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F.H. Ebner, J.S. Marquardt, B. Hirt, G.C. Feigl, M. Tatagiba, et al.. Broadening Horizons of Neuroendoscopy with a Variable-View Rigid Endoscope: An Anatomical Study. *EJSO - European Journal of Surgical Oncology*, 2010, 36 (2), pp.195. 10.1016/j.ejso.2009.07.185 . hal-00557765

HAL Id: hal-00557765

<https://hal.science/hal-00557765>

Submitted on 20 Jan 2011

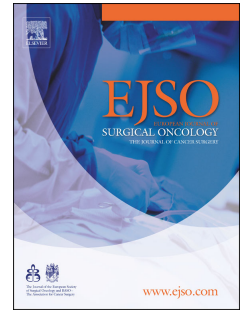
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Accepted Manuscript

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PII: S0748-7983(09)00408-9

DOI: [10.1016/j.ejso.2009.07.185](https://doi.org/10.1016/j.ejso.2009.07.185)

Reference: YEJSO 2872

To appear in: *European Journal of Surgical Oncology*

Received Date: 23 June 2009

Revised Date: 27 July 2009

Accepted Date: 30 July 2009

Please cite this article as: Ebner FH, Marquardt JS, Hirt B, Feigl GC, Tatagiba M, Schuhmann MU. Broadening Horizons of Neuroendoscopy with a Variable-View Rigid Endoscope: An Anatomical Study, *European Journal of Surgical Oncology* (2009), doi: 10.1016/j.ejso.2009.07.185

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Broadening Horizons of Neuroendoscopy with a Variable-View Rigid Endoscope:
An Anatomical Study

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Abstract

Aim: To test the versatility and usefulness of a prototype rigid endoscope with a continuously variable-view-angle tip (Endochamaeleon, Karl Storz, Tuttlingen, Germany) with regard to field of vision and applicability for endoscopic assisted neurosurgery.

Methods: In five formaldehyde fixed specimens frontolateral and retrosigmoid approaches were prepared on both sides and five target positions of the endoscopes tip were defined. A rigid 4 mm endoscope, which offers in one plane a viewing range of approximately -10° to $+120^{\circ}$ by turning a proximal knob coupled to fine distal optomechanics was compared to 0° , 45° , and 70° rigid endoscopes. The visualisable neuroanatomical structures were assessed for each position, endoscope angle, and plane of view as well as the over-all visibility of neuroanatomical structures and the time factor.

Results: 1905 recorded images of 1800 different views were analyzed. The EC offers a variable angle of view in one plane without need to change the endoscope position. This feature is well suited for inspection of functionally delicate areas at the skull base. The maximum number of visible structures for each position was only seen with the EC. Endoscopic exploration was significantly less time consuming with the EC than with the other endoscopes.

Conclusion: The EC provided superior usability and visualization potential compared to standard rigid endoscopes with fixed angulation. It combines the ergonomic and safety advantage of not having to insert endoscopes with different angles with the opportunity to “scan” the surgical field with a variable angle of $0-120^{\circ}$ within one plane of view.

Introduction:

The roots of endoscopy are originally in urology and internal medicine. Thus, for many decades endoscopes and instruments have significantly been influenced by these disciplines. The real breakthrough of endoscopy in neurosurgery occurred in the 1980s [1]. Since then, the specific problems of illumination, viewing- and working-angles, and visualization have been solved stepwise. Continuous improvement of lens systems has enhanced the optical quality, and the introduction of flexible endoscopes has enlarged the angle of view. However, in endoscope-assisted neurosurgery of the skull base, flexible endoscopes harbour an unacceptable risk of injury to the delicate neurovascular or nervous structures within the small working spaces of the cisterns. The insertion of angled optics into the surgical field under microscopic vision, which is current practice, is cumbersome and time consuming and does not enable an easy 360° view and orientation within the field of surgery. The ideal solution in terms of optimal visualization, safety, economy of time and ergonomics would be a rigid endoscope with a continuously variable tip, enabling a multidirectional 180° view angle, to cover a 360° horizon.

