Development of a Cadaveric Multiport Model of Posterior Circulation Aneurysm Clipping for Neurosurgery and Otolaryngology Residents
--Manuscript Draft--

Development of a Cadaveric Multiport Model of Posterior Circulation Aneurysm Clipping for Neurosurgery and Otolaryngology Residents

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This protocol describes the steps to produce a realistic cadaveric model for training neurosurgery and otolaryngology residents on management of posterior circulation aneurisms. The benefits of this model are its reproducibility and cost-effectiveness, making it accessible to training programs. It can be used innumerable times to train resident learners over the course of several sessions. This repetition is beneficial to learners, as it is required for developing the technical skill needed for endoscopic approaches. This model involves static and dynamic training options to train learners at different levels of expertise. We feel our work to be a good candidate for publication in the JoVE multimedia format, as this is a dynamic protocol that can be best described by video demonstration.

Author Contributions:
- <u>Haley Gillham</u>: conduct study, drafting manuscript
- <u>Brandon Lucke-Wold</u>: conduct study, drafting manuscript
- <u>William Cameron</u>: conduct study
- <u>Jeremy Ciporen</u>: Principal Investigator, developmental, conduct study, drafting manuscript

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1 **TITLE**
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4
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28 **SHORT ABSTRACT:**
29 A model protocol to train neurosurgery and otolaryngology resident learners on endoscopic
30 transclival clipping of posterior circulation aneurysms is described. Two endoscopic approaches
31 to access the silicone-injected or perfused posterior circulation of cadaveric heads are
32 established for training. Learners are tasked with clipping of posterior circulation based on
33 clinical scenarios.
34

35 **LONG ABSTRACT:**
36 Posterior circulation aneurysms are difficult to treat with the current methods of coiling and
37 clipping. To address limitations in training, we developed a cadaveric model to train learners on
38 endoscopic clipping of posterior circulation aneurysms. An endoscopic transclival approach
39 (ETA) and a transorbital precaruncular approach (TOPA) to successfully access and clip
40 aneurysms of the posterior circulation are described. The model has flexibility in that a colored
41 silicone compound can be injected into the cadaveric vessels for the purpose of training
42 learners on vascular anatomy. The other option is that the model could be connected to a
43 vascular perfusion pump allowing real-time appreciation of a pulsatile or ruptured aneurysm.
44 This cadaveric model is the first of its kind for training of endoscopic clipping of posterior

45 circulation aneurysms. Learners will develop proficiency in endoscopic skills, appropriate
46 dissection, and appreciation for relative anatomy while developing an algorithm that can be
47 employed in a real operative arena. Going forward, various clinical scenarios can be developed
48 to enhance the realism, allow learners from different specialties to work together, and
49 emphasize the importance of teamwork and effective communication.
50
51 **INTRODUCTION:**
52 Treatment of posterior circulation aneurysms presents unique challenges and has higher
53 complication rates compared to other cerebral aneurysms[1]. Transcranial clipping of posterior
54 circulation aneurysms is technically challenging, with high complication rates and morbidity[2].
55 Endovascular coiling and endoscopic endonasal surgery are safe alternatives, as they reduce
56 complication rates and limit traction on the cerebrum[3]. Endovascular coiling has been shown to
57 have benefits over open skull base approaches, and most centers now use an endovascular
58 approach to treat cerebral aneurysms[4]. However, many posterior circulation aneurysms are not
59 amenable to coiling due to the location, vessel tortuosity, and vessel size[2]. Recent studies have
60 shown the feasibility of using endoscopic approaches for the clipping of posterior circulation
61 aneurysms[5-8].
62
63 Although endoscopic endonasal surgery has demonstrated benefits over more invasive
64 procedures, several studies document a learning curve associated with the use of endoscopic
65 equipment[9-11]. It is this learning curve and lack of surgeon training and experience that limit the
66 use of this safe and beneficial treatment option[3]. As endoscopic clipping for aneurysms is
67 revealing itself to be a feasible and a safe treatment course, neurosurgery and otolaryngology
68 residents will need to develop these surgical skill sets during their training. This need for
69 technical skill combined with a steep learning curve necessitates the development of realistic
70 training models, as several repetitions are needed to reduce operative room time and
71 complication rate in endoscopic endonasal surgery[9,11]. In a human placental model of cerebral
72 aneurysm clipping, Belykh *et al.* have demonstrated improvement in the use of aneurysm clip
73 applicators in learners after simulation[12]. Similarly, training with 3-dimensional printed models
74 has been shown to improve learner technical skills in aneurysm clipping[13]. As with any training
75 model, cost-effectiveness and reproducibility are leading objectives for wider accessibility. We
76 have previously demonstrated the utility of an ETA and a TOPA in a cadaver model of posterior
77 circulation aneurysm clipping, with approach access and visualization affected by clip location[14].
78 TOPA can be used in conjunction with endoscopic endonasal approaches, and has previously
79 demonstrated shorter working distances, improved visualization, and angles resulting in
80 increased access to structures[4,14]. The TOPA procedure is a new approach for clip ligation of
81 aneurysms, and its applicability can be further explored via simulation for access to both
82 tumors and aneurysms. In this protocol, we present the steps for development of a realistic,
83 cost-effective, reproducible posterior circulation aneurysm-clipping model using ETA and TOPA
84 as options to train neurosurgery learners. An advantage of our model is learner's exposure to
85 authentic physical anatomy, with the option to incorporate realistic dynamic bleeding in the
86 training of aneurysm clipping. This model can be set up with a static (silicone compound
87 infused) or a dynamic (perfused) anatomy and is applicable to train neurosurgery or
88 otolaryngology learners at various levels of expertise on the anatomy and management of

