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Establishing a Multidisciplinary Cavernous Carotid Injury Simulation to Train Neurosurgical, Otolaryngology, and Anesthesia Residents

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Abstract:	Carotid artery injuries are serious complications of endoscopic endonasal surgery. As these occur rarely, simulation training offers an avenue for technique and algorithm development in resident learners. This study develops a realistic cadaveric model for training of crisis resource management in the setting of cavernous carotid artery injury. An expanded endonasal approach and right cavernous carotid injury is performed on a cadaveric head. The cadaver's right common carotid artery is cannulated and connected to a perfusion pump delivering pressurized simulated blood. A simulation mannequin is incorporated into the model to allow for vital sign feedback. Surgical and anesthesia resident learners are tasked with obtaining vascular control with a muscle patch technique and medical management over the course of 3 clinical scenarios, increasing in complexity. Crisis management instructions for an endoscopic endonasal approach to the cavernous carotid artery and blood pressure control were provided to the learners prior to beginning the simulation. An independent reviewer evaluated the learners on communication skills, crisis management algorithms, and implementation

	of appropriate skill sets. After each scenario, residents were debriefed on how to improve technique based on evaluation scores in areas of situation awareness, decision-making, communications and teamwork, and leadership. After the simulation, learners provided feedback on the simulation, and data used to improve future simulations. The benefit of this cadaveric model is ease of set-up, cost-effectiveness, and reproducibility.
Author Comments:	
Additional Information:	
Question	**Response**
If this article needs to be "in-press" by a certain date, please indicate the date below and explain in your cover letter.	

Establishing a Multidisciplinary Cavernous Carotid Injury Simulation to Train Neurosurgical, Otolaryngology, and Anesthesia Residents

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This protocol describes the steps to produce a realistic cadaveric model for cavernous carotid artery injury, and design of a simulation course. 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. Our work should be published in JoVE multimedia format, as this is a dynamic protocol that can be best described by video demonstration.

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- <u>Brandon Lucke-Wold</u>: conduct study, drafting manuscript
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KEYWORDS:
Crisis management, cavernous carotid injury, neurosurgery simulation, otolaryngology simulation, multidisciplinary simulation, anesthesia simulation

SHORT ABSTRACT:
This protocol establishes a multidisciplinary model to train learners on management of cavernous carotid artery injury. Cadaveric heads undergo expanded endonasal approach and injury to the cavernous carotid artery, and perfusion pump simulates blood flow to the injury point. Learners are tasked with medical and surgical management over 3 scenarios.

LONG ABSTRACT:
Carotid artery injuries are serious complications of endoscopic endonasal surgery. As these occur rarely, simulation training offers an avenue for technique and algorithm development in resident learners. This study develops a realistic cadaveric model for the training of crisis resource management in the setting of cavernous carotid artery injury. An expanded endonasal approach and right cavernous carotid injury is performed on a cadaveric head. The cadaver's

right common carotid artery is cannulated and connected to a perfusion pump delivering pressurized simulated blood. A simulation mannequin is incorporated into the model to allow for vital sign feedback. Surgical and anesthesia resident learners are tasked with obtaining vascular control with a muscle patch technique and medical management over the course of 3 clinical scenarios with increasing complexity. Crisis management instructions for an endoscopic endonasal approach to the cavernous carotid artery and blood pressure control were provided to the learners prior to beginning the simulation. An independent reviewer evaluated the learners on communication skills, crisis management algorithms, and implementation of appropriate skill sets. After each scenario, residents were debriefed on how to improve technique based on evaluation scores in areas of situational awareness, decision-making, communications and teamwork, and leadership. After the simulation, learners provided feedback on the simulation and this data was used to improve future simulations. The benefit of this cadaveric model is ease of set-up, cost-effectiveness, and reproducibility.

INTRODUCTION:
Internal carotid artery injuries are a serious, albeit rare, complication of endoscopic endonasal approaches that require surgical dissection of tumor or vascular pathology adjacent to the cavernous sinus[1]. Techniques and algorithms for managing this type of complication can only be obtained through realistic simulation[2]. Wormald and colleagues have pioneered a training protocol for how to manage carotid injuries using a sheep model simulation[3]. They used a crush muscle patch with direct pressure over the injury site for hemostasis followed by direct vessel closure. This simulation has successfully improved outcomes in actual practice for multiple surgeons[4]. While beneficial, it has been shown that a cadaveric model of vascular injury is both more clinically relevant and cost-effective than using sheep and can be used for crisis management training[5]. Simulation training provides learners from neurosurgery and otolaryngology residencies the opportunity to develop algorithms for managing complications in real-time settings[5,6]. What is important going forward is establishing a replicable model for broad training across institutions, and multidisciplinary collaboration within simulations.