The aim of this study was to test in the anatomical lab a prototype rigid endoscope with a continuously variable-view-angle tip (Endochamaeleon, Karl Storz, Tuttlingen, Germany) with regard to field of vision and applicability for endoscope-assisted neurosurgery.

Methods:

Endochamaeleon - Technical description

The Endochamaeleon (EC) is a rigid 4 mm endoscope that is capable of changing its angle of view while remaining stationary and shape-invariant. By turning a proximal knob, which is coupled to fine distal optomechanics, the user can change the endoscope's angle of view without moving the endoscope shaft or the attached camera. This, however, is only possible in one plane, since the tip of the endoscope cannot be rotated around the shaft axis without turning the shaft (and the attached camera) itself. Nevertheless, this provides the operator with a greater viewing mobility: instead of having to insert a different endoscope with a different viewing angle, the operator can actuate the knob (and thus the angle of view) and keep the endoscope in place. The EC provides in one plane a viewing range of approximately -10° to $+120^{\circ}$, which effectively means that it combines the capabilities of 0° , 12° , 30° , 45° , 70° , and 90° fixed-angle rigid endoscopes into a single instrument and goes beyond by allowing views “backwards” up to 120° .

Set-up of Anatomical study

In five 4% transfemoral whole body formaldehyde fixed, arterially injected head specimens, frontolateral and retrosigmoid skull base approaches [2] were performed on both sides in standard technique and size. After meticulous microsurgical dissection of the intradural neurovascular structures, 0° , 45° , and 70° rigid endoscopes (Karl Storz, Tuttlingen, Germany) and the Endochamaeleon (Karl Storz, Tuttlingen, Germany) were inserted. For each approach, five target positions of the endoscope tip were defined (Figures 1 A and B). In preparation of the study, high-resolution computed tomography scans of all specimens with acquisition of dataset for neuronavigation were performed. Thus, the topographic position of the endoscope's tip could be

defined additionally by neuronavigation (Cbyon, Sunnyvale, USA). Images were taken with the 0° optic in the straight plane and with the 45° and 70° optics in cranial, medial, caudal, and lateral rotation (by 90° each). Digital image documentation of the specific view per tip position, angle of rotation, and used endoscope was carried out with the AIDA-system (Karl Storz, Tuttlingen, Germany). For each image, specimen number, type and side of approach, angle of endoscope optics, endoscope position and viewing direction were recorded. The EC was positioned with 0° straight view at the desired tip position and the viewing angle was continuously changed from 0 to 120°. Images were taken so to cover the whole horizon of 120°. Then the endoscope was rotated by 90° in the next plane of view.

To investigate the supposed time advantage of the Endochamaeleon compared to a set of different fixed angle optics a checklist guided inspection of surgically relevant structures in the supra- and parasellar cistern was performed with both options, and the time necessary to visualize all check-list structures was recorded. Fixed-angle optics with 0°, 45°, and 70° were used in comparison to the EC. The inspection included view of the parasellar area from both the right and the left frontolateral approach in each specimen (10 sides) and included insertion and extraction of the endoscopes, white balance when the optic was changed, exploration of the anatomical check-list structures and pivoting the operation microscope for the controlled insertion of fixed-angle endoscopes (45° and 70° optics) compared to the direct insertion of the EC and continuously variable inspection.

Analysis

For efficient analysis of the large amount of recorded images (n=1905) two software tools were developed: A first tool for the systematic naming of the image files, which initially were serially

numbered, and as second tool an image browser, allowing categorized selection and comparison of up to four images by accessing the previous parameterized files.

The parameterization with the objective of explicit identification of every single image includes information with reference to specimen number, type and side of approach, angle of endoscope optics, endoscope position and viewing direction, encoded as a sequence of numbers.

On the basis of these parameters images can be viewed in the image browser whose user interface contains, besides the control elements for the selection of the image source folder on the right, four image panels, each with the corresponding drop-down menu for the selection of the required parameters.