89 posterior circulation aneurysms.
90
91 **PROTOCOL:**
92 In the development of this model, three cadaveric heads were obtained through the Oregon
93 Health & Science University Body Donation Program and handled per the Code of Ethics
94 approved by the Oregon Health & Science University Institutional Review Board.
95
96 **1. Head Preparation**
97
98 1.1. Obtain fresh cadaveric heads. Secure the head in the sink, resting on a block with the neck
99 facing upwards.
100
101 1.2. Prepare a 5 L 1:100 solution of anticoagulant citrate dextrose and warm water. Use the
102 solution within 72 h.
103
104 1.3. Insert a 5-mm arterial cannula into the right jugular vein (lateral to carotid) and apply an
105 arterial cannula clamp around the vessel. Perfuse the vessel for 15 min with a perfusion pump
106 and anticoagulant citrate dextrose solution to wash the vessel. Remove the cannula and repeat
107 with the left jugular vein and carotid arteries bilaterally. Repeat with a 3-mm cannula on the
108 vertebral arteries bilaterally.
109
110 1.4. Allow the heads to sit and dry overnight. Position the heads with the face facing upwards
111 and neck positioned at a 45 ° angle with a supporting block underneath. Then store in a cold
112 room at 5 °C overnight.
113
114 1.5. Embed the heads in 2 L of embalming solution. Store heads in a bucket, submerged in 10%
115 formalin fixative solution.
116
117 1.6. Use the prepared heads with either silicone compound injections to train with static
118 anatomy (step 2) or arterial injury and perfusion setup to train with dynamic anatomy (step 4).
119
120 1.6.1. To complete the silicone compound injections (step 2): complete step 2, then move to
121 step 3 to complete the dissection.
122
123 1.6.2. To complete the arterial injury and perfusion setup (step 4): complete the step 3
124 dissection, then move to step 4 for perfusion instructions.
125
126 **2. Silicone Compound Injections**
127
128 2.1. Prepare the silicone compound solution according to the manufacturer's instructions (50
129 µL diluent, 40 µL red silicone compound dye, and 4.5 µL curative agent).
130
131 2.2. Use dissection to identify the external carotid arteries. Clamp the right external carotid
132 artery with a hemostat to focus the injection into the intracerebral vasculature.

2.3. Insert the arterial cannula into the right internal carotid artery and apply the arterial cannula clamp around the vessel. Inject 20 µL of silicone compound solution. Stop the injection when the flow of the silicone compound solution is noted at the left common carotid artery.

2.4. Clamp the common carotid arteries bilaterally with hemostats.

2.5. Insert an arterial cannula into the right vertebral artery and apply an arterial cannula clamp around the vessel. Inject 10 µL of silicone compound solution. Stop the injection when the flow of silicone compound solution is noted at the left vertebral artery.

2.6. Clamp the vertebral arteries bilaterally with hemostats.

2.7. Allow the head to sit at room temperature for 30 min, then gently remove all clamps.

3. Tissue Dissection

3.1. Position heads with the face upwards and the neck positioned at a 45° angle with a block positioned beneath it in order to visualize the nasal passages.

3.2. Obtain 0- and 30-degree endoscopes of 4 mm diameter and 18 cm length. Connect it to a fiber optic camera and a light source.

3.3. Prepare all heads with both ETA and TOPA dissections.

3.4. ETA[14]:

Note: See **Figure 1A** for representation of the ETA dissection.

3.4.1. Use a speculum to move the middle turbinates laterally on bilateral sides.

3.4.2. Use suction and a Penfield 1 dissector to identify the sphenoid ostium bilaterally.

3.4.3. With an 11-blade knife, make an incision on the right side of the nasal septum at the articulation of the sphenoid rostrum and vomer to bone. Make the incision 1 cm below the cribriform plate and to the floor of the nasal cavity.

3.4.4. Dissect the mucoperiosteum from the bone using a Penfield 1 dissector.

3.4.5. Disarticulate the sphenoid rostrum from the bony nasal septum with a Penfield 1 dissector and perform septectomy.

3.4.6. Use a Kerrison 2 to cut the bone from the sphenoid ostia to the floor of the sphenoid sinus bilaterally.

177

3.4.7. Grasp and remove the keel with a large pituitary rongeur to expose the sphenoid sinus, and remove mucosa.

3.4.8. Use a trans sphenoidal drill to drill the remaining inferior rostrum of the sphenoid flush with the floor of the sphenoid sinus.

3.4.9. Identify the bony impressions of the cavernous carotid arteries, opticocarotid recess, sella, and clivus (**Figure 2**); drill the clivus to expose its dura.

3.4.10. Retract the pituitary gland (which should be in clear view) and drill out the clivus using a 5-mm coarse diamond burr.

3.4.11. Remove the posterior clinoid.

3.4.12. Dissect the lateral pituitary gland dura free from the pituitary gland; it is not necessary to dissect the dura over the pituitary gland.

Note: If any inadvertent pituitary gland dura dissection occurs, it will not impact the function of the model.

3.4.13. Use a Kerrison to remove bone fragments to expose the clival dura.

3.4.14. Excise the clival dura to expose the basilar artery, anterior inferior cerebellar arteries (AICA), superior cerebellar arteries (SCA), and posterior cerebral arteries (PCA) (overview in **Figure 3**, anatomy detailed in **Figure 4**).

Note: The clival dura may be retracted with a U-based flap and stabilized with a 2-0 silk suture.

3.5. TOPA[14]:

Note: See **Figure 1B** for representation of the TOPA dissection.

3.5.1. Move the caruncle laterally using forceps, then use scissors to make an incision medial to the caruncle where the conjunctiva meets the skin.

3.5.2. Use iris scissors to widen the incision superiorly and inferiorly: the incision should continue behind the superior and inferior limbs of the medial canthal tendon; perform blunt dissection along the posterior limb of the medial canthal tendon to the posterior lacrimal crest.

3.5.3. Use a Penfield 1 dissector to make an incision in the periosteum posterior to the lacrimal crest.

3.5.4. Lift the periosteum from the medial orbit wall; continue to lift the periosteum toward the

221 orbit apex in the subperiosteal plane.

223 3.5.5. Identify and divide the anterior and posterior ethmoid arteries along the fronto-
224 ethmoidal suture.

226 3.5.6. Infracture the lamina papyracea between the ethmoid arteries and below the fronto-
227 ethmoid suture with gradual pressure from a joker.