The purpose of this study is to highlight the steps to produce a realistic cadaveric model for cavernous carotid artery injury and how to set up a multidisciplinary crisis management simulation. This model provides a method for neurosurgery and otolaryngology residents, in collaboration with anesthesia residents, to train on medical management of cavernous carotid injury. The benefits of this model are its reproducibility, cost-effectiveness, and ease of set-up. This study utilizes a cadaveric head model with perfusion pumps, which is more transportable and less-expensive than the whole body perfusion model developed by Pham and colleague [7]. It can be used innumerable times to train resident learners over the course of several sessions. The benefit of replication is that different clinical scenarios can be devised to train learners on important clinical considerations in a real-time context and to train residents on important steps for crisis management. The cadaveric head model has been combined with a simulated mannequin body to allow representation of clinical vital signs during the scenarios, and facilitate collaboration with anesthesia residents. The following protocol highlights a step-by-step procedure for how to set up the model.

PROTOCOL:

Cadaveric heads used in this protocol were acquired from the Oregon Health & Science University Body Donation Program. All methods described have been approved by the Oregon Health & Science University Institutional Review Board (IRB).

1. Head Preparation

1.1   Secure the fresh cadaveric head in the sink with the neck facing upwards.

1.2   Using a 1:100 anti-coagulant citrate dextrose solution, rinse out the jugular veins, vertebral, and carotid arteries bilaterally. Start by inserting a 5mm diameter cannula into the right jugular vein and secure the vessel around the cannula with a 5-inch hemostat clamp. Run the perfusion pump for 15 min. Rotate the tube to the left jugular vein and then carotid arteries and repeat the washout for 15 min at each vessel. Use a 3 mm diameter cannula for the vertebral arteries. The fluid should be clear, not bloody, at the end of the washout.

1.3   Let the heads dry overnight with the face upwards and the neck positioned at a 45° angle with a block positioned beneath it. Store in a cold room at 5 °C.

1.4   The following day, embed the head in 2 L of embalming solution and store it in a bucket with formalin fixative.

Caution: embalming solution and formalin fixative are corrosive. Please wear protective equipment.

2. Tissue Dissection

2.1   Support the head with a block and position it in the neutral orientation avoiding over flexion or extension.

2.2   Use a zero degree endoscope of 4 mm diameter and 18 cm length.

2.3   Lateralize the middle turbinates and perform a bilateral sphenoidotomy. Make the incision at the articulation of the rostrum and vomer.

2.4   Clear the mucoperiosteum with a cottle elevator and remove the rostral bone bilaterally with a rongeur.

2.5   Drill flush to the floor of the sphenoid sinus and laterally to the medial orbital walls bilaterally with a high-speed drill and matchstick type drill head.

3. Preparing Cavernous Carotid Injury

3.1   Visualize the regions of the sella, clival structures, and cavernous carotid arteries. Remove the bone overlying the sella and cavernous carotid artery on the right with a rongeur. Note: Multiple options can be utilized for the carotid injury. Option 1: use an 11-blade knife to make a 3-mm laceration in the right internal carotid artery at the level of the genu. Option 2: puncture directly into the vessel with a nerve hook to produce a tear. Option 3: take a small piece of the vessel wall with a rongeur.

4. Perfusion Set-up

4.1   Insert a 5mm diameter cannula into the common carotid artery and secure with a 5-inch hemostat clamp.

4.2   Connect the cannula to a pressurized perfusion pump.

4.3   Prepare artificial blood consisting of red food coloring, water, and commercially purchased vampire blood [see **Table of Materials**]. Make artificial blood of the same relative density of real blood by using a 3:1 ratio of water to vampire blood. Add 2 drops of red food coloring for each 250 mL of water added.

Note: Artificial blood may be reused for multiple simulations. 3 liters of blood should be prepared for each cadaveric head prior to the start of simulation. It can be stored at room temperature, but should be shaken and mixed prior to use.

5. Establish Realistic Bleeding

5.1   Set up an arterial line via the cannulated carotid artery.

5.2   Start the perfusion pump and measure actual mean arterial pressure (MAP) delivered to the cadaver head via an arterial line transducer and vital signs monitor. Visualize the realism of the carotid injury via endoscopic examination.

Note: MAPs of 65-110 mm Hg should be used to produce realistic bleeding parameters depending on the clinical simulation scenario. Flow rate can be adjusted on the perfusion pump in order to reach physiologic MAPs.

