Hemostasis in Endoscopic Endonasal Skull Base Surgery

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Abstract

William Halsted established the basic principles of modern surgical technique highlighting the importance of meticulous hemostasis and careful tissue handling. These concepts hold true today and are even more critical for endoscopic visualization, making hemostasis one of the most relevant cornerstones for the safe practice of endoscopic endonasal surgery (EES) of the skull base. During preoperative assessment, patients at higher risk for serious hemorrhagic complications must be recognized. From an anatomical point of view, EES can be grossly divided in two major components: sinonasal surgery and sellar-cranial base surgery. This division affects the choice of appropriate technique for control of bleeding that relies mainly on the source of hemorrhage, the tissue involved, and the proximity of critical neurovascular structures. Pistol-grip or single-shaft instruments constitute the most important and appropriately designed instruments available for EES. Electrocoagulation and a variety of hemostatic materials are also important tools and should be applied wisely. This article describes the experience of our team in the management of hemorrhagic events during EES with an emphasis on technical nuances.

Keywords

- ▶ endoscopic endonasal surgery
- ▶ hemorrhagic complications
- ▶ hemostatic techniques
- ▶ surgical technique

Introduction

At the end of the 19th century, William Halsted established the basic principles of modern surgical technique highlighting the importance of meticulous hemostasis and careful tissue handling.¹ These concepts hold true today and are even more critical for endoscopic visualization, making hemostasis one of the most relevant cornerstones for the safe practice of endoscopic endonasal surgery (EES) of the skull base.^{2–6}

Similar to transcranial microsurgery, control of bleeding can be attained by a conjunction of gentle microsurgical dissection and the use of a myriad of different hemostatic techniques and materials.^{2–4,6} Given its particularities, the application of these techniques in EES can be challenging for

inexperienced surgeons. Two-dimensional vision and restricted space with hindrance of instruments can provide further difficulties, especially during profuse bleeding. Thus the purpose of this article is to describe the experience of our team in the management of hemorrhagic events during EES with an emphasis on technical nuances.

Preoperative Evaluation

During preoperative assessment, patients at higher risk for serious hemorrhagic complications must be recognized. Several factors such as age, systemic disease, medications, social habits, bleeding and bruising history, and previous surgery may increase the chance of catastrophic bleeding if not properly anticipated and managed.⁷

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Careful preoperative radiologic evaluation is mandatory to establish a proper diagnosis and identify unfavorable anatomical findings that may lead to inadvertent vascular injuries. Furthermore, vascular involvement must be assessed and, in case of highly vascularized tumors, preoperative embolization considered. Other options such as surgical approach, staging of operations, and deliberate subtotal resection may also decrease the risk of high-volume blood loss⁵ (→Fig. 1).

Systemic Factors That May Affect Coagulation: The Role of Hypothermia

It is well known that primary or secondary systemic bleeding disorders have to be managed adequately during all phases of the surgical procedures.⁷ However, one important aspect that can profoundly affect coagulation is commonly neglected: hypothermia. Studies demonstrate that clotting times of plasma are prolonged in lower temperatures.^{8,9} However, it was also reported that coagulation enzyme activities are not affected by hypothermia.¹⁰ Facing this controversy, Dirkmann et al¹¹ conducted an experimental study using whole blood and rotational thromboelastometry that confirmed the adverse effects of hypothermia on coagulation.

These data provide basic scientific support for the positive effects of hot-water irrigation in the treatment of posterior epistaxis.^{12,13} In our experience, applying this information to

EES has several advantages. Gently done, with a bulb syringe or ventricular catheter, it clears the operative field by removing clot and other debris and facilitates the identification of sites of active bleeding that can be effectively targeted. Moreover, irrigation at near physiologic temperature (~ 40° C) facilitates ideal conditions for clot formation,¹⁴ potentially leading to spontaneous hemostasis of venous bleeding. Warm saline irrigation has widespread application in EES and avoids excessive use of cauterization and hemostatic packing.

