endoscopes combined with digital signal processing video systems provide excellent image quality of the surgical anatomy. Given these technical advances, transsphenoidal endoscopic pituitary surgery is increasingly performed and has replaced the conventional microscopic technique in some centers.

However, neurosurgeons are used to the handling and the three-dimensional picture provided by an operating microscope. Thus, a learning curve is needed for endoscopic surgery. Not only does the new technique require a different handling of the optic device, but it is also the endoscopic view of the anatomy that neurosurgeons are unfamiliar with: The endoscope produces a two-dimensional image with a large, magnified and laterally distorted field of view (the so-called “fish eye” phenomenon) at unusual viewing angles. Thus, for safe application of this new technique, experience, special training, and preoperative planning of the surgical intervention are crucial.

First described in 1994 by Vining *et al* [26, 27], virtual endoscopy (vE) is a postprocessing tool for radiological images. It creates a virtual 3-D environment by computerized reconstruction of image data and identification of inner surfaces and organic structures through a threshold process. Inside this virtual 3-D space, movements, angles and rotations of the viewing position are possible. vE has applications in many fields of medicine (for a review see [3]) including otorhinolaryngology for visualization of the nasal cavity and paranasal sinuses [8, 12, 17, 19, 23] and in neurosurgery for simulation of ventriculoscopy [2, 11, 14, 15] and cisternal endoscopy [1, 10, 18]. However, to our knowledge, only one study has reported so far on vE for transsphenoidal pituitary surgery [24]. The aim of our study was to systematically evaluate the feasibility of vE and its potential benefits for endoscopic transsphenoidal pituitary surgery.

Methods and Patients

Image acquisition

Assessment of the nasal and sphenoid anatomy by computed tomography (CT) is part of the preoperative routine diagnostic workup in patients with pituitary adenoma. Due to the superior delineation of fine bony structures as compared to magnetic resonance imaging (MRI), the CT data were used for reconstruction of vE images: After application of iodinated contrast media (iopamidol, Iopamiro® 300 mg iodine/mL, Bracco, Milan, Italy) at 1 mL/kg body weight, axial images with 512 x 512 matrix starting inferior to the nares and advancing at 1 – 2 mm slice distance with a fixed tube voltage of 120 kV and current of 260 mA were acquired on a multislice CT scanner (Somatom Sensation 4®, Siemens, Vienna, Austria) and stored on recordable compact disc (CD-R) in DICOM format.

Development of vE software

Initially, we listed the requirements of an optimal system as follows: 1) A haptic device simulating an endoscope. 2) Software applicable on a standard personal computer. 3) No necessity for additional radiological patient examination. 4) Real-time visualization of virtual structures, i.e. in a “fly-through” fashion including picture-archiving and movie-capturing. 5) Transparency of pivotal anatomical structures as defined by previous segmentation through the walls of the virtual 3-D space. 6) Virtual instruments for simulating simple surgical actions.

vE was realized with the commercially available Java® (Sun Microsystems, Santa Clara, CA, USA) -based picture archiving and communications system (PACS) J-Vision® (TIANI Medgraph AG, Brunn/Gebirge, Austria). We adapted the ray-casting software plugin RayCaster® (TIANI Medgraph AG, Brunn/Gebirge, Austria) according to the needs of transsphenoidal endoscopic surgery [20]:

1. Endoscopic view. To simulate a virtual endoscope, the circular field of view was fixed at 120° with a peripheral distortion. An option to change the virtual endoscopic view between different angles (0, 30, 45, 70 degrees) was implemented. Shading of anatomical structures was provided by the ray-casting software.

2. Orientation. For proper orientation in the virtual space, a multiplanar reconstruction of the image data was displayed on the monitor. The actual position of the virtual endoscope as defined by its tip was marked as a dot, the actual field of view as defined by a pyramid-shape was marked as a contour on the CT images (*figure* 1). Corresponding CT images were updated during virtual endoscopy in real-time just as neurosurgeons are used to from working with intraoperative navigation systems.

3. Steering. A commercially available force-feedback joystick was used for maneuvring the virtual endoscope. We implemented a collision detection in the software that provided haptic feedback via the joystick whenever the user hit a virtual anatomic border.

4. Segmentation and transparency. Volume segmentation of important structures such as the internal carotid arteries was realized by manually outlining the objects on CT images. The 3-D objects were transparently displayed behind the walls of the virtual space.