6. Training Resident Learners

6.1   Pair one neurosurgery or ENT resident with one anesthesia resident for each of the simulation scenarios.

6.1.1   Give resident teams approximately 10 min to complete each scenario, with a 10 min debrief (5 min specialty specific, 5 min interprofessional) after each scenario.

6.1.2   Provide a specialty-specific debrief for 5 mins.

6.2   Surgery residents

Note: The following steps are to be carried out as instructed by the supervising faculty.

6.2.1   Provide each learner with the same bony exposure, location, and size of cavernous carotid injury.

6.2.2   Hold the endoscope and provide instructions to the surgery resident for how to manage vascular control. The residents work with the supervising faculty to manage the vascular injury using the 4-handed approach.

6.2.3   Manage the scenario by 1) giving instructions to anesthesia residents to decrease blood pressure 2) asking for proximal vascular control, 3) using suction to guide the bleeding away from the endoscope, and 4) using a pituitary instrument to place a half cottonoid patty over the bleeding site and apply pressure. The bleeding must be adequately controlled with suction to visualize where to place the cottonoid patty.

6.2.4   Exchange the cottonoid patty for a free muscle graft harvested from the temporalis muscle. Place the muscle directly over the right cavernous carotid artery injury with a good seal over the incision site. Blood should not be flowing into the cavernous cavity when the muscle patch is in place.

6.3   Anesthesia residents

6.3.1   Connect the anesthesia station to a simulated mannequin that is connected to a laptop, patient monitor, anesthesia cart with drug tray, anesthesia machine, anesthesia monitor, IV poles, IV bag, and two functional IV units.

6.3.2.   Setup arterial line with pressure monitor.

6.3.3   Provide anesthesia residents with instructions on use of provided materials, computer, and monitor before starting the simulation.

6.3.4   Task anesthesia residents with medical management and working as a team with the surgical resident during the simulation scenarios.

7. Enhancing realism

7.1   Give learners different clinical scenarios for patients with varying comorbidities. The comorbid factors will cause changes in bleeding rate and pressure, which should be manually controlled by the faculty by adjusting the perfusion pump settings.

7.2   Task learners with technical and medical management challenges of catastrophic bleeding, and have learners appreciate the medical ramifications that develop.

7.3   Incorporate a simulated mannequin with the cadaveric head model to provide realistic feedback about changes in vital signs and patient stability.

8. Crisis management

8.1   Provide learners with cases of increasing complexity and have them manage multiple changes in vital signs while successfully maintaining vascular control.

Note: Learners should effectively communicate so that team members address worsening patient status in a quick and effective manner.

9. Charting Outcomes

9.1   Provide learners with post-simulation surveys to assess the value of the simulation.

9.2   Facilitators should provide focused sessions with the individual learner to discuss ways to improve on communication and technique.

9.3   Provide pre- and post-simulation anatomy exams to assess knowledge gain.

REPRESENTATIVE RESULTS:
To successfully set-up the model it is important to select an appropriate perfusion pump and to properly prepare the cadaveric head. The pump should be fed into the internal carotid artery as depicted in **Figure 1**. Once the perfusion pump is set up, the steps outlined above should be employed to gain exposure to the cavernous carotid artery and to produce a realistic cavernous carotid injury. Visualization of the injury with subsequent placement of the muscle patch can be appreciated in **Figure 2**. The cadaveric head can be combined with the simulated mannequin to produce more clinically relevant scenarios. Vital signs and biometric data change in response to the learner's decisions and intervention choices made during the simulation. The complexity of the cases can vary in terms of patient comorbidities and how these comorbidities may exacerbate management. Representative scenarios are outlined in **Table 1**. The learners can be evaluated during the simulation on technique, confidence, communication, and leadership. A representative scoring rubric is shown in **Table 2**. Following the completion of the training, debriefing occurs where facilitators discuss guidelines and algorithms for clinical management, effective communication strategies, and how to effectively manage a crisis. Key points for the facilitator discussion are outlined in **Table 3**. Following the simulation, learners have the opportunity to provide feedback about the training experience. This feedback can be incorporated to improve the training for subsequent sessions. Representative feedback questions are provided in **Table 4**.

FIGURE AND TABLE LEGENDS:

Figure 1. Cadaveric head model with attached perfusion pump[5] – simulated mannequin shown without attachment at neck of cadaver head.

Figure 2. Endoscopic visualization of the cavernous carotid artery injury and successful placement of muscle flap

A. Endoscopic endonasal transphenoidal approach to the pituitary gland
   1. Right cavernous carotid with injury at the genu
   2. Sella
   3. Left cavernous carotid
   4. Clivus
B. Active bleeding from the right cavernous carotid artery
C. Muscle patch technique for repair of right cavernous carotid injury

Table 1. Representative clinical scenarios that can be utilized for crisis management training
Table 2. Feedback scoring chart for crisis management – scenario performance chart. 1=poor, 2=fair, 3=good, and 4=excellent.
Table 3. Debriefing questions that can be used by the facilitator.
Table 4. Representative post-training survey questions with scoring rubric.