229 3.5.7. Use a pituitary rongeur to remove bone in order to expose the sella, clivus, contralateral
230 opticocarotid recess, and cavernous carotid arteries.

232 **4. Arterial Injury & Perfusion Setup**

234 4.1. Prepare arterial injury.

236 4.1.1. Use an endoscope to visualize the anatomy of the posterior circulation (representation in
237 **Figure 3** and **Figure 4**).

239 4.1.2. Select the location for the desired bleeding. For possible locations for simulated
240 aneurysm bleed see **Figure 5**. Make a 3-mm laceration in the desired artery.

242 4.2. Perfusion setup & bleeding

244 4.2.1. Cannulate the common carotid artery and secure with a clamp. Connect the cannula to
245 the perfusion pump.

247 4.2.2. Prepare artificial blood with a 3:1 ratio of water to commercially purchased fake blood.
248 Then add 2 drops of red coloring for every 250 mL of water.

250 Note: Prepared artificial blood may be reused for multiple simulations. 3 L of blood is prepared
251 for each cadaveric head prior to the start of the simulation. This can be stored at room
252 temperature. Shake before use.

254 4.2.3. Start the perfusion pump and measure the mean arterial pressure (MAP) delivered to the
255 cadaver head via an arterial line transducer and vital signs monitor. Maintain MAPs within a
256 range of 65–110 mmHg to produce realistic bleeding depending on the desired simulation
257 scenario.

259 **5. Clip Placement in Simulation Training**

261 5.1. Use an aneurysm clip and clip applier for vessel clipping in this model (**Figure 6**).

263 5.2. Use a clip applicator for clip placement (**Video 1**) at the simulated aneurysm sites of the
264 posterior circulation (**Figure 5**).

REPRESENTATIVE RESULTS:
This model presents learners with multiple clinically-relevant sites for posterior circulation clipping, with either static (silicone compound-injected) or dynamic (perfused) options for training. Once dissection is complete, the investigators may use ETA and TOPA to provide learners with improved visualization of the posterior circulation[14]. Overview of ETA and TOPA are illustrated in **Figure 1.** For success of the model, investigators should complete the dissection protocol to expose posterior circulation clipping sites. **Figure 2** details relevant anatomy to guide dissection. An endoscopic image of the completed dissection is shown in **Figure 3**, with relevant anatomy detailed in **Figure 4**. For investigators using the dynamic perfusion model, a small incision can be made at the desired clipping site and carotid arteries can be perfused via pump to produce simulated bleeding. Possible clip application sites for training are detailed in **Figure 5**. During simulation, learners are tasked with applying clips to obtain hemostasis. Representative images of endoscopic clip application using both ETA and TOPA methods are shown in **Figure 6.** A video representation of clip application to the SCA is shown in **Video 1**.

FIGURE LEGENDS:
Figure 1: Representation of ETA (A) and TOPA (B). Results obtained after completion of Protocol step 3. (**a**) Right cavernous carotid artery. (**b**) Basilar artery. (**c**) Left PCA. (**d**) Right SCA. This figure has been modified from Ciporen *et al.* with permission[4].

Figure 2: Endoscopic view and anatomy of ETA dissection. (**a**) Tuberculum sella. (**b**) Left optic nerve. (**c**) Left opticocarotid recess. (**d**) Sella. (**e**) Clivus. (**f**) Right cavernous carotid artery.

Figure 3: Image of completed posterior circulation exposure via the endoscope. Results obtained after completion of Protocol step 3. (**A**) Overall endoscopic view. (**B**) Close-up image of exposed posterior circulation.

Figure 4: Endoscopic view and anatomy of the exposed posterior circulation. Visible after completion of Protocol step 3. (**a**) Basilar artery. (b) Basilar apex. (**c**) Left PCA. (**d**) Left Cranial nerve III. (**e**) Left SCA. (**f**) Left AICA. (**g**) Brainstem.

Figure 5: Description of applicable posterior circulation clipping sites. Clips may be applied at the indicated locations for training purposes: basilar tip, SCA, PCA, AICA.

Figure 6: Endoscopic images of sample clip application using ETA and TOPA methods. First panel: ETA approach to SCA clip application. (**A**) Application of clip to the left SCA. (**B**) Clip applied to the left SCA. **Second panel:** ETA + TOPA approach to SCA clip application. (**C**) Application of clip to the left SCA. (**D**) Clip applied to the left SCA.

Video 1: Aneurysm clip application to left SCA. This figure has been modified from Ciporen *et al.* with permission[4].

DISCUSSION:

Posterior circulation aneurysms have been historically hard to clip or coil, especially those originating off the SCA and AICA. Several techniques have been tried, such as endovascular pipeline embolization devices, microsurgical skull base approaches, and the supraorbital keyhole approach for clip application[15-17]. While these techniques are successful in some cases, the widespread applicability is limited due to stark differences in patient anatomy and the difficult to access posterior location of the vessels. This has led to the increased use of flow diversion in aneurysms deemed unclippable, untrappable, and uncoilable[18]. While flow diversion can lead to some aneurysmal obliteration, some aneurysms remain patent and therefore have a risk of rupture. We present, in this paper, the combined ETA + TOPA approach model, which may be an alternative for treating posterior circulation aneurysms.

Utilizing cadaveric models provides a multitude of advantages in training learners about the details of the procedure and enhancing competence in real-life management. First, variants in the anatomy can be readily appreciated through the utilization of silicone compound injections. These injections on cadaveric heads allow for appreciation of realistic anatomy. The silicone compound provides an excellent visualization of the vessel anatomy (both arterial and venous), which can be appreciated as the learner performs the dissection procedure. This dissection also allows for the authentic tactile feedback that may not be available in other simulated models[19,20]. It is important for the learner to localize the vessels early in order to avoid injuring them during dissection. Second, by providing cadaveric heads connected to a perfusion pump, the learner is able to develop the skill sets and algorithm for how to manage a pulsatile aneurysm or aneurysm rupture. This type of simulated training has been extremely successful in the cardiovascular literature for abdominal aortic aneurysms. Tomee *et al.* showed that learners who were able to develop an algorithm for aneurysm rupture during simulation had significantly lower death rates in real life[21]. Similarly, simulated cadaveric training will allow learners to have a go-to standard and alternatives to apply for hard to treat posterior circulation aneurysms.