5. Surgical instruments. A rongeur was simulated by removal of a cylindric piece of virtual tissue in front of the endoscope tip when pressing the trigger button of the joystick. The stroke of the virtual instrument was adjustable by depth and radius.

6. Image and video acquisition: Capturing of screen shots and movies for later comparison with intraoperative images is possible via the PACS software during the vE session.

Endoscopic pituitary surgery

For endoscopic pituitary surgery we used rigid rod-lens endoscopes with 4 mm outer diameter, 20 cm shaft length and viewing angles of 0, 30 and 45 degrees (Hopkins®, Storz GmbH, Tuttlingen, Germany) attached via a 3 charge-coupled-devices video camera (Image One®, Storz GmbH, Tuttlingen, Germany) to a 20” TFT computer monitor with a resolution of 1280 x 1024 pixels. A 300 W xenon cold-light lamp was used as light-source. Intraoperative images and movie sequences were stored on CD-R via a documentation system (AIDA®, Storz GmbH, Tuttlingen, Germany). We used a pneumatic holding device (Unitrack®, Aesculap, Tuttlingen, Germany) for fixation of the endoscope during surgery.

Briefly, the nostril of the larger nasal cavity and/or contralateral to the side of parasellar tumor extension was chosen for the approach. After decongestion with 10% cocain-solution-soaked cottonoids, the mucosa around the sphenoid ostium was coagulated and the ostium enlarged. If a wide access was needed, the septal bone was fractured to the contralateral side in a swing-door fashion to gain access to both sphenoid ostia. Inside the sphenoid sinus, parts of the mucosa covering the sellar floor and the sphenoid septae were removed. After removal of the bony sellar floor the dura was opened in a quadrangular shape and its double fold edges sealed with bipolar cautery to prevent bleeding from intercavernous sinuses. The adenoma was then removed using differently shaped curettes and suction. Endoscopes with 30 and 45° viewing angle were used for inspection and tumor removal in para- and suprasellar areas. At the end of the procedure, the sellar floor was reconstructed using haemostyptic material, fibrin glue and septal bone.

Postoperatively, virtual endoscopic and intraoperative images where compared. We assessed the value of vE in a series of 22 patients by simulated 3-D visualization of 1) septal anatomy for improved orientation within sphenoid sinus, 2) position of the adenoma in relation to the pituitary gland in a color-coded fashion, 3) adenoma in relation to ICA.

Results

vE was tested on 22 patients with pituitary pathology (20 pituitary adenomas, 2 Rathke's cleft cysts). Three-dimensional simulation of the transnasal transsphenoidal approach to the sella was possible with our vE system in all patients. The 3-D simulation of the virtual endoscopic view and its corresponding position on the radiological image data concurrently shown by the system is illustrated in *figure* 1. The virtual endoscope was maneuvered by keyboard or joystick, which was capable of providing a force-feedback in case of collision with a tissue border. A learning curve was needed for proper guidance of the virtual device. The transnasal transsphenoidal approach as visualized by vE is illustrated in *figure* 2: During the nasal phase of the virtual approach the septum and its variations (eg, septal spurs; *figure* 4b), the nasal turbinates and meatus, the choana with torus tubarius and auditory tube, and the ostium of the sphenoid sinus were clearly visualized by vE. During the sphenoid phase vE illustrated the bulging of the sella, the clivus and sphenoid septations. These were seen as single and/or multiple, complete and/or partial divisions of the sphenoid sinus. The sphenoid sinus landmarks were clearly visible: tuberculum sellae, protuberances of internal carotid artery and optic nerve, and the optico-carotid recess as the inversion of the anterior clinoid process (*figure* 3). As an anatomic variation, an Onodi cell was found in one patient (*figure* 4f). The sphenoid phase of the virtual surgery was commenced by removal of the septations. This was made possible by reducing the sensitivity of the vE system to Hounsfield units of the CT data (*figure* 3). The sellar lesion, pituitary gland, ICA and its major branches, and the optic nerves and chiasm, were manually segmented on the vE system beforehand. At the sphenoid stage of the virtual operation these structures were transparently visible through the walls of the sphenoid sinus (*figures* 1, 5). The opening of the sellar floor was simulated by a virtual rongeur with variable impact diameter and depth (*figure* 1).