DISCUSSION:

Carotid injury is a rare event but does occur in cases that involve the extended transphenoidal approach[8]. This approach is commonly used for pathology of the sella, suprasellar, parasellar, and clival spaces. Most skull base surgeons will face a carotid vascular injury at some point in their career. The expertise and confidence to handle such a dilemma can only be obtained through adequate training and appropriate crisis management simulation[3]. Valentine and colleagues have shown the relevance of using simulated training for carotid vascular injury[2]. Several models have been designed for such training purposes including Wormald's sheep model, Pham's whole body cadaver model, and Muto's synthetic polyamid nylon and glass bead model[1,4,7]. This paper presents the detailed protocol and results for a cadaveric head model, which incorporates multidisciplinary training in surgical and medical management.

The benefit of using a cadaveric head model is its cost-effectiveness, reproducibility, and ease of set-up[5]. Furthermore, as described in both the protocol and video, the model can be combined with a simulated mannequin. This opens the door to interdisciplinary training between residents from different specialties such as anesthesiology, neurosurgery, and otolaryngology. The clinical scenarios can then be expanded from building techniques alone to the more important skill of establishing interdisciplinary algorithms for crisis management. One of the key training points is how to effectively communicate with team members from different disciplines. Facilitators, in real-time, adjust parameters to make the model respond to the learners' actions. Resident learners can then be debriefed on both technical performance as well as effective communication between colleagues. By having such a dynamic model,

teamwork can be emphasized during the simulation session and learners can appreciate a more realistic view of crisis management.

Padhye and colleagues have set up catastrophe management workshops that have trained numerous surgeons over the years[9]. These workshops have shown the superiority of muscle patches for managing carotid vascular injury and have been an excellent resource for surgeons in training to improve techniques[10]. While workshops are beneficial, the primary limitation is the lack of widespread adaptability due to the limited resources available at other sites to implement similar training. The reproducibility of this cadaver preparation has been demonstrated previously[5]. Doumouras and colleagues have shown that implementing simulation early on improves residents' surgical technical skills throughout residency[11].

One of the benefits of simulation is that early training enhances learner confidence so that he or she can then focus on interdisciplinary communication. Interdisciplinary simulation has been shown to be more effective in improving patient outcomes than single specialty training sessions or workshops[12]. The model outlined in this paper allows simulation to be adaptable to the institution and to focus on the crisis management most relevant to their region. This is valuable in that surgery teams can train and practice in a realistic setting prior to entering the operative arena. It also provides a safe learning environment so that algorithms can be established without jeopardizing patient care[13]. By modifying the debriefing sessions, institutions can also focus on the aspects they deem most relevant to their learners[14].

This paper highlights a protocol for establishing a cadaveric head cerebral perfusion model and crisis management simulation. The benefits of this model are its cost-effectiveness, ease of set-up, and adaptability. The video shows how the model can be combined with a simulated mannequin to enhance the realism of the training. This ultimately opens the door to interdisciplinary training, focused clinical scenarios, and individualized debriefing sessions. By incorporating the model early on in resident training, learners will be able to develop skill sets and algorithms that will last their entire career.