For minimization of operation effort, the drop-down menus can be synchronized in such a way, that changes in the left upper image panel also affect the other panels, so that analogous images in terms of the synchronized parameters are shown.

This concept provided for a convenient analysis and comparison of the graphical material coming from the four different endoscopes.

Hence, according to each specific endoscope tip position, the visualizable neuroanatomical structures were assessed for each endoscope angle and plane of view. Further, the quality of view was evaluated.

In addition, the pictures were used to compare the anatomical preparations with each other regarding the over-all visibility of neuroanatomical structures without consideration of the endoscope model.

Results:

At least one image in all five positions per surgical approach was taken, in four or five possible directions with each of the four endoscopes in each of the five specimens. So a number of 1800 different views resulted. The variable optic of the EC allowed to take images at different angles from the same target position. The visible neuroanatomic structures of interest are itemized in Table 1 regarding the frontolateral and the retrosigmoid approach. Summarizing the data of all specimens, the maximum number of visible structures for each position was defined as 100% and in relation to that, percentages of visualized structures per endoscope were reported (Table 2A and Table 2B). Table 3 shows a representative extraction of visible structures with the EC in absolute terms. Furthermore, the EC allows to „follow“ a structure of interest, e.g. a cranial nerve or vessel during its course through a cistern, within the degree of its viewing angle (Figure 2), while the rigid, not variable endoscopes visualized only a certain section of the structure. However, used in combination, the 0°, 45°, and 70° optics complement one another and cover almost the full range of the structure of interest compared to the EC

Exploring the parasellar region and identifying pituitary stalk, the diaphragma sellae, the ipsi- and contralateral medial border of the ICA, the ophthalmic artery and the infero-medial border of both optic canals was much less time consuming with the EC (15-30 s; mean 22 ± 9 s) than with the standard, invariant rigid endoscopes (120-150 s; mean 134 ± 5 s). The difference is statistically significant according to the non-parametric Man-Whitney U-test ($p < 0.0001$).

Discussion:

The Endochamaeleon (EC) offers a variable angle of view in one plane without the need to change the endoscope. This feature is well suited for inspection of functionally delicate areas at the skull base and for example within the third ventricle. The Endochamaeleon is inserted into the operating field with a straight axis of view (0°), which is an important safety feature preventing the collision of the endoscope with neurovascular structures. The optic is fixed at the target point by the mounting device and the surrounding structures may be explored continuously between 0° and 120° in the preselected plane of view without any external movement of the endoscope's tip. Since the surgeon knows the viewing direction and is able to modify the viewing angle continuously by manual operation of the turning knob coupled to the optomechanics, the sense of orientation is preserved at any time.

Thus, a tailored and controlled visualization of the anatomical structures of interest is possible (Figure 2). The benefits become apparent when the EC is applied e.g. in endoscopic assisted skull base surgery: After microsurgical tumor removal, the operating site may be explored in detail for tumor remnants even in the depth, below and behind delicate neurovascular structures. In this situation the surgeon will benefit from the advanced characteristics of the EC since viewing angles outside the straight microscopic view can be explored in a safe and little time consuming way compared to the current way of inserting different angled rigid endoscopes under microscopic control. This feature may be of particular aid in removing tumours that grow inside the internal auditory canal, like acoustic neuromas and meningiomas, or tumours located ventrally to delicate cranial nervous, like petrous apex meningiomas, where every retraction and new insertion of the endoscope harbours the danger of injuring important structures. Endoscopic extended approaches [3] in oncologic skull base surgery become even more feasible with this

variable-view rigid device.