We observed a good correlation of the intraoperative and virtual anatomy (*figure* 5), making preoperative 3-D simulation of individual patient anatomy feasible.

Preliminary clinical experience

Of the 22 patients studied, 15 had more than one complete or incomplete sphenoid septum; in all of these patients vE could simulate individual 3-D anatomy of the sphenoid sinus chambers, facilitating identification of the opening site of the sellar floor (*figure* 5c+d). In 12 of 22 patients transparent 3-D simulated vE visualization of the intrasellar position of the pituitary gland was useful for the planning of an individually tailored approach to the sellar lesion minimizing possible damage to the gland (*figure* 5a+b). In 10 of 22 patients vE visualized parasellar extension of the lesion partially encasing the ICA (*figure* 5c+d). In these cases, vE facilitated planning of the operative removal of the lesion, thus minimizing the risk of damage to ICA.

Discussion

The application of endoscopes for pituitary surgery has further minimized the transsphenoidal approach as a keyhole-sized corridor for introduction of endoscope and instrument is sufficient [4, 7, 13]. At the same time, working at supra- and parasellar regions under direct visual control has become possible by the use of angled endoscopes and dedicated instruments [5]. However, microscopy-based neurosurgeons are unfamiliar with the magnified, angled, large and laterally distorted field of view of an endoscope. Thus with the new technique, a need for training and preoperative planning facilities has evolved. The aim of this study was to evaluate the feasibility and possible benefits of vE for transsphenoidal endoscopic pituitary surgery. Having developed a vE system we report on our preliminary experience in a series of 22 patients with sellar lesions.

vE as a training tool

According to our experience, vE may be beneficial as a training tool for the beginner of endoscopic pituitary neurosurgery. Currently available training tools for neurosurgeons who want to get acquainted with transsphenoidal endoscopic pituitary surgery are cadaver training or workshops. vE can be used for training the endoscopic anatomy through its simulated 3-D view. The advantage of vE over cadaver training is its unique design to study the individual endoscopic patient anatomy before the teaching operation. This may reduce operation time and, even more importantly, increase the safety of the procedure. However, a drawback of vE is the lack of haptic feedback from tissue contact that is so important in real endoscopy in creating the third dimension of depth.

Surgical planning with vE

For the neurosurgeon who is already experienced in endoscopic pituitary surgery, vE is beneficial for preoperative planning. Thereby, vE provides prospective information about the anatomic variations in the individual patient: vE may aid in the descision making of the side of the approach by depicting the size of the nasal meatus, the middle turbinate, and septal deviations or spurs. Due to the possibility of angled views, an approach contralateral to the parasellar extension of the pathology is not as crucial in endoscopic pituitary surgery as is in microscopic surgery.

For a safe and individually tailored approach to sellar lesion, it is essential to interpret the anatomy of the sphenoid sinus correctly:

1) Sphenoid septation: Considerable variation exists in terms of number and completeness of septa dividing the sphenoid sinus in chambers. Some septa have to be opened for sufficient access, and some that insert at the sellar floor may be used as landmarks during opening. However, the large and most constant intersinus septum often deviates from the midline and can be attached to the protuberance of the ICA [24]. This septal deviation must be kept in

mind when removing the bony septa to avoid damage to the underlying artery. vE can visualize such an anatomic situation preoperatively.

In a cadaver series the ICA was not completely covered by bone in 4% of cases [22] and may therefore be injured inadvertently during opening of the sellar floor. As in the case of adenomas that have arroded the bone and bulge through the sellar floor (*figure* 5d), an ICA that is not covered by bone will be shown by vE through a stronger coloration.

2) Prevention of vascular injury: If a wide opening of the sellar floor is desired, such as in case of a macroadenoma, the landmarks of the sphenoid sinus have to be interpreted correctly not to laterally damage the ICA. Arterial injury has been reported in less than 0.2% of cases in large series of microscopic transphenoidal pituitary surgery [9, 25] and is a major contributor to the mortality still associated with the procedure [21, 25]. Cappabianca *et al* [6] reported of one injury to ICA out of 233 transsphenoidal endoscopic procedures that was successfully managed by endovascular treatment. vE provides prospective information about the anatomic variations in the individual patient that may be fraught with possible vascular injury: bony landmarks overlying the ICA, inter-carotid-distance (mean 12 mm at the closest point but can be as low as 4 mm [22]), parasellar tumor extension with variable encasement of the ICA.