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**Vital Signs
Monitor**

A-line Transducer

**Perfusion
Pump**
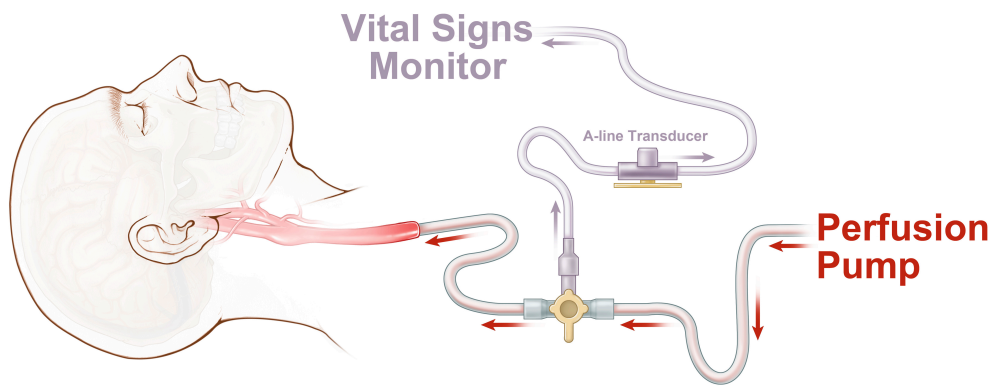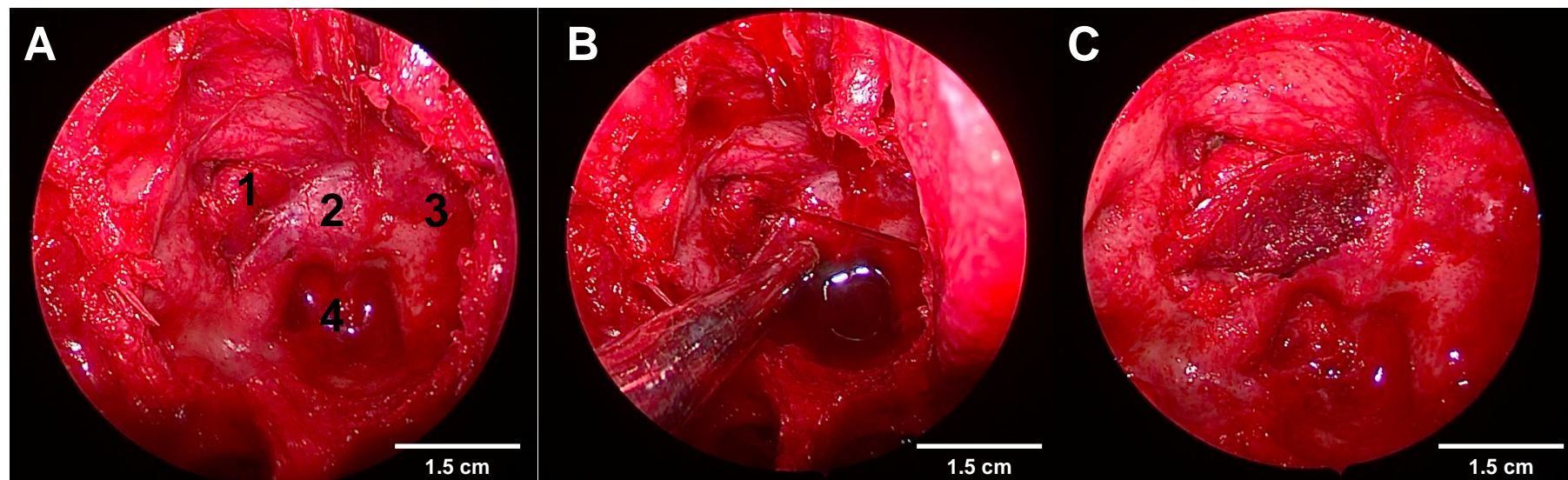
Scenario	Description
Scenario 1	41-year-old male scheduled for a trans-nasal resection of a pituitary adenoma. The patient had complaints of a headache and feeling cold.
Scenario 2	78-year-old female scheduled for a trans-nasal resection of a pituitary adenoma. The patient has complaints of headache, loss of peripheral vision, and feeling cold.

Scenario 3	66-year-old male scheduled for for a trans-nasal resection of a macroadenoma.

Relevant History	Induction
Hypothyroidism treated with levothyroxine.	The case had an uneventful induction with fetanyl 150 mcg, propofol 180 mg, lidocaine 100 mg, and rucoronium 70 mg. Intubation was easy and a 16 gauge PIV was placed in the right AC. Ancef was given as well as dexamethasone.
Coronary artery disease with 4 stents placed in the RCA and LAD distributions. Ischemic cardiomyopathy with LEVF 35% on ECHO. Hypertension and OSA on CPAP. Diabetes mellitus type 2, hypothyroidism. Medications include levothyroxine, simvastatin, carvedilol, NPH and normal insulin, and plavix.	The case had an uneventful induction with fentanyl 150 mcg, propofol 120 mg, lidocaine 100 mg, and rocuronium 60 mg. Intubation was easy and a 16 gauge PIV was placed in the right AC. Ancef was given as well as dexamethasone.

Healthy patient with normal labs. Hypocortisolemia has been present for the past year.	The case had an uneventful induction with fentanyl 150 mcg, propofol 120 mg, lidocaine 100 mg, and rocuronium 60 mg. Intubation was easy and a 16 gauge PIV was placed in the right AC. Ancef was given as well as dexamethasone.

Case

BP 124/78, HR 78, SpO2 99%. Tidal volume is 450 and rate 12. PEEP was 0. Bleeding begins to increase from surgical site. The anesthesia and neurosurgery residents must work together to manage the bleed and reduce BP.