It is a limitation of the device, however, that the endoscope shaft still has to be rotated in order to change the plane of view. In addition, the camera, which is attached in a 90° angle, turns around which makes the procedure of rotating the shaft at least inconvenient. With regard to a skull base environment a 180° rotation with a camera attached at 90° is even impossible. The goal of further technical development of the EC endoscope is to achieve multiplane viewing in addition to the variable viewing angle without rotating the entire shaft and the attached camera. Then the endoscope can be fixed in the holding-device and the operating field explored in a range of 360° with the tip position immobile. One of the technical challenges to be solved is the preservation of the image horizon, which is an essential requirement for the surgeon's ability to orientate his instruments in the operation field.

Furthermore, the results of our study clearly show, that the fixed 0° optic gives a panoramic view with advantages at greater distance, whereas the angled optics allow for a better exploration of the deeper located neurovascular structures. As demonstrated by the data in Table 1, the EC combines with its continuously adjustable optic the advantages of both. This characteristic facilitates inspection, delicate dissection and tumour removal in deep-located areas such as the perisellar region or petrous apex. However, individual anatomical conditions still can limit the feasibility to visualize specific structures even with this multivariable endoscope (Table 3).

The next intermediate-term goal in endoscopically assisted skull base surgery will be the step from seeing to working around the corner. To visualize residual tumour creates the need to remove those tumour parts, which are, after exploration, known to exist. If targeted displacement of covering structures, like optic nerve, brain stem or major arteries, to remove tumour remnants

is not possible, then the angulated view has to be combined with angulated instruments for tumour removal. The requirements to do so are preserved horizontal/ vertical orientation and a frame fixed endoscope in the surgical field that does not hinder the introduction and manipulation of angulated surgical instruments. The EC endoscope is the first important step to broaden the horizons and thus, in the long run, the possibilities of endoscope assisted skull base surgery.

Conclusion:

The EC provided superior usability and visualization potential compared to standard rigid endoscopes with fixed angulation. It combines the ergonomic advantage of not having to retract and insert scopes with different angles with the opportunity to “scan” the surgical field with a variable angle of 0-120° within one plane of view. Currently, the device limits risks, saves operating time and broadens the applicability of endoscopy in skull base surgery. It is the first important step towards a multiplane, variable view endoscope for skull base surgery.

Acknowledgments

The authors are thankful to Mr.H.Schramm, Foto-Repro-Grafik CRONA, Eberhard-Karls-University Tübingen, for preparing the illustrations.

Conflict of interest statement

The present study was sponsored by Karl Storz GmbH, Tuttlingen, Germany on request of the authors with regard to the costs of injection and preparation of the anatomical specimens. Karl Storz supplied as well the Endochamaeleon as the fixed view endoscopic equipment for the time of laboratory investigation. Karl Storz did not influence the study design and collection, analysis

and interpretation of data; The decision to submit the manuscript for publication was taken exclusively by the authors, which have no financial and personal relationship to Karl Storz and its representatives.

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Figure legend:

Figure 1 A: The intradural target positions for endoscopic exploration in the frontolateral approach are at the level of 1. the craniotomy, 2. the planum sphenoidale, 3. the anterior clinoid process, 4. the sella turcica, 5. the oculomotor nerve.

Figure 1 B: The intradural target positions for endoscopic exploration in the retrosigmoid approach are at the level of 1. the craniotomy, 2. the inner auditory canal, 3. the plane between tentorium and trigeminal nerve, 4. the plane between trigeminal nerve and facial/vestibulocochlear nerve, 5. the plane between facial/vestibulocochlear nerve and caudal cranial nerves.

Figure 2: Endoscopic images taken with the EC demonstrating the variable view by focusing on the tip of basilar artery (A), cisternal course of CN III (B) and PCA/ PcomA (C) from a fixed endoscope position (frontolateral approach on the right side, position 5). An anatomic particularity in this specimen is the splitted basilar artery.