Talala *et al* [24] were the first to use vE for visualization of the ICA inside the virtual sphenoid sinus. However, they projected the ICA on the non-perspective 3-D image of the sphenoid bone and did not use transparent view of the arteries with endoscopic distortion as in our series. Moreover, our system allows simulation of bone opening using virtual instruments.

3) Protection of pituitary gland: If the pituitary gland is in an endosellar position, as in case of a micro- or small macroadenoma, the opening of the sellar floor can be specifically tailored to the location of the lesion in order to protect the pituitary gland and preserve pituitary function. In microadenomas, loss of one or more anterior pituitary functional axes has been reported to

occur in approximately 3% of cases following surgery [16]. In macroadenomas pituitary function can be preserved in > 95% of cases [25]. vE can transparently visualize the pituitary gland and sellar pathology in relation to the individual sphenoid sinus anatomy and may therefore aid in pre-surgical planning of an approach specifically tailored to the lesion [19].

Future perspectives

To make the vE system a useful tool for the routine clinical setting, the following limitations need to be overcome: 1) Maneuvring of the virtual endoscope. The maximum excursions of an endoscope introduced into the nasal cavity are limited by the surrounding tissue borders which differ in terms of their elasticity. Future projects include the simulation of elastic deformation by the vE system. This together with the force-feedback in case of collision with a tissue border should improve haptic interaction with the user. 2) Manual segmentation of the vessels is time consuming: An average of 15 minutes are needed for segmentation on contrast-enhanced CT scan. Picture fusion with magnetic resonance angiography (MRA) and automated segmentation of the arteries will greatly enhance ease of use. 3) Refinement of simulation of surgical instruments: At present, only anatomical structures that have been segmented beforehand are displayed after tissue removal by virtual instruments. Insertion of MRI anatomy behind the virtual wall would enhance pre-surgical planning.

Conclusion

Our study proves the feasibility of vE in endoscopic transsphenoidal pituitary surgery. The simulated 3-D images correspond with the intraoperative endoscopic view. With vE it is possible to preoperatively depict the individual patient anatomy, transparently visualize the pituitary gland, the sellar pathology and the adjacent anatomic structures in an endoscopic fashion. This is useful for getting acquainted preoperatively with the individual sphenoid sinus anatomy, prevention of vascular injury and protection of the pituitary gland.

According to our preliminary data, vE harbours the potential to become a valuable tool in endoscopic pituitary surgery for training purposes and preoperative planning. Furthermore, vE may add to the safety of interventions in case of anatomical variations.

Figures

Figure 1 – Screen layout of the vE system: 3-D virtual endoscopic view (*top left*), CT images in axial view, sagittal and coronal reconstruction (*clockwise*). The virtual endoscope is inside the sphenoid sinus. For access to a pituitary macroadenoma (*green*) the sphenoid septum and parts of the sellar floor have been removed on 3-D view as well as on radiologic images using virtual instruments. The pituitary gland (*purple*) is elevated by the tumor. The carotid siphon (*red*) and the optic nerves (*yellow*) are transparently visible through the sphenoid sinus wall.