Middle cerebral artery aneurysm clipping models have been developed using both cadaveric heads and human placentas[22]. The ETA + TOPA model is the first cadaveric human model developed for posterior circulation aneurysms, which offers a unique learning environment. Other animal models, virtual reality models, and cranial base models have been employed for the posterior circulation but are limited in the lack of ability for learners to appreciate and visualize human anatomical variants[23-25]. Middle cerebral artery aneurysms are often treated using open approaches with subsequent clipping. Posterior aneurysms, however, are more accessible via endoscopic procedures. The ETA + TOPA model provides a skill training experience in endoscopic neurosurgical procedures. Jukes *et al.* showed that endoscopic neurosurgical procedures require a different type of training and have unique stressors[26]. By providing a realistic learning environment, learners can drastically reduce the learning curve and feel a sense of confidence when entering the operative arena.

Critical steps in this protocol include proper silicone injection to allow proper visualization of anatomy, tissue dissection to view vasculature and generate a standardized model between

353 learners, and maintenance of physiologic blood pressure range. These critical steps when
354 performed properly ensure a model that more closely mimics realistic physiologic and anatomic
355 parameters. Check for silicone leaks during injection. If leaks are present, remove the arterial
356 clamp, advance the arterial cannula and re-clamp the vessel. If there is difficulty in titrating
357 perfusion target blood pressure goals, re-zero the arterial line and repeat the perfusion. One of
358 the limitations of this model is tissue consistency, as the embalming process may alter the
359 tactile feedback during simulation. Additionally, although the TOPA method used in this model
360 has been published previously, it is not yet an established method for clip ligation of aneurysms
361 and warrants future training via simulation.
362
363 Going forward, improvements to the simulation experience can be provided. This will focus on
364 altering various clinical scenarios in order to make the experience realistic to what is frequently
365 seen in the operating room. Furthermore, neurosurgery and learners can work with anesthesia
366 and otolaryngology residents in a team-based training. By providing team scenarios, learners
367 will become more comfortable working with colleagues from different disciplines in the
368 operating room. Instruction about effective communication and teamwork can be provided
369 through debriefing sessions and focused instructor to provide feedback. These communication
370 techniques will be applicable to a broad range of procedures and operations.
371