Materials and Equipment

Bayonnetted instruments commonly used for transcranial microsurgery are not helpful in EES. Even after the removal of the posterior portion of the nasal septum and the middle turbinates, there is not enough room for ergonomic and efficient use of these devices through the nose. Pistol-grip or single-shaft instruments constitute the most important and appropriately designed instruments available for EES.^{2,5}

Electrocoagulation is another important tool but should be applied wisely. The surgeon must be aware of the potential of thermal dispersion when using monopolar electrocautery. Therefore, these devices cannot be used intracranially.² Monopolar electrocautery should also be strongly discouraged within the sphenoid sinus or over the cranial base due to proximity to critical neurovascular structures; the bone

Fig. 1 Preoperative radiologic evaluation. (A) Computed tomography (CT) scan, sagittal view, showing a poorly pneumatized sphenoid sinus. (B) CT scan, axial view, showing a sphenoid septation attaching to the right internal carotid artery (ICA) protuberance. (C) Magnetic resonance (MR) scan, coronal view, showing a pituitary macroadenoma with right cavernous sinus invasion and ICA encasement. (D) MR scan, coronal view, showing a large nasopharyngeal angiofibroma requiring preoperative embolization. (E) MR scan, axial view, showing a very large chondrosarcoma warranting a combined approach for surgical resection.

overlying the paraclinoid segment of the carotid artery and the intracanalicular segment of the optic nerves can be very thin or even dehiscent.¹⁵ However, bipolar coagulation can be safely used both intra- and extradurally. Pistol-grip or other single-shaft bipolars with a variety of distal tips can be selected and used for very precise cauterization with minimal thermal damage to surrounding tissues.^{2,4} A variety of tips are required due to angles of visualization and the need for varying levels of precision.

A variety of hemostatic materials in different formats are available for use in EES, such as Surgifoam (Ethicon, Johnson & Johnson, Somerville, New Jersey, United States) and Avitene (Davol, Warwick, Rhode Island, United States) among others. These materials must be placed and kept in direct contact with the source of bleeding to achieve hemostasis. As a technical note, for irregular and rough extradural surfaces, we prefer to use Surgifoam in a gelatinous paste format because it tends to conform more easily. It is applied by means of a long nonvented syringe tip under discrete pressure directed directly into the source of the hemorrhage. It is used exclusively for venous bleeding and therefore is often injected directly into the vessel or sinus. As such, its immediate effect is mechanical. Direct arterial injection should be avoided. The tip of the syringe must be in close contact to the surface just before the application; otherwise, the blood flow will wash the product out. A small cottonoid, gently pressed over the site for a few seconds, completes the task. For intradural bleeding, we prefer to use an Avitene pack ("sandwich"). This product is put on a small cottonoid and then gently pressed against the bleeding tissue.² This maneuver commonly needs to be repeated before control is achieved. The use of topical thrombin in conjunction with these materials is an important adjuvant and should be used because it shortens the time required for hemostasis (► **Fig. 2**).

Prevention of arterial injury is a key principle, and a long fine micro-Doppler probe is used in any case that requires localization of the internal carotid artery (ICA) or other critical vascular structures. The real-time confirmation of vessel location with the Doppler probe is superior to image guidance, but its limitations due to the angle of contact must be understood.

Sources of Bleeding and Management: Surgical Perspective and Intraoperative Care

Some general aspects should be addressed before discussing specific hemostatic techniques. First of all, patient positioning has a direct impact on bleeding control. Head elevation (10–30 degrees) promotes venous return, especially in obese patients, thus decreasing venous bleeding.¹⁶ As with the semisitting position, it also favors blood flowing away from the operative field but with no risk for air embolism. The head should generally be hyperextended to compensate for the reverse Trendelenburg position.

Anesthesia is another important factor. For routine sinus surgery, controlled hypotension is desirable, and it can be more easily achieved by the use of flexible reinforced laryngeal masks,¹⁷ whereas for skull base surgery, especially with potential neural compromise, arterial pressure should be maintained at normal levels. In both situations, total intravenous anesthesia with remifentanyl and propofol is preferable.¹⁸

An underappreciated factor is the importance of team surgery. Team surgery improves visualization, increases operative efficiency, facilitates problem solving, and is essential for the effective management of a bleeding crisis. Even vascular tumors, such as angiofibromas that are extracranial, are best managed by a team of surgeons.