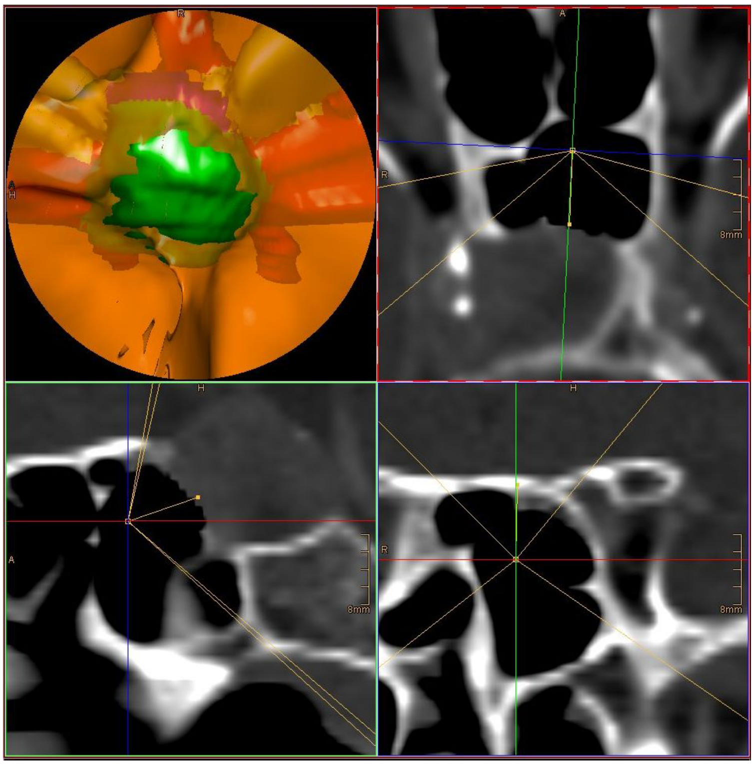


Figure 2 – vE transnasal transsphenoidal approach to the sella: (*a*) The right nostril is chosen as entry point, note the peripheral endoscopic distortion ("fish eye effect"). (*b*) The endoscope is advanced through the lower nasal meatus along the medial border of the inferior nasal turbinate. (*c*) The choana is visible at the posterior end of lower nasal meatus. (*d*) The endoscope is elevated and the posterior end of the middle nasal turbinate is visible laterally, the rostrum of the sphenoid medially, the sphenoid ostium superior to the choana. (*e-f*) The endoscope is advanced, and the anatomy of the sphenoid sinus is visible through the ostium of the sphenoid: the floor of the sella and the clivus posteriorly, an incomplete sphenoid septum laterally, a complete sphenoid septum medially.