Abbreviations: BA = Basilar artery; CN III = Cranial nerve III; PCA = Posterior cerebral artery; PcomA = Posterior communicating artery; SCA = Superior cerebellar artery

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Structure	Endoscope	Position 1				Position 2				Position 3				Position 4				Position 5				
		EC	0°	45°	70°	EC	0°	45°	70°	EC	0°	45°	70°	EC	0°	45°	70°	EC	0°	45°	70°	
Anterior cerebral artery		●	●			●				●	○	●	●	●		●	●					
CN II contralateral		●	●	○		●	●	●	●	●		●	●	●	●		●	●				
CN II ipsilateral		●	●	○		●	●	●	●	●	●	●	●	●	●		●	●				
CN III		●	●			●				●	●	●	●	●		●	●	●	●	●	●	●
ICA contralateral		●				●		●	●	●		●		●	●	●	●					
ICA ipsilateral		●	●			●	●			●	●	●	●	●	●	●	●	●		●	●	●
Optic chiasm		●	●	○		●	●	○	○	○		○	○	○	●	○	●	●				
SF contralateral		●				●		●	●	●		○	●	●		●	●					
SF ipsilateral		●	○	●	●	●		●	●	●		●	●	●	●		●	●		○	●	●
Caudal CN		●	●	○	○	●	●	●	●	●		●	●	●	●		○	●	●	○	●	●
CN IV		●				●				●	●	●	●	●		●	●			○	●	●
CN V		●	●			●	●	○		●	○	●	●	●	●	●	●	●		○	●	●
CN VI		●				●				●	○	●	●	●	●	○	●	●	●	●	●	●
CN VII/VIII		●	●	○		●	●	○		●				●		●	●					
Exit zone CN V		●				●				●				●		●	●					
Exit zone CN VI		●				●				●				●		○	●	●		○	●	●
Meckel's cave		●				●				●	○	●	●	●	○	○	●	●				
Basilar artery		●				●				●	○	●	●	●	○	○	●	●	●	●	●	●

● excellent visible

○ tangential visible

Table 1 : Visible neuroanatomic structures with the EC, the 0°, 45° and 70° rigid optics through the frontolateral approach (light grey) and through the retrosigmoid approach (dark grey). The column of the Endochamaleon (EC) is highlighted in grey.

Abbreviations: CN = Cranial nerve; SF = sylvian fissure

Endoscope	Position 1	Position 2	Position 3	Position 4	Position 5
EC	100%	100%	100%	100%	100%
0°	69%	50%	38%	18%	13%
45°	31%	75%	92%	100%	88%
70°	31%	83%	92%	100%	100%

Table 2 A: Percentages of visualized structures per endoscope at the frontolateral approach.