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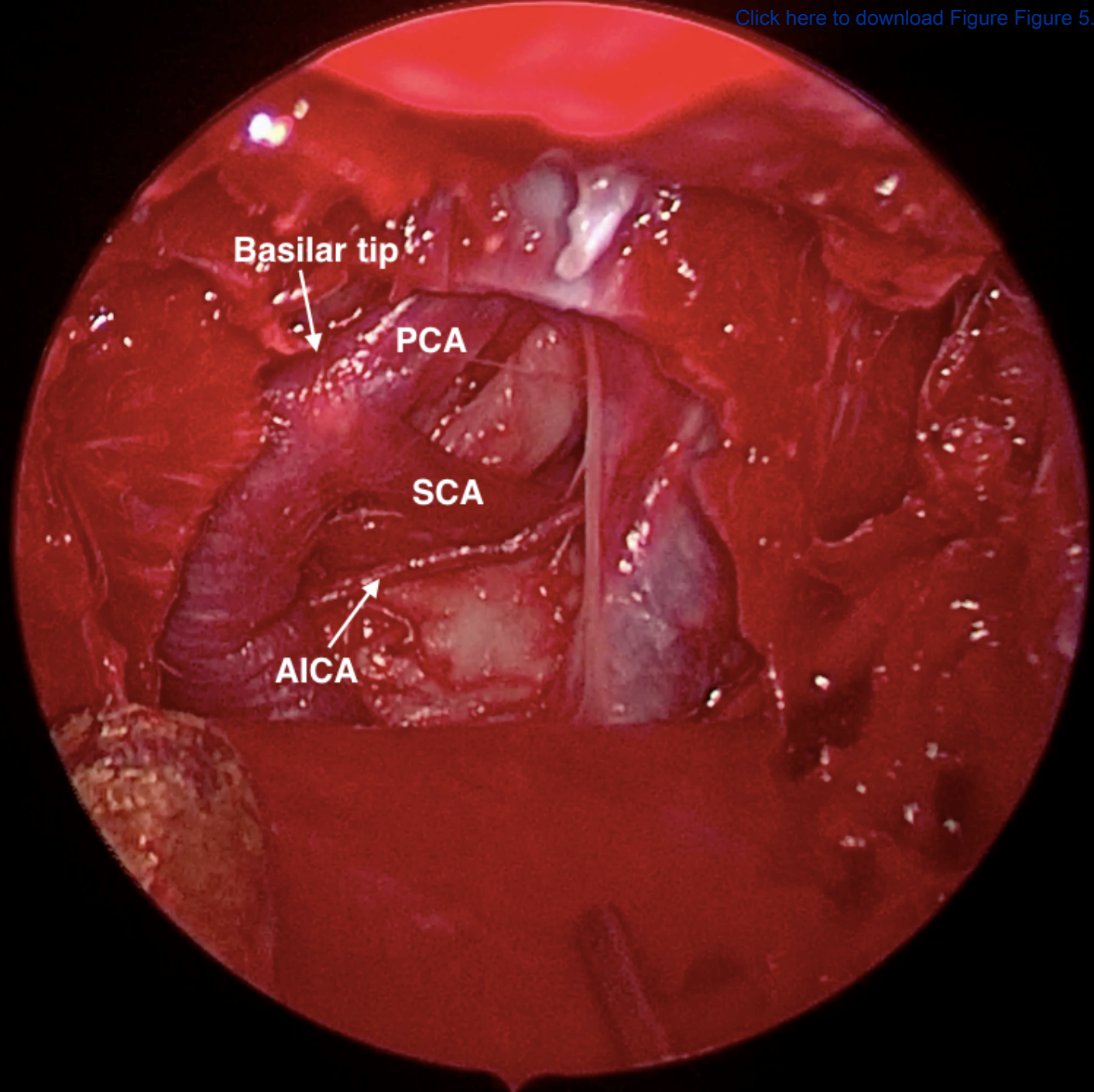452 *Allergy Rhinol.* doi:10.1002/alr.21941, (2017).
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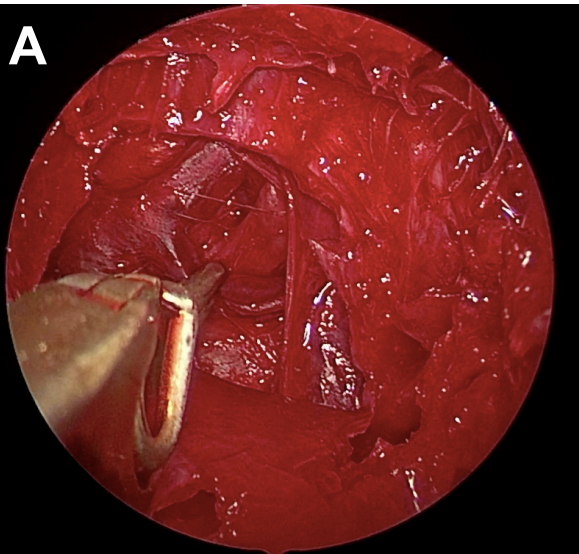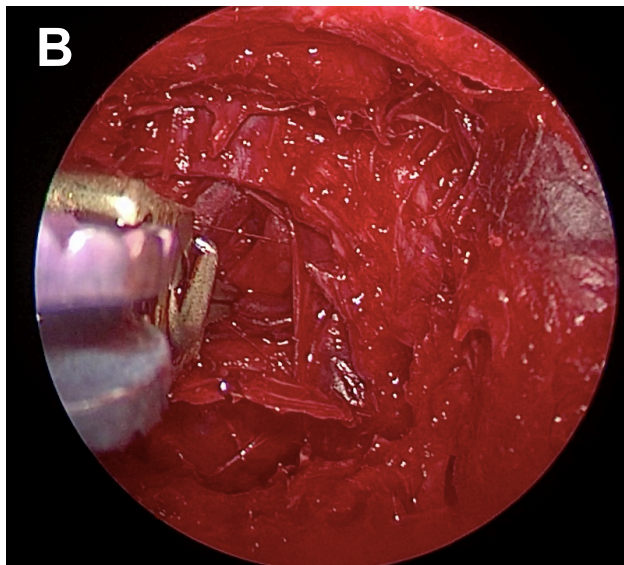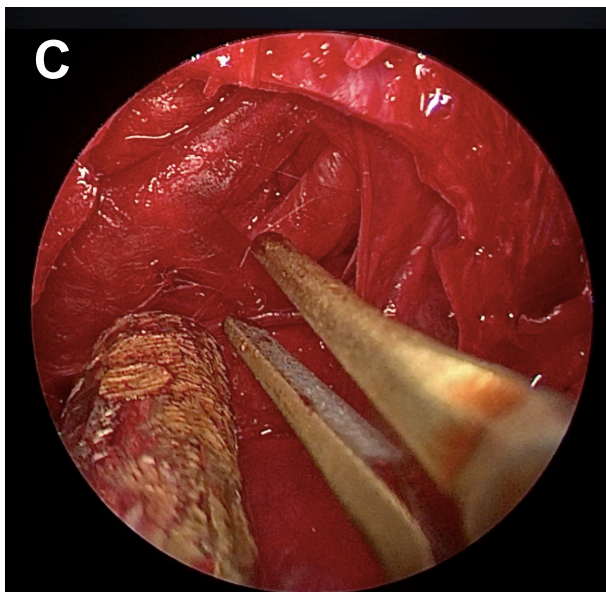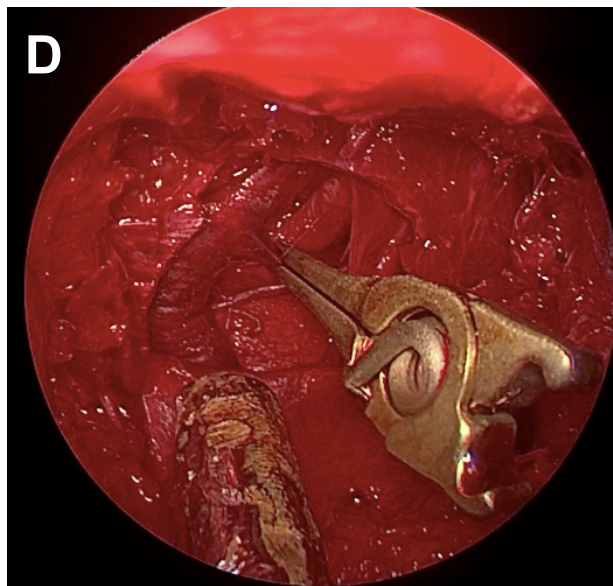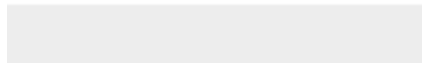**A** labels: **a**, **b**, **c**, **d**