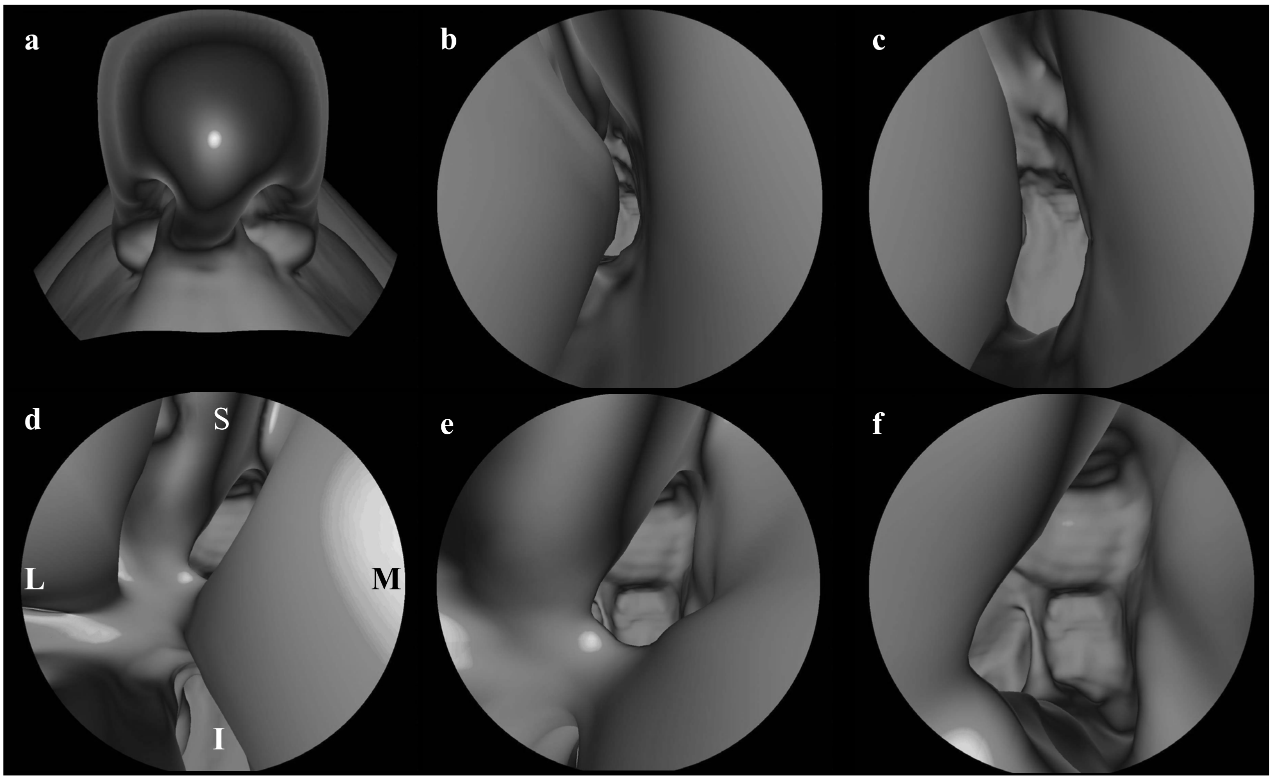


Figure 3 – Virtual removal of a sphenoid sinus septum (*asterisk*): By increasing the systems threshold to CT Hounsfield units, mucosal and bony structures can be eliminated. Note the incomplete septum (*arrowheads*), the inverted tuberculum sellae (*double arrow*), the optic protuberance (*short arrow*) and the optico-carotid recess (*long arrow*).

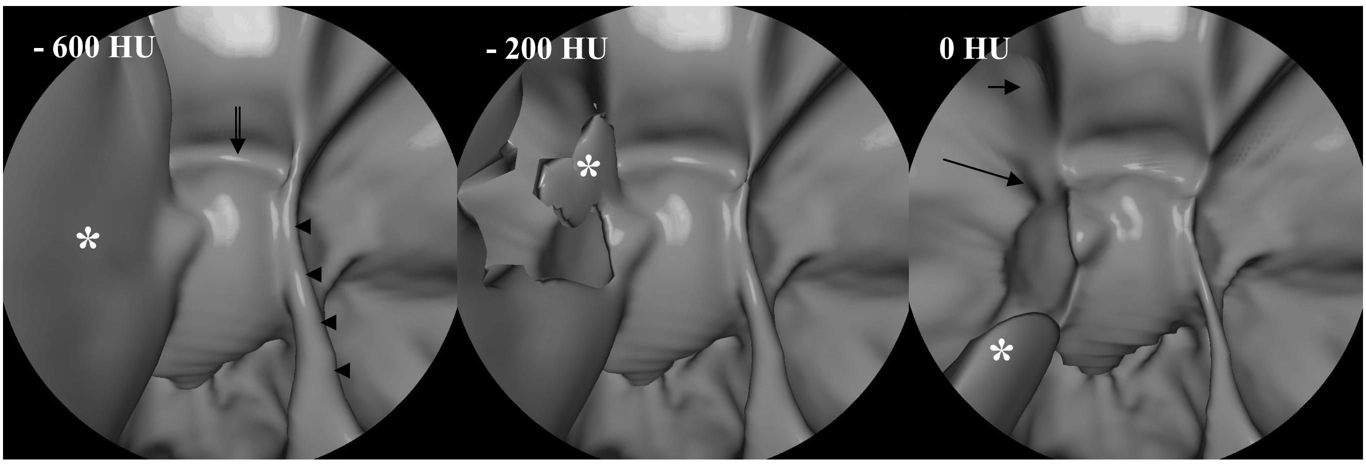


Figure 4 – Comparison of virtual endoscopic with intraoperative images.
(*a+b*) Right transnasal approach. A nasal septum spur (*asterisk*) that causes partial stenosis of the meatus is clearly observed with both imaging modalities. In this case vE can be useful for planning the side of the approach.
(*c+d*) Sphenoid sinus. Sellar floor (*asterisk*), clivus (*ring*). Multiple partial and complete septae are seen intraoperatively and correspond to the vE image. Preoperative knowledge about multiseptated sinus may facilitate septum removal intraoperatively.
(*e+f*) Sphenoid sinus. As an anatomical variation an Onodi cell (*asterisk*) is observed. The sellar floor is opened on the intraoperative, not on the virtual endoscopic picture (*ring*).