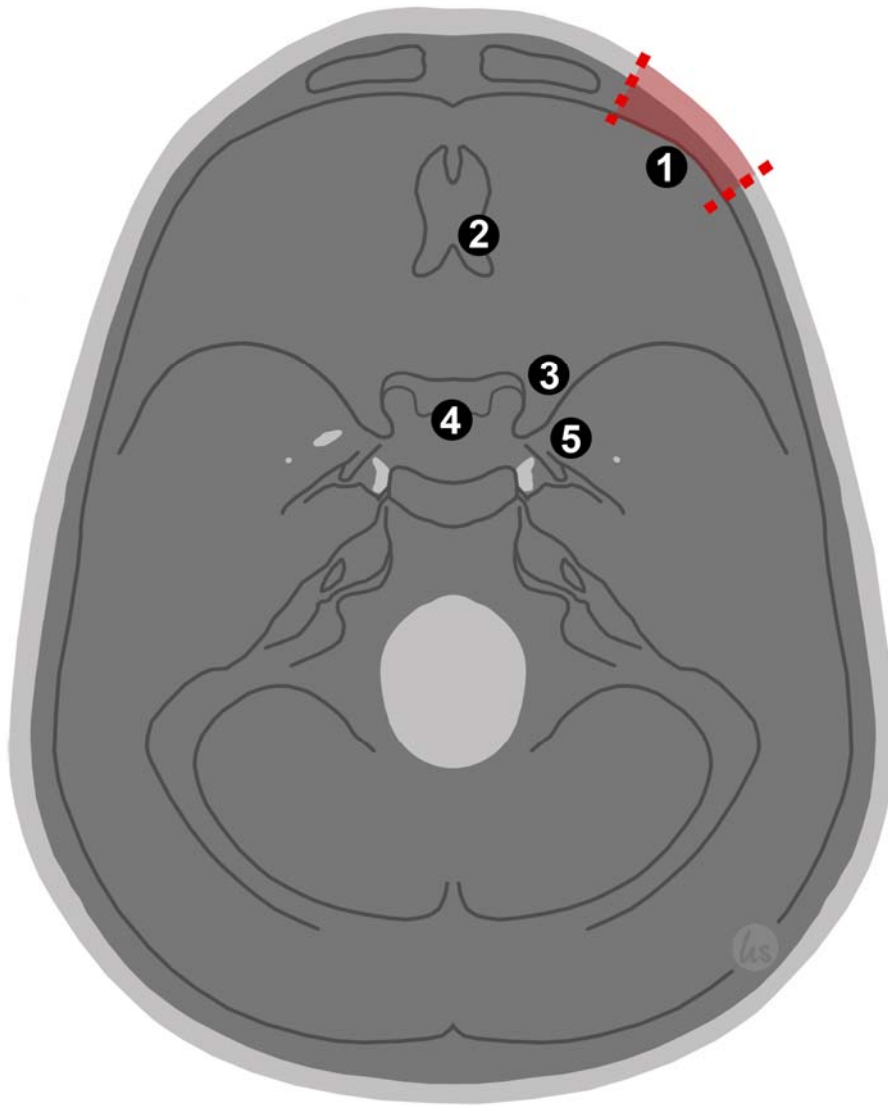
Endoscope	Position 1	Position 2	Position 3	Position 4	Position 5
EC	100%	100%	100%	100%	100%
0°	89%	75%	50%	13%	17%
45°	44%	67%	100%	75%	50%
70°	33%	67%	100%	88%	100%

Table 2 B: Percentages of visualized structures per endoscope at the retrosigmoid approach.

Structure	Specimen	Position 1					Position 2					Position 3					Position 4					Position 5				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Anterior cerebral artery						•						•	•	•	•	•		•	•	•	•					
CN III		•	•		•				•	•	•	•	•	•	•						•	•	•	•	•	
Pituitary stalk		•			•	•	•			•	•				•	•		•	•	•	•					
Exit zone CN VI																	•	•	•	•	•		•	•	•	
Meckel's cave												•	•	•	•	•	•	•	•	•	•	•		•		•
PICA		•	•	•			•	•	•	•	•											•	•	•	•	•