BP 164/78, HR 74, SpO2 99%. Tidal volume 450 and rate 12. PEEP was 0. Bleeding begins to increase from surgical site. The anesthesia and neurosurgery residents much work together to mange the bleed and reduce BP. If BP becomes very low, may increase ectopy with or without ischemia.

BP 102/61, HR 88, SpO2 99%. Tidal volume 450 and rate 12. PEEP was 0. Bleeding begins to increase from surgical site. Severe hypotension develops that is refractory to IV fluids and pressors. The anesthesia and neurosurgery residents much work together to mange the bleed and reduce BP. In order to successfully treat the patient, the residents have to note that the hypocortisolemia is the cause of the refractory hypotension.

Category	Element	Score (1-4)
Situation Awareness	Gathering Information	
	Understanding Information	
	Projecting and anticipating future state	
Decision Making	Considering options	
	Selecting and communicating options	
	Implementing and reviewing decisions	
Communications and Teamwork	Exchanging information	
	Establishing a shared understanding	
	Coordinating team activities	
Leadership	Setting and maintaining standards	
	Supporting others	
	Coping with pressure	

1
2
3
4

What went well? What might you do differently next time? What are areas where you need to improve?

How do you feel you did with communication? How are these communication skills relevant to other situations? Was it helpful working with other team members?

How is this simulation relevant to other crisis situations? Do you feel you are more equipped to manage a crisis in the operating room?

Did you develop an algorithm for vascular control? Do you feel you can apply this algorithm to other similar situations?

1	Did you find the simulation session valuable?	Strongly Disagree	Disagree	Neutral	Agree
2	Did you develop an algorithm for managing carotid artery?	Strongly Disagree	Disagree	Neutral	Agree
3	Do you feel more comfortable using endoscopic instrumentation?	Strongly Disagree	Disagree	Neutral	Agree
4	Do you feel comfortable working with residents from other specialties?	Strongly Disagree	Disagree	Neutral	Agree
5	Is simulation a good complement to operative experience?	Strongly Disagree	Disagree	Neutral	Agree
6	Simulation improved my surgical skill set	Strongly Disagree	Disagree	Neutral	Agree
7	Do you feel comfortable with Crisis Resource Management	Strongly Disagree	Disagree	Neutral	Agree
8	Would you like to see further similar simulated experiences offered in the future?	Strongly Disagree	Disagree	Neutral	Agree
9	Can the lessons learned/experienced in the simulation be translated to other crisis scenarios?	Strongly Disagree	Disagree	Neutral	Agree
10	The simulation model offers benefits not available in existing training models	Strongly Disagree	Disagree	Neutral	Agree
11	Was this course valuable in your training experience?	Strongly Disagree	Disagree	Neutral	Agree
12	Skills learned in the simulated environment translate to the operating room	Strongly Disagree	Disagree	Neutral	Agree

13	Simulated experiences should be incorporated into surgical training prior to entering the operating room	Strongly Disagree	Disagree	Neutral	Agree
14	Simulation improved/reinforced my understanding of the relevant anatomy	Strongly Disagree	Disagree	Neutral	Agree
15	Would you like to see simulation integrated into the curriculum?	Strongly Disagree	Disagree	Neutral	Agree
16	If given the choice, would you participate in simulation in the future?	Strongly Disagree	Disagree	Neutral	Agree

| Strongly Agree |
| Strongly Agree |
| Strongly Agree |
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Strongly Agree
Strongly Agree
Strongly Agree
Strongly Agree

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Anti-coagulant citrate dextose solution	Pierce Laboratories	117037	
Embalming solution	Chemisphere		
Formalin fixative	Chemisphere	B2915DR55	
Zero degree endoscope (4mm and 18 cm length)	Karl Storz	H3-Z TH100	
Penfield 1	Jarit	285-365	
Kerrison rongeur	Aesculap	FM823R, 3mm/180 mm	
Anspach eMax 2 Plus High Speed Drill	Depuy-Synthes	eMax2 plus	
3 mm cutting ball	Depuy-Synthes		
11-blade surgical blade	Bard-Parker	371111	
Arterial cannula clamp			
Arterial cannula	Instrument Design & Mfg. Co.	ART187-2-CT	
Perfusion Pump	Belmont Instrument Corporation, Billerica, MA, USA	Belmont Fluid Management System 2000	
Vampire blood	Forum Novelties, Inc., Melville, NY, USA	65368	
Cottonoid surgical patties	Codman	80-1480	
Laerdal SimMan	Laerdal Medical, Wappingers Falls, NY, USA	SimMan 3G	
Laerdal SimMan Laptop	Laerdal Medical, Wappingers Falls, NY, USA	SimMan 3G	
Pituitary rongeur	Aesculap	FF806R	
Bayonet	Aesculap	BD 845	
Suction - 7 and 10 FR	V. Mueller		
IV poles	Pedigo		
IV unit	Care Fusion	Alaris PC Unit	

