Simulating Internal Carotid Artery Injury during Transsphenoidal Transclival Endoscopic Surgery in a Perfused Cadaver Model

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Abstract

Introduction Managing internal carotid artery (ICA) injury during extended endoscopic transsphenoidal surgery is an extreme challenge. We aimed to find a possible surgical treatment strategy.

Methods We operated seven fresh, perfused cadaver heads with a transsphenoidal endoscopic approach of the ICA using a three-dimensional-high definition (3D-HD) endoscope. We made a paraclival ICA leak, which we tried to manage with clips and microsutures.

Results Accurate transsphenoidal clip application on the ICA was impossible with standard aneurysm clips and applier. It was only feasible with a 9 mm slightly bended clip that could be opened from the inside and be applied with a dedicated flexible thin applier. Transsphenoidal suturing of an ICA leak was impossible from the ipsilateral nostril or with standard microinstruments. Suturing was only feasible from the contralateral nostril using flexible microinstruments with a thin 90-mm shaft. This was technically very challenging and involved a steep learning curve.

Conclusion Tamponade with muscle or fat and a quick transfer to the angiography suite for endovascular control remains the preferable option in case of an ICA leak during endoscopic transsphenoidal surgery. If tamponade gives insufficient initial control, ICA clipping could be possible with dedicated instruments, with risk of increasing the defect, stenosis, or occlusion of the vessel. Transsphenoidal ICA suturing remains extremely difficult, and laboratory practice seems essential.

Keywords

- ▶ internal carotid artery injury
- ▶ transsphenoidal endoscopic Surgery
- ▶ perfused Cadaver Model

Introduction

Internal carotid artery (ICA) injury is a potential devastating complication of endoscopic-assisted transnasal, transsphenoidal surgery (ETTS).^{1,2} Profuse bleeding of the ICA impairs the visual field quickly, and in combination with the limited space available, this makes it very challenging to control the

bleeding. Local or cervical compression followed by bipolar cautery, sealants with or without crushed muscle, aneurysm clips, and endovascular stent placements have been described as potential rescue options.^{1–4} Mostly these efforts result in sacrificing the ICA, with estimated high rates of mortality or permanent morbidity.²

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For neurosurgeons, building experience in extended ETTS, especially in the approach of clival or paraclival lesions, and practicing how to treat vascular adverse events seem of critical importance. Training of these procedures is sometimes performed on fixed cadaveric heads.⁵ However, unfortunately, most neurosurgeons face ICA injury for the first time during ETTS in a patient. The learning curve is steep.⁶ Therefore, it seems rational to train ETTS in a perfused cadaver model as described by Pham et al.⁶

We performed a study in a perfused cadaver model to simulate an ICA rupture during extended ETTS and to determine the best strategy to cope with this complication if normal tamponade is insufficient.

Methods

Experimental Setup

We operated seven fresh cadaveric heads from the Department of Anatomy at the University Medical Center, Utrecht, the Netherlands. All procedures were performed in the cadaver laboratory of the Brain Technology Institute (BTI) in Utrecht, the Netherlands. In the laboratory, both common carotid arteries and both vertebral arteries were cannulated in the neck using a protocol earlier described.⁷ We attached all cannulas to a pulsatile pump, delivering a pressure of 120/80 mm Hg. Cadavers were pressurized with a mixture of water and red poster paint. The head was subsequently fixated in a holder in a flexed position. A navigation stealth station was installed using contrast computed tomography (CT) scans of all heads (Medtronic, Minneapolis, United States). A VSiii 3DHD endoscope system (Visionsense Corp., New York, United States) was installed with a 0° and a 30° rigid scope, both 18-cm long and 4-mm in diameter.