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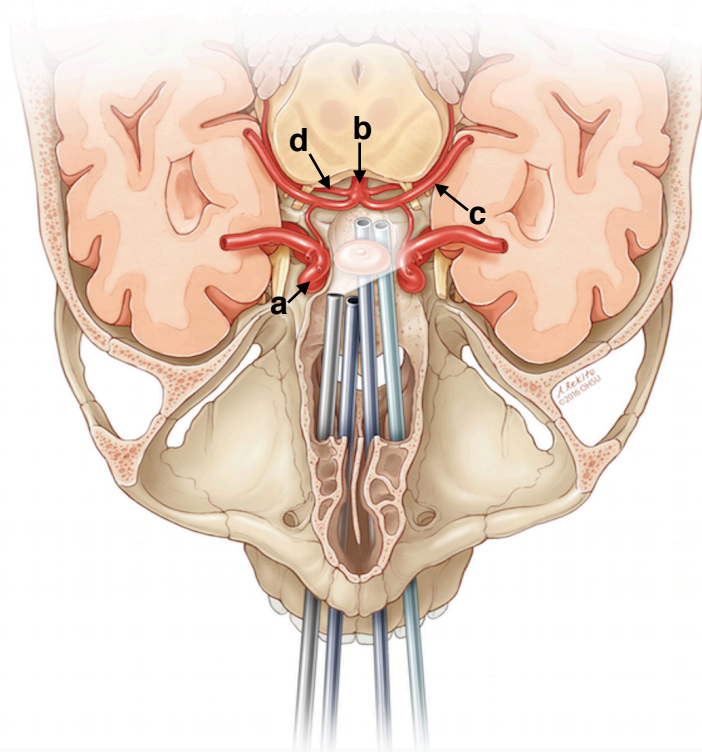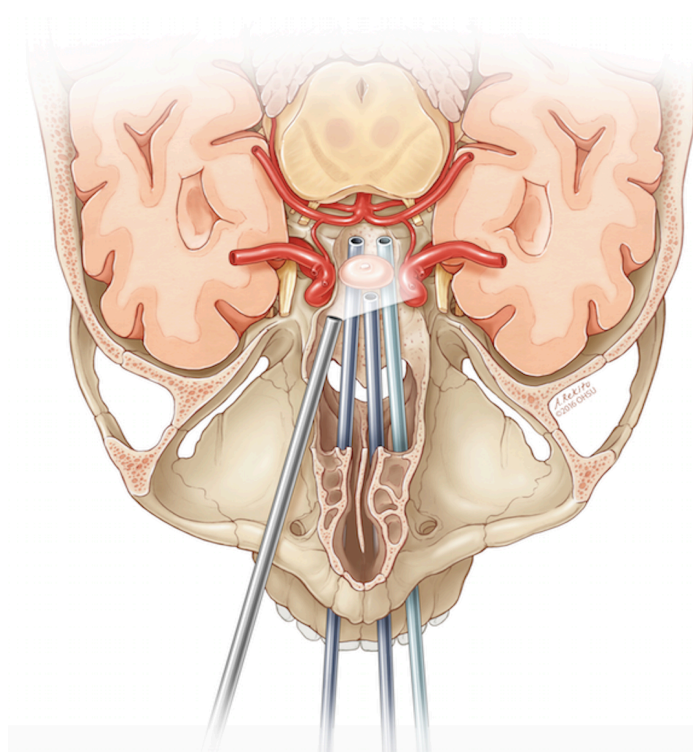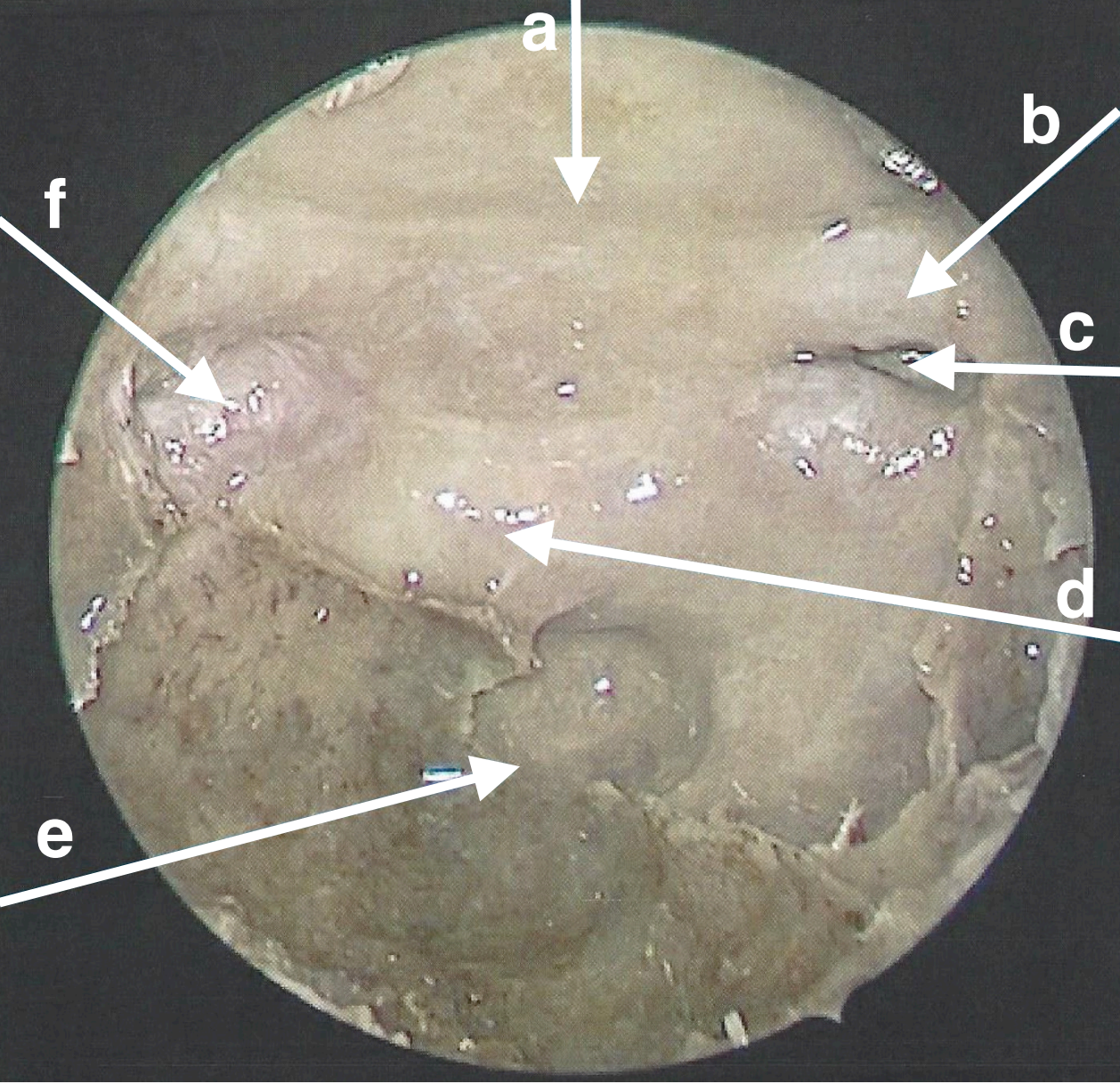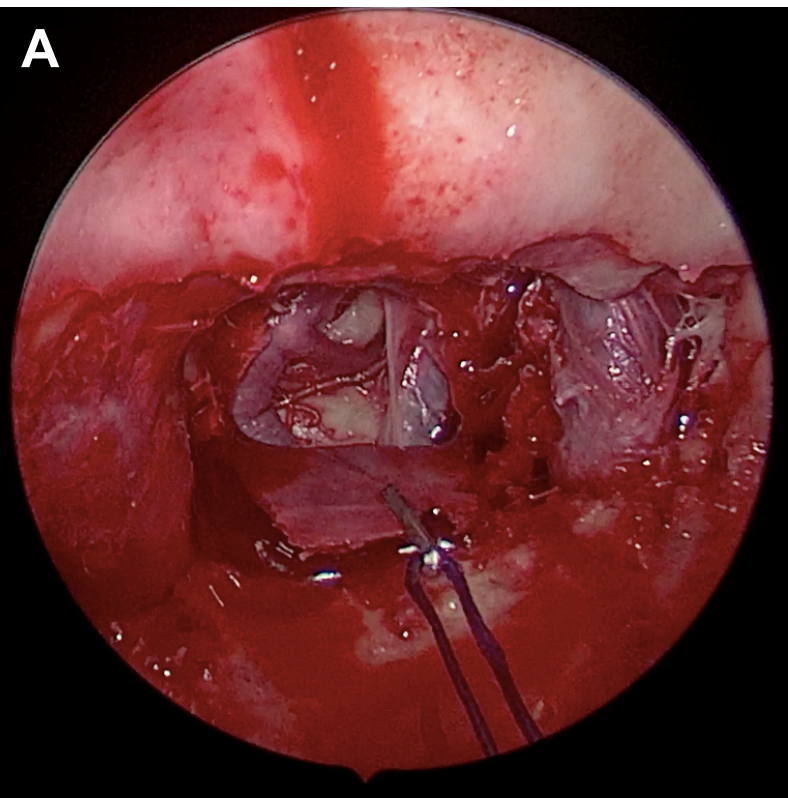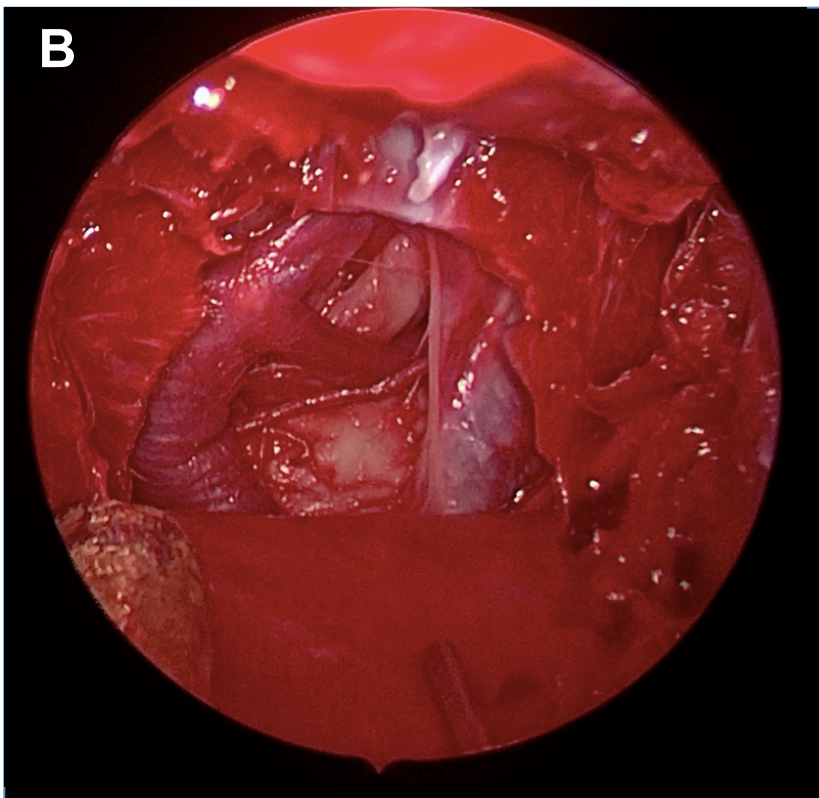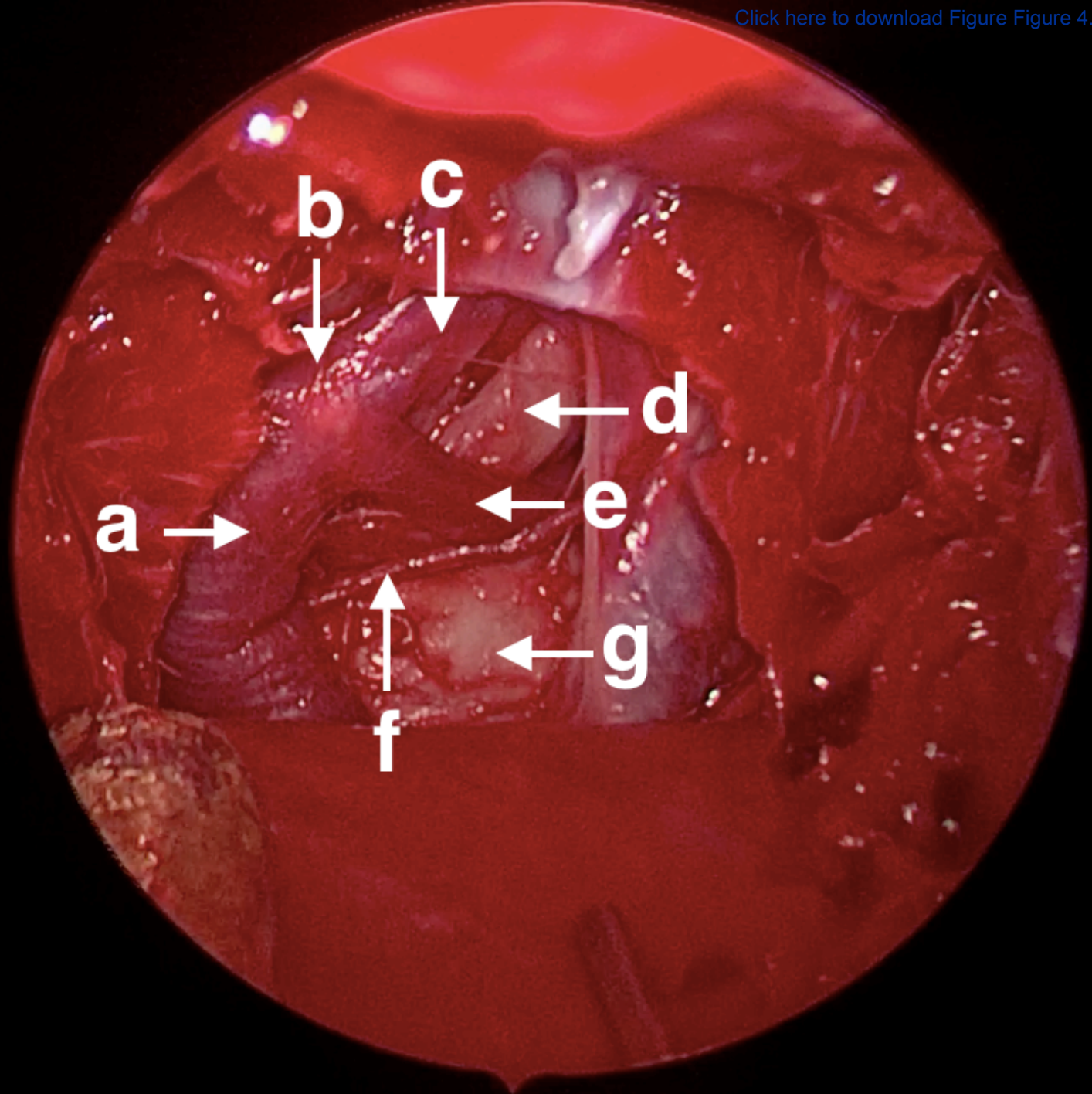
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Media1.m4v