Pump modules	Care Fusion	Alaris Pump Module
Kit Arterial Line	Arrow International	RA-04020
Kit Pressure Monitor	ICU/BMP Inc	426340405
Fluid IV NaCl 0.9 1000CC)	Baxter Healthcare	2B1324X
Fluid IV lactated ringers 1000CC	Baxter Healthcare	2B2324X
Integra SL Anesthesia Machine	DRE	00104RS
AVS2 Remote Ventilator	DRE	409AVS2
Sigma Delta ISO Selectatec Vap Pour Fill	DRE	39001O
MP5 Bedside Monitor	Philips Healthcare	PMS-M8105a

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Title of Article:

Establishing a Multidisciplinary Cavernous Carotid Injury Simulation to Train Neurosurgical, Otolaryngology, and Anesthesia Residents

Author(s):

Brandon Lucke-Wold, Haley E. Gillham, Mark Baskerville, William E. Cameron, Dawn Dillman, Caleb A. Haley, Michele Noles, Donn Spight, Jeremy N. Ciporen

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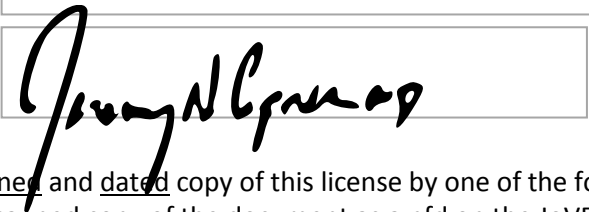
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Institution: Oregon Health & Science University

Article Title: Establishing a Multidisciplinary Cavernous Carotid Injury Simulation to Train Neurosurgical, Otolaryngology, and Anesthesia Residents

Signature: *Jeremy N Ciporen*   Date: 03/24/2017

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Response to Reviewers

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We have included approval in the resubmission.

3 Add the following to Table of Materials – embalming solution,

We have added this to the Table of Materials.

• **Protocol:**

1 Line 88 – rinse out jugular veins – how? which needle, syringe do you use? Where is the needle inserted? Please provide all the details.

2 Line 90 – are the heads stored in any position / orientation? If yes, please specify.

3 Line 91 – embalming solution – how much is typically required per head?

4 Line 92 – add a "Caution: embalming solution and formalin are corrosive. Please wear appropriate personal protection".

5 Line 94 – supported - how? write in imperative tense

6 Line 100 – what is used to Drill?

7 Line 104 – remove the bone – how? do you drill, cut? Using what?

8 Line 108 – specify the size of cannula, clamp

9 Line 110 – store – at what temperature?

Details have been added.

10   Line 110 – typically how many liters of artificial blood is prepared? Or required per head? Add a note:

Details have been added.

11   Line 110-112 – please provide the recipe for preparation of artificial blood?

Details have been added.

12   Line 115 – do you set the flow rate on the perfusion pump?

Details have been added.

13   Please re-write steps 6 through 9 of your protocol section in imperative tense, as if you are telling someone how to do the technique (i.e. "Do this", "Measure that" etc.). For example, re-write step 6.1 as - Pair one neurosurgery or ENT resident with one anesthesia resident for each of the simulation scenarios. 6.1.1. Give approximately 10 min to each team of residents to complete each scenario,…….

The sections have been rewritten.

• **Figures:**
1 Please add a scale bar to figure 2

Scale bar has been added.

• **Highlighting:**

1 After you have made all the recommended changes to your protocol (listed above), please highlight <u>2.75 pages or less</u> of text (which includes headings and spaces) in yellow, to identify which steps should be <u>visualized / filmed</u> to tell the most cohesive story of your protocol steps. Please see JoVE's instructions for authors for more clarification. Remember that the non-highlighted protocol steps will remain in the manuscript and therefore will still be available to the reader.

Steps have been highlighted.

2 In case the paper is accepted for publication, which scenario do the authors intend to film for the video? Please pay attention to this when you highlight the protocol text.

Utilize scenario 1 as outlined in Table 1.