Fig. 2 Hemostatic tools. (A) Pistol-grip clip applier and aneurysm clip. (B) Syringe connected to an adapted applier (suction tip) filled with Surgifoam. (C) Pistol-grip bipolar showing three different tips. (D) Avitene packing. (E) Ultrasound Doppler for accurate localization of major vessels.

As with any approach, surgical technique has to be gentle, meticulous, and all sources of bleeding should get full attention. They must be promptly identified and carefully managed, ideally one at a time as they occur.

From an anatomical point of view, EES can be grossly divided in two major components: sinonasal surgery and sellar-cranial base surgery. This division affects the choice of appropriate technique for control of bleeding, which relies mainly on the source of hemorrhage, the tissue involved, and the proximity of critical neurovascular structures.

Sinonasal Cavity and Mucosal Bleeding

The most common source of bleeding in EES is the mucosa of the nasal cavity and the paranasal sinuses. We always pack the nose with topical oxymetazoline on pledgets after the patient is intubated and well before making the first intranasal incision. We typically inject 1:200,000 epinephrine solution prior to making incisions for our nasoseptal flaps, which also facilitates later dissection. Care should be taken when passing the instruments through the nasal corridor because abrasion and direct laceration of the mucosa may frequently occur. Mucosal stripping from the sinus is a frequent reason for constant and low-flow bleeding if not managed properly. For this reason, cutting instruments are preferred.

The management of intraoperative mucosal oozing includes warm saline irrigation, reverse Trendelenburg positioning, temporary packing with topical vasoconstrictors, and electrocoagulation. Nasal packing may be used postoperatively. Monopolar electrocoagulation may be used on the mucosa of the nasal septum and nasal walls and should be avoided at the cranial base as previously mentioned.

Important sites of arterial bleeding in the sinonasal cavity are the sphenopalatine artery and the anterior and posterior ethmoidal arteries. They should be identified early and preemptively cauterized or ligated when necessary (► Fig. 3). Further details about arterial bleeding hemostasis are discussed in a later section.

Sphenoid Sinus, Cranial Base, and Venous Bleeding

The sphenoid sinus is the central core of EES. Therefore, recognition of important landmarks is mandatory. Foremost, the bony impression of the paraclival and paraclinoid segments of the

ICA as well as the optic nerve should be identified as soon as possible. Sphenoid septations, commonly inserting at the carotid prominence,¹⁹ should be removed with a diamond drill to avoid inadvertent injury with a rongeur.

Bleeding from mucosal stripping can be managed, as previously mentioned, with warm saline irrigation and topical application of Surgifoam. Monopolar electrocoagulation should be avoided because of the proximity of the optic nerves and carotid artery. Surgifoam, bone wax, or gentle drilling over the affected site with a diamond bit can manage osseous bleeding. This and other low-flow venous bleeding coming from small tears of the cavernous and intercavernous sinuses walls can be bothersome. Head elevation above 20 degrees increases venous outflow and can be very helpful in these situations.

If the venous sinuses have to be accessed, however, these maneuvers will not be enough. The sinuses can be controlled by partial thrombosis with Surgifoam. Initially, a small opening into the sinus is made, either through tumor dissection or directly through an area not directly overlying the ICA. The high-flow venous bleeding from this area can be controlled with a controlled/slotted suction tip. Thereafter, Surgifoam must be injected directly into the sinus (► Fig. 4) in a controlled fashion. In fact, a surgical approach to any compartment of the cavernous sinus through its anterior wall can be done safely with this technique. In addition, it is important to mention an elegant technique to deal with superior intercavernous sinus bleeding described by de Divitiis et al,²⁰ in which two parallel incisions, one above and another below the sinus, allow for safe bipolar cauterization and subsequent division. Care must be taken during this coagulation to avoid thermal spread to underlying superior hypophyseal arteries or even a rare, anteriorly displaced optic chiasm.