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Anticoagulant citrate dextrose	Pierce Laboratories	117037	
Embalming solution	Chemisphere		
10% Formalin fixative	Chemisphere	B2915DR55	
Red Microfil solution	Flow Tech	MV-130	Silicone compound
Arterial cannula clamp			
5 mm Arterial cannula	Instrument Design & Mfg. Co.	ART187-2-CT	Used for jugular vein and carotid artery cannula
3 mm Arterial cannula	Instrument Design & Mfg. Co.		Used for vertebral artery cannulation
Curved hemostat	Aesculap	BH139R	
Zero-degree endoscope (4 mm diameter, 18 cm length)	Karl Storz	H3-Z TH100	
30-degree endoscope (4 mm diameter, 18 cm length)	Karl Storz		
Suction - 7 and 10 FR	V. Mueller		
11-blade surgical blade	Bard-Parker	371111	
Penfield 1	Jarit	285-365	
Kerrison rongeur	Aesculap	FM823R, 3mm/180 mm	
Pituitary rongeur	Aesculap	FF806R	
Transsphenoidal drill	Depuy-Synthes		
5 mm coarse diamond burr drill	Depuy-Synthes		
Forceps	Jarit	Carb bite I22-500	
Iris scissors	Black & Black	B 66110	
Perfusion Pump	Belmont Instrument Corporation, Billerica, MA, USA	Belmont Fluid Management System 2000	
L-aneurysm clip	Peter Lazic Microsurgical Innovations	45.782	