Surgical Procedure

The approach was performed by the first author (Tristan P.C. van Doormaal, skull base and vascular neurosurgeon) or by a senior author (Paul R.A.M. Depauw, skull base neurosurgeon) via the right nostril. The middle and superior turbinates were pushed laterally, and the sphenoid ostium was identified. A nasal septal flap was created, respecting the sphenopalatine artery, mimicking the preparations of an extended approach. This step was also necessary because the perfusion of the cadaver caused the nasal mucosa to leak profusely if not systematically resected and coagulated. The bilateral ostia were exposed and widened. The posterior 1 cm of the nasal septum adjacent to the vomeric bone and maxillary crest was resected, and any sphenoid septum was removed. The rostrum of the os sphenoidale was drilled flush with the floor of the sphenoid sinus using a Midas Rex electric drill (Medtronic, Minneapolis, United States) to accomplish full exposure of the posterior wall of the sphenoid sinus. We identified the two carotid protuberances, the medial aspect of the optic canals, and the upper clivus. Subsequently, the left carotid protuberance and part of the clivus were drilled, exposing the paraclival part of the ICA. The ICA was exposed medially, respecting the cavernous sinus and the VIth cranial nerve. Subsequently, the second author (Sander Diederens,

neurosurgical resident) handled the camera, and the first author handled the microinstruments. A longitudinal incision in the ICA was made (►Fig. 1A), creating a strong artificial bleeding (►Fig. 1B). Subsequently, we tried to place a clip over the ICA defect to control the bleeding. We tested two different sets of clips: first, standard Yasargil aneurysm clips applied with a standard Yasargil clip applier (B. Braun Aesculap, Tuttlingen, Germany) and second, L-line clips applied with an L-Clip applying forceps (Lazic, Tuttlingen, Germany) (►Fig. 2A, B). If this was a success, defined by stopping the bleed, we placed a proximal clip on the ICA at the level of the floor of the sphenoid sinus and a distal clip just proximal from its parasellar part. We then removed the clip over the ICA defect to expose it. We tried to close the defect with 6.0, 7.0, or 8.0 Prolene sutures (Ethicon, Somerville, New Jersey, United States). We tried two different sets of instruments: first, a 19-cm bayonet 225-mm needle holder and forceps (FD096R and BD846R, B. Braun Aesculap, Tuttlingen, Germany) and second, an L-line memory 9-cm Nitinol microneedle holder (►Fig. 3) and L-line memory microforceps (46.604 and 46.603, Lazic, Tuttlingen, Germany) (►Fig. 1D–G). The Lazic instruments were made of Nitinol (memory steel), which is flexible and automatically returns into original shape when heated (e.g., hot water or sterilization).

Results

We operated four male and three female fresh cadaver heads. Mean age at the moment of decease was 80 years (range: 71–90 years).

The 3-dimensional (3D) visualization of the carotid canal facilitated easy drilling around the ICA. Mean width of the ICA was 5 mm (range: 5–6 mm). After exposure of the ICA and creating the leak, we tried to apply several clips from the ipsilateral and contralateral nostril. A standard Yasargil clip was impossible to apply with its standard applier in an accurate way from any angle. A 9-mm, slightly bended L-line Lazic clip could be applied around the ICA over the leak from the contralateral nostril in all cadavers, without severe manipulations or technical difficulty. When the ipsilateral side was used, manipulation of the ICA during the application of the clip was very severe, in all cases causing leakage worsening by increasing the defect. We noted that the subsequent removal of the middle turbinate improved the space significantly at both sides, and then ipsilateral ICA clipping with Lazic clips was also possible. In one cadaver, the ICA was injured at the posterior side at the moment the clip was placed from the contralateral side. After removal of the clip and temporary stopping perfusion pressure, in this cadaver, we noted severe calcifications and adherence of the ICA to the lateral side of the carotid canal.