Reviewers' comments:
Reviewer #1:
Manuscript Summary:
•   Lucke-Wold et al describe a simulation model for the training of residents on management of intraoperative cavernous carotid artery injury during endoscopic endonasal surgery. The topic is important to address, as such injuries - though uncommon - can have catastrophic consequences. Not only can such injuries result in overwhelming blood loss, placing the patient's life at imminent risk, but they may also be susceptible to pseudoaneurysm formation, vasospasm, thrombosis, embolism and even the formation of caroticocavernous fistulae. There is certainly utility in developing methods for training doctors across disciplines in the management of such injuries, which the authors attempt to do with a cadaveric model. 3 scenarios of varying complexity are described, in which surgical and anesthesia residents must obtain vascular control via muscle patch technique.

Thanks for the comments and highlighting the significance of the model for training learners.

•   Strengths of the manuscript include the development of the model and the opportunity it provides to practice crisis management. The stepwise escalation in complexity of cases also provides a logical sequence in which to gain familiarity with the crisis and tailor the simulation to skill level. The setup of the model is well-detailed and should be reproducible from the description provided. And while many animal models are available for practicing management of this event, this is to our knowledge the first described employing human cadavers. The opportunity for immediate feedback is also a positive attribute.

We appreciate the comments, especially for recognizing the novelty of the model. Thank you for taking the time to review our manuscript.

•   One glaring weakness of the manuscript is the relative paucity of photographic or video demonstration of the model (they do mention a video, but none seems to be provided). The use of an 11-blade to induce the injury, while easily reproducible, is likely somewhat different in mechanism than how these injuries occur. A punch or stellate injury may be more common than a linear injury. More detail should be provided in section 6 as to how vascular control is obtained (e.g. positioning and orientation of suction and scope, application of muscle patch, etc) Valentine and Wormald have already described a similar model for controlling the surgical field during such an injury, and though theirs was an animal model, many of the same fundamental principles are employed.

JoVE will be helping film the video for the model in the coming months to show step by step how it is performed. The video will accompany the paper when it is published. We appreciate the

comment about how the injury occurs in the operative arena and have added detail about the management of vascular control. In particular, we added details regarding the technique that Valentine and Wormald utilize in the introduction and describe our technique in further detail in the protocol section. The key difference is that we propose using a cottonoid to control the bleeding prior to the muscle patch. This two-step process allows learners to practice endoscopic techniques of transference in a high stakes scenario. Furthermore, we have added different options for how to cause the injury based on your suggestions.

• A major vascular injury is one of the most challenging scenarios a surgeon can face. The high-pressure and high-flow environment can prove difficult even in the most experienced hands, so any opportunity to practice the skills necessary to manage the situation in a controlled environment is of value.

Again, thank you for the comment. We appreciate that you recognize the value of the model.

Major Concerns:
• N/A
•
Minor Concerns:
• N/A
•
Additional Comments to Authors:
• N/A

Reviewer #2:
Manuscript Summary:
• The authors provide a relatively simple but realistic and reproducible technique for simulating carotid artery injury during endonasal neurosurgical procedures. This is the most life

threatening complication of these procedures and may occur unexpectedly. Management requires effective multidisciplinary management by the surgeons and anesthesiologists in a rapid and coordinated fashion. Surgical simulation using a realistic model is very important and this model is easily constructed and reproducible.

Thank you for providing an overview of the importance of the model.

Major Concerns:
• N/A

Minor Concerns:
• The authors should provide more detailed scripted clinical scenarios for the simulators to follow to ensure the model is well executed across multiple sites.

Thank you for this comment. In the video JoVE is helping us film, we are going to go into more detail for scenario 1. Please see below why we intentionally left the descriptions a bit vague in the text. We hope you agree this is a reasonable strategy to hopefully have the model be applicable to the widest audience.

We provided a description of three relevant scenarios relevant to our geographic region in table 1. We didn't want to specifically limit the reader to using those scenarios alone because different regions of the country have a different prevalence and incidence of various diseases and comorbidities. We want the model to be adaptable so that the faculty member leading the session can change the scenarios in order to be most relevant to the learner's training environment. There is intrinsic flexibility in the model to allow the faculty member to adapt it to his or her needs or what he or she deems most relevant to the geographic region.

Additional Comments to Authors:
• Very nicely constructed model to simulate a potentially life threatening event during endonasal surgery. The authors recognize that multidisciplinary coordinated efforts are necessary to successfully control carotid artery bleeding while resuscitating the patient hemodynamically and this model provides a useful, reliable, and reproducible simulation technique

We appreciate the comment. Thank you for taking time to review the article.

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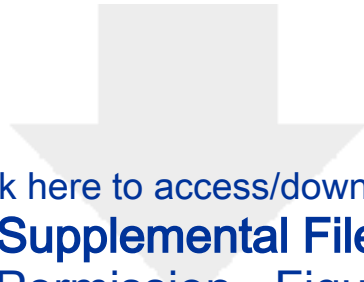
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