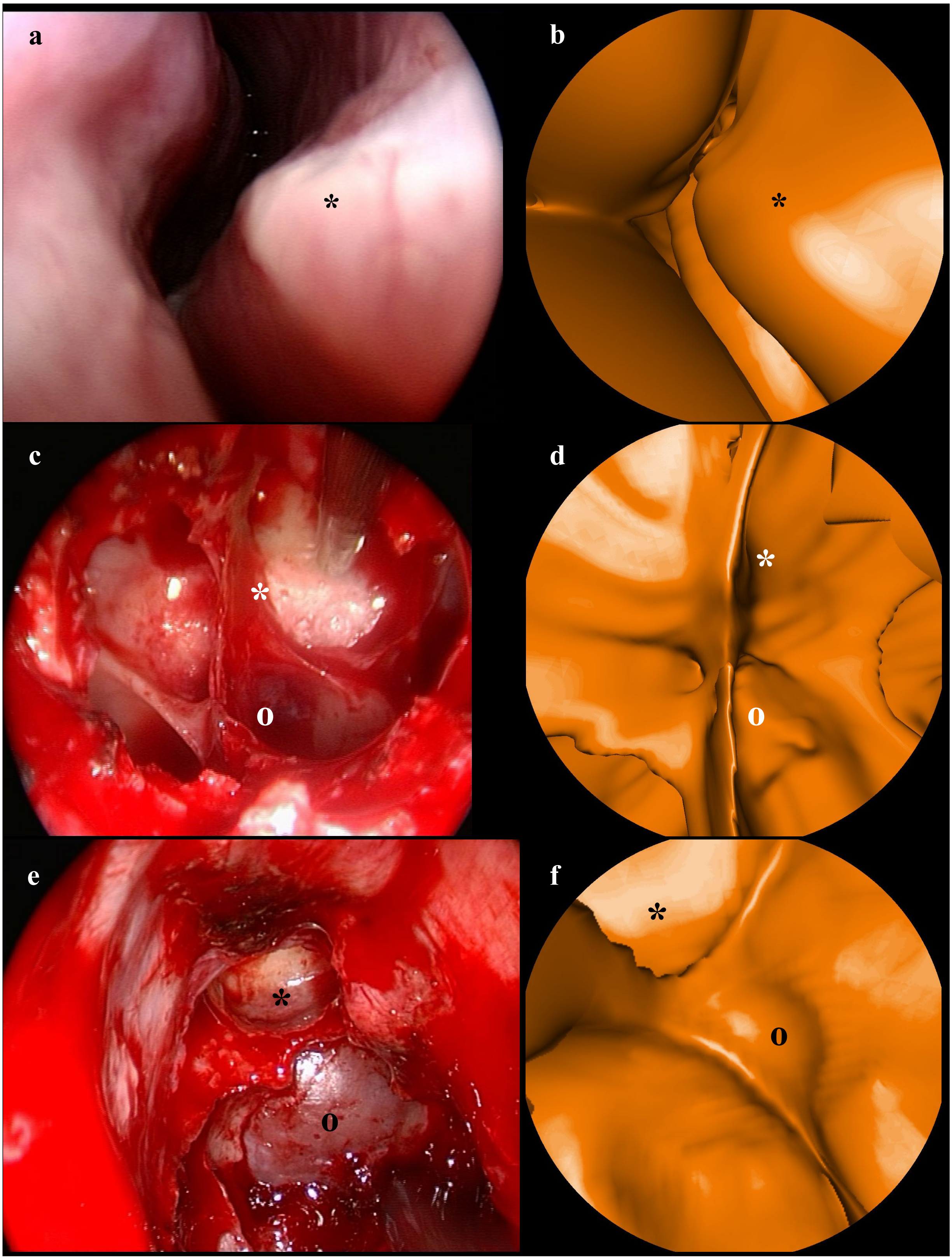
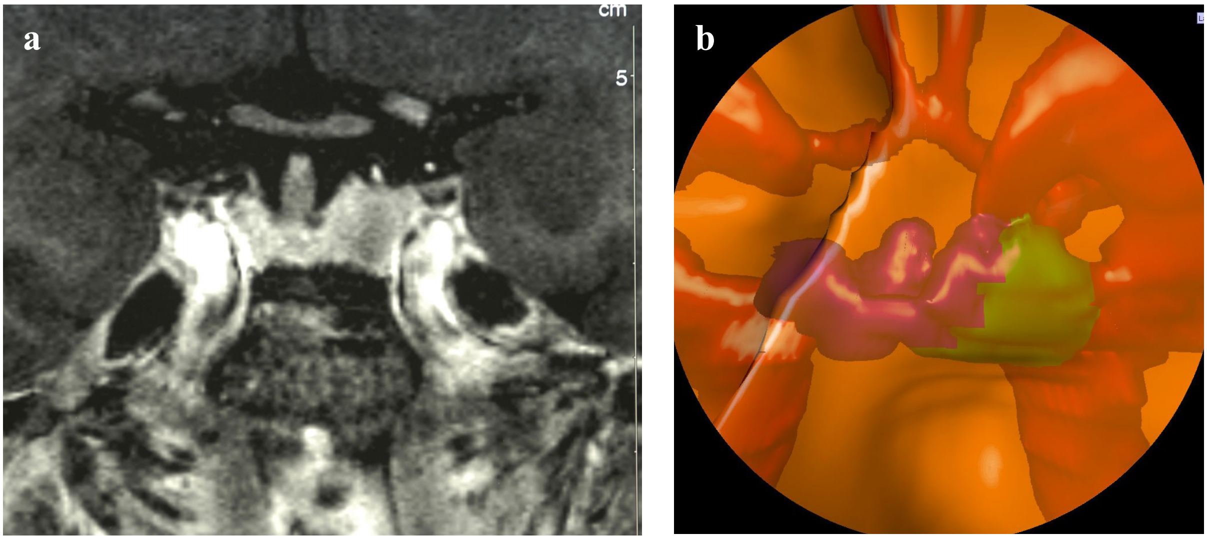
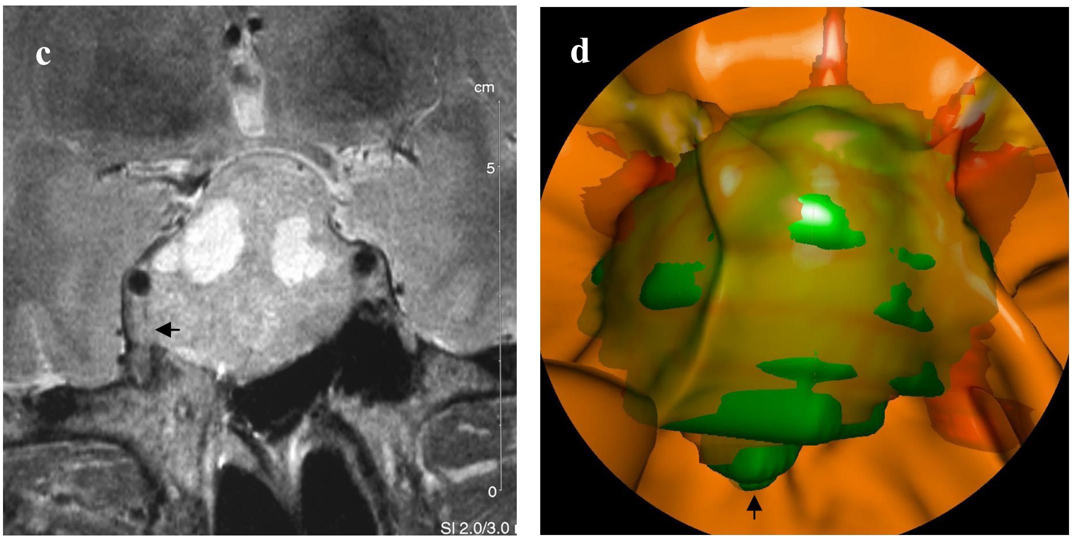


Figure 5 – Case examples. Transparent visualisation of structures through the virtual sphenoid sinus walls: Pituitary gland (*purple*), adenoma (*green*), ICA/ACA (*red*), optic nerve (*yellow*).

Left endosellar GH-producing microadenoma (*a*+*b*):
(*a*) T1-weighted contrast enhanced coronal MP-RAGE 3T MRI.
(*b*) vE image (contrast-enhanced CT, slice thickness 1 mm, threshold -100 HU): Safe left paramedian opening of the sellar floor can be planned with the aid of virtual endoscopy. Note the peripheral distorted view of the internal cerebral arteries due to the simulation of the endoscopic fish-eye effect.



Null-cell adenoma with supra- and right parasellar extension *(c+d)*.
(*c*) T2-weighted coronal RARE 3T MRI: The medial wall of the right cavernous sinus is inconsistently delineated (*arrow*), and has intraoperatively been found infiltrated.
(*d*) vE (contrast-enhanced CT, slice thickness 1 mm, threshold -50 HU): Multiseptated sphenoid sinus. Note the arrosion of the sellar floor and basal bulging of the adenoma (*arrow*) as confirmed intraoperatively. The C3 segment of the right internal carotid artery is hidden behind the parasellar adenoma extension.



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