After applying the temporary clip, it was possible in all cases to put a proximal and distal L-line clip on the ICA. This was followed by removal of the initial temporary clip. This exposed the laceration. It was impossible to suture the defect with conventional long bayonet microinstruments in all cadavers because it was not feasible to reopen the

Fig. 1 Management of internal carotid artery (ICA) leak in perfused cadaver. Images are derived from a 3D scope and therefore not in optimal resolution. Images are showing the inside of the sphenoid sinus. The sella covering the pituitary is still intact. The left side of the clivus is partly drilled away; the dura is visible. The carotid protuberance is partly drilled away on the left side, revealing the carotid artery. (A) Puncturing the ICA with small knife. (B) Brisk artificial bleeding from defect in the ICA. (C) Temporary clip is placed on defect in the ICA. (D) A Prolene 6.0 is positioned inside the sphenoid sinus. Note the proximal temporary clip placed at the level of the floor of the sphenoid sinus and the distal clip placed just proximal from the parasellar ICA. (E) Suturing of the ICA defect. (F) Finishing the suture with a knot. (G) End result with pressurized and patent ICA.

Fig. 2 (A) Lazic L-clip applying forceps. Automatically return into original shape when heated. The shaft is flexible, and the clip can be applied 50° left and right over the instrument tip. (B) L-Clip on tip of applier. For this experiment, the 45.252 of 9 mm was used. (Reproduced with permission of Peter Lazic, Tuttlingen, Germany.)

instruments through the nose and to move the instrument tip to steer the needle. However, although technically challenging, we could suture all defects with the Lazic instruments. We noted that it was important to learn how to move the needle with tiny manipulations inside the instrument tip, how to drive it as perpendicular as possible into the vessel wall, and finally how to use the curve of the thread to make knots. After suturing and reopening, all sutured ICAs seemed patent. Mean occlusion time was 44 ± 17 minutes. A distinct learning curve was observed; the first temporary ICA

Fig. 3 Lazic L-line needle holder. Automatically returns into original shape when sterilized. The shaft is flexible and is not widening when the instrument tip is opened. (Reproduced with permission of Peter Lazic, Tuttlingen, Germany.)

occlusion time was 63 minutes, and the final occlusion time was 18 minutes.

We noticed during this stage of the procedure that there were also some other limiting factors. The Visionsense scope was very short, which resulted in the camera body hampering microsurgical movements. The Lazic needle holder had neither a catch nor diamond dust at the instrument tip. This caused the 7.0 and 8.0 sutures to continuously flip in the needle holder when not applied perfectly perpendicular to the vessel wall at the point of penetration. The needles on the 6.0 sutures (BV-1) provided better grip and were, therefore, the most suitable.

Recognizing the anatomy, drilling, applying clips, and suturing seemed easier in 3D mode of the endoscope than those in 2D mode to both surgeons. However, this was not further qualified.

Discussion

In this cadaver study, ICA rupture was simulated and, subsequently, controlled using Lazic L-line clips and memory instruments while using a 3D-high definition (HD) Visionsense endoscope. Based on the observation, feeling of the neurosurgeon, and decrease in the occlusion time, we think that the process included a steep learning curve. We found the procedure to be technically challenging, and dedicated instruments were needed.

Mean carotid leak rate during endoscopic paraclival or transclival procedures is estimated 0.9 to 3.3%, with associated morbidity of 40 to 70%.^{1,8} Obviously prevention of ICA rupture is preferred. The chance of an accidental ICA rupture can be minimized by profound anatomical knowledge, a good bimanual technique by two operating surgeons, and preoperative analysis assessing risks (e.g., routing ICA, preoperative radiation, and possible aneurysms in the region),

combined with the use of neuronavigation, Doppler probe, and microhook blades.^{2,9,10} Training is one of the most important features and should preferably be done on a perfused cadaver model in a dedicated laboratory.⁶

If an ICA leak occurs, good visualization is essential. This includes two suction devices, handled by well-trained surgeons, and an adequate endoscopic lens cleaning system.¹¹