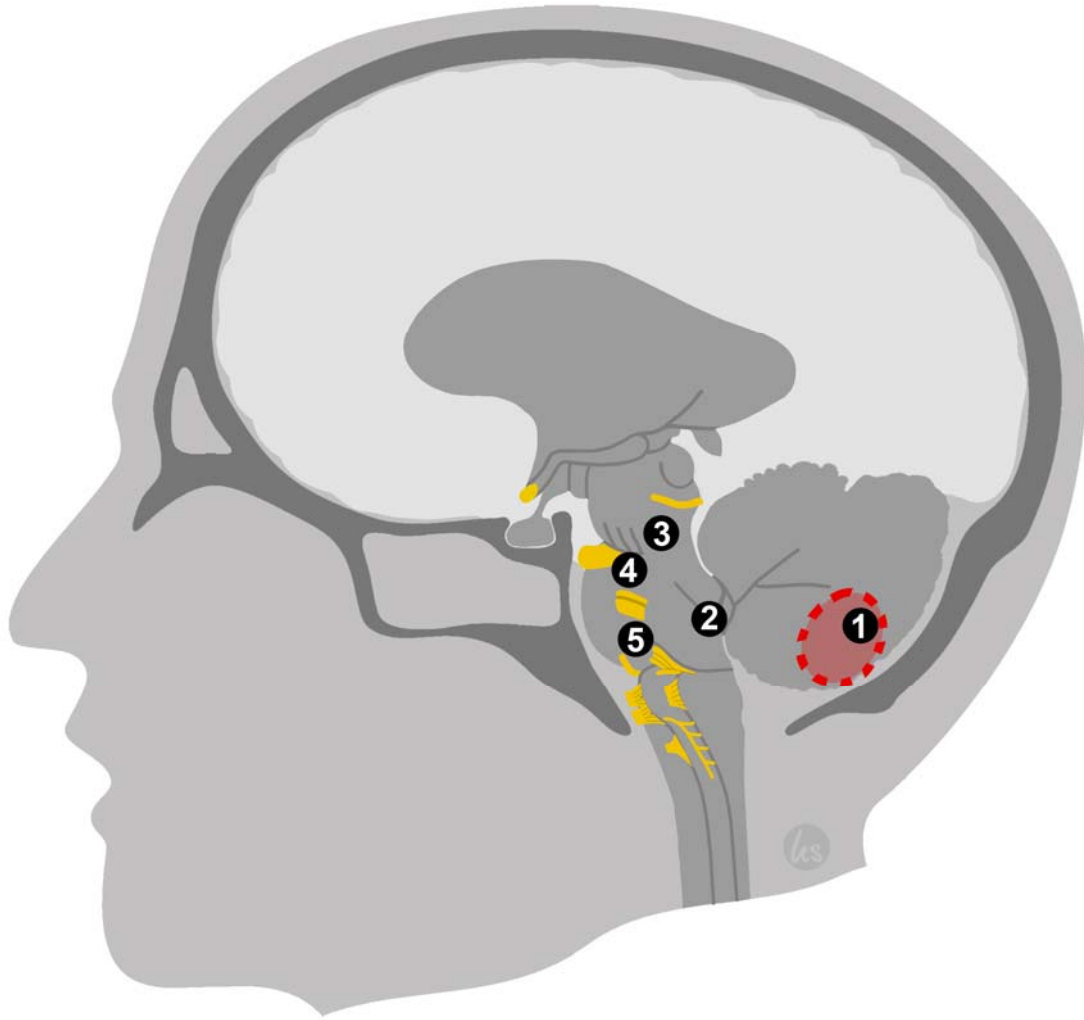
• visible

Table 3: Representative extraction of visible structures with the EC through the frontolateral approach (light grey) and through the retrosigmoid approach (dark grey).
Abbreviations: CN = Cranial nerve; PICA = Posterior inferior cerebellar artery

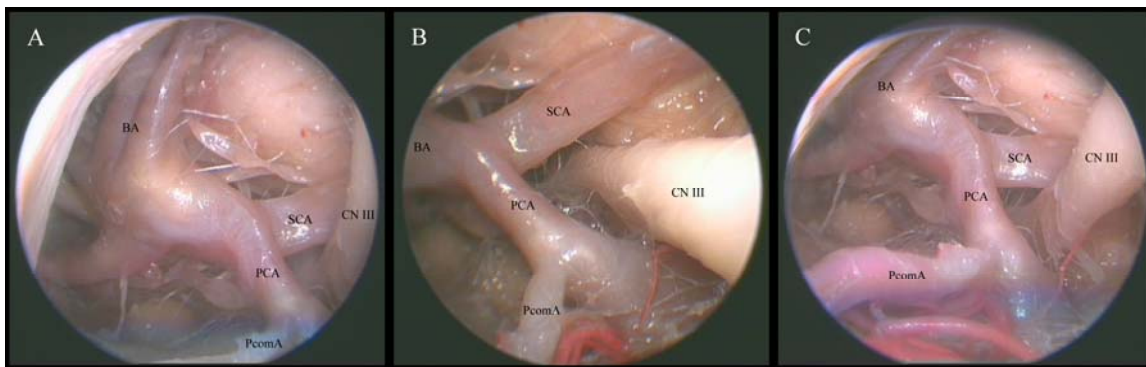


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