Vessel clip system	Peter Lazic Microsurgical Innovations	45.442
Dural flap clip	Weck	523242

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Author(s):

Haley E. Gillham, Brandon Lucke-Wold, Aclan Dogan, Justin Cetas, William E. Cameron, Jeremy N. Ciporen

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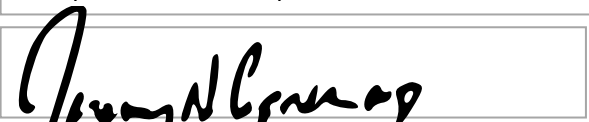
CORRESPONDING AUTHOR:

Name: Jeremy Ciporen, MD

Department: Department of Neurological Surgery

Institution: Oregon Health & Science University

Article Title: **Development of a Cadaveric Multiport Model of Posterior Circulation Aneurysm Clipping for Neurosurgery and Otolaryngology Residents**

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2. Please ensure that only the highlighted part of the protocol will be filmed.

   We have reviewed the highlighted portion for accuracy.

3. Please remove the Figure Legends from the uploaded figures. The information provided in the Figure Legends after the Representative Results is sufficient.

   We have removed the Figure Legends from the uploaded figures.

4. Please expand the Representative Result section. The Discussion of the Figures should be placed in the Representative Results.

   We have discussed the Figures in greater detail in the Representative Results section.

5. Figure 5 is referred before Figure 4. Please ensure that figures are numbered in the order of their reference in the manuscript.

   Order of reference has been updated.

6. Figure 1: Please label the anatomy being seen by endoscopy and describe it in the figure legend.

   The purpose of this figure is to give an overall representation of

endoscopic view after dissection. This anatomy of this view is detailed in Figure 2.

7. Figure 3: Please label the visible anatomy.

   We have labeled the relevant visible anatomy.

8. Figure 4: Please label the location where the clip is applied.

   We have updated the legend to include detailed the location of clip application (Note: Figure 4 is now Figure 6).

9. Figure 5: Please remove the clipping site details from the left and add it to the legend

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