Additional digital compression of the cervical carotid artery may help in gaining control. Some authors suggested operating in an operation room with angiography available, having a deflated angioplasty balloon already in place in the ICA.¹² This is, however, far from current clinical reality. We believe that standard groin access in the operation room is not a current prerequisite to perform extended endoscopic surgery, but in the current era of interventional radiology, an angiography suite and a neurointerventionalist should be readily available in the same hospital. It should be noted that ICA occlusion longer than 10 minutes without pharmacologic brain protection has an associated ischemic risk of 5 to 45%.^{2,13,14} Therefore, brain perfusion must be kept adequate by maintaining normal individual blood pressure during the rest of surgery and subsequent endovascular procedure, and eventually using a neuro-protective agent.^{1,2} The use of hemostatic agents alone is described to be ineffective by some authors.¹⁵ Packing with muscle combined with hemostatic agents seems a good first option.² Hereby, the surgeon has to realize that tamponade and packing could result in redirecting the bleeding posteriorly/upward via the parasellar and paraclinoid route toward the intracranial space. Moreover, these measures could occlude or severely stenose the ICA, creating an ischemic risk and causing inaccessibility by the neurointerventionalist.^{2,11} If tamponade gives control, urgent transfer to an endovascular suite is the most described option in patients, often resulting in embolization of the affected artery, or if possible stent placement.^{3,4} However, stent placement is difficult because of the curvatures of the ICA, the need for anticoagulants and embolization often results in neurological deficits.

In the literature, alternative operative management strategies for ICA laceration are described. Solares et al describe reconstructing of the vessel using aneurysm clips or using Sundt-Keyes clips. They also mention that suture repair seems impractical.⁹ The use of Wormald vascular clamps (Medtronic, United States) and U-clips (Medtronic, United States) have been described to close an ICA leak when performing transsphenoidal surgery.¹⁵ Successful endoscopic-assisted transsphenoidal deployments of different femoral arteriotomy-closure devices, normally used in endovascular procedures, were described in a cadaveric setting.¹⁶ However, these devices were not tested in hemodynamic models. If clipping or suturing is attempted, applicators and microinstruments should be used, which can pass the nasal cavity and can be opened and closed in different angles in the sphenoid sinus like the instruments used in this study. Inadequate clip application or unsuitable instruments could lead to increase in the vessel injury. The surgeon should be trained well, and we believe that a perfused cadaver model can facilitate this.

The current study has some limitations. The model simulates a sharp laceration to the paraclival part of the carotid when already partially exposed and proximal and distal control is possible. This represents an unknown portion of many different possible carotid injuries. For example, it does not account for injuries due to inadvertently biting the carotid with a bone punch in which there is a large hole in the vessel or to injuries with the carotid still fully covered with bone. When the carotid is injured, most often in reality, it is not fully exposed and ready for a clip to be applied. In our laboratory setting, we had material readily available after the laceration was made with a fully exposed carotid. For these reasons, our model was potentially not critical enough. However, in this situation, it was still an extreme challenge to control the bleed. In a more difficult situation, for example, a non-fully exposed carotid or a big hole in the carotid, in our opinion, given the observations during the current study, it is definitely not advisable to try to expose the carotid any further and try to clip or suture. Therefore, we did not mimic this further in our experimental model. Another limitation is that we did not standardize study endpoints. In follow-up studies, pre- and post-task evaluation would be one form of qualitative measurement that could be used.

We believe that further development of dedicated surgical instruments would be helpful. Some examples derived from this study are, for instance, the camera part of the Vision-sense scope that could be increased in length to facilitate fixation in a dedicated holder or the Lasic needle holder that should incorporate diamond dust and a catch.

In conclusion, ICA injury during transsphenoidal endoscopic assisted surgery is a rare, but dangerous complication. Tamponade with muscle or fat combined with surgical glue and a quick transfer to the angiography suite for endovascular control is the first treatment option. A surgical attempt to clip in case there is no control with tamponade could be possible using dedicated instruments with risk of stenosis or occlusion of the vessel. Suturing the accidental carotid rupture during endoscopic transsphenoidal surgery is possible, but is extremely difficult. Practice in the laboratory is paramount for confidence and skill. This could serve to develop some useful solution in the future for this dreadful problem.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or with non-financial interest (such as, personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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