Intradural Microsurgery and Arterial Bleeding

Every precaution should be taken to prevent arterial bleeding by awareness of involved vasculature, early identification, and careful microsurgical technique. Arterial injuries represent the most feared complications during EES of the cranial base. Computed tomography (CT) angiography is a useful and noninvasive tool for preoperative assessment of arterial displacement. Digital subtraction angiography may be used

Fig. 3 Hemostatic techniques in the sinonasal cavity. Left: Monopolar electrocoagulation of mucosa of the nasopharynx during endoscopic endonasal surgery for odontoid resection. Center: Bipolar cauterization of the right sphenopalatine artery during a transpterygoid approach. Right: Bipolar cauterization of left posterior ethmoidal artery during endonasal resection of olfactory groove meningioma.

Fig. 4 Hemostatic techniques for cavernous sinus bleeding. (A) Preoperative magnetic resonance scan, coronal view, showing a chondrosarcoma with invasion of the left cavernous sinus. (B–F) Step-by-step technique for control of cavernous sinus bleeding. The source of bleeding is identified (B). Two suctions are used, one to keep the view of the field clear and the other, connected to a syringe filled out with Surgifoam, is inserted into the cavernous sinus wall opening (C). The Surgifoam is injected into the cavernous sinus (D), and a small cottonoid is placed over the region that is gently compressed for a few seconds (E) providing effective hemostasis (F).

in cases of carotid encasement and high risk of carotid injury (e.g., chordoma, chondrosarcoma) and for therapeutic measures (preoperative embolization) depending on tumor type, supply, and patient needs.

The intraoperative use of both Doppler ultrasound probe and image guidance is of paramount importance to minimize the risk of injury to the ICA and its major branches,⁶ especially in recurrent tumors. However, perforator arteries and other small branches are usually not detected through these methods, and meticulous and careful dissection is always warranted. These types of injuries usually occur as a result of excessive traction on tumors. Visualization must be maintained constantly during dissection, often requiring a suction tip to be used as one of the debulking or dissecting tools. In case of injury to a small artery, bipolar cautery is generally required for safe and consistent hemostasis. If the exact location is difficult to reach with a bipolar electrocautery device or cannot be precisely identified, the affected region can be packed with Avitene and irrigated with warm saline. The site should not be covered with hemostatic material or blindly packed because this can lead to intracranial hemorrhage with disastrous consequences. As with any bleeding, if the source is unclear, warm saline irrigation to clear the field can be critical. Small perforator avulsions or small tears in the side wall of an artery can often be controlled with bipolar welding.

Management of Internal Carotid Artery Injury

Generally, risk factors for intraoperative ICA injury in EES include anatomical anomalies or displacement, extended

approaches to the cranial base, previous surgery, radiation, dopamine agonist therapy, acromegaly, and invasive tumors.^{21,22} In our experience, seven ICA injuries occurred in a total of > 2,000 EES of the cranial base performed since 1998. In addition to factors just described, we found a relationship between carotid injuries and chondroid tumors (three cases).²¹

Iatrogenic ICA injuries are among the most devastating and potentially harmful intraoperative complications in EES.^{2,6,22} Due to high-pressure blood flow, these injuries can quickly jeopardize visualization that further complicates its management. Therefore, during this event, as with transcranial approaches, we recommend the use of two suction tips and the four-hands technique (teamwork) to keep the operative field visible. Alternatively, Valentine and Wormald published an interesting technical nuance where they place the tip of the endoscope at the nostril while one of the suctions is placed in the opposite side, thus allowing this device to guide the vascular stream away from the endoscope.²³ Regardless, we find it critical to have two experienced surgeons involved, one to maintain the view necessary to identify the injury and the other to control bleeding, at first with a suction and then with a cottonoid patty.

The principles of management are identical regardless of approach (open or endonasal). Proximal control, isolation of the precise site of bleeding, and increasing the exposure are mandatory initial steps to deal with this problem. An emergent exploration of the neck with temporary clamping or digital compression of the carotid artery at the neck region can achieve proximal control. Increasing exposure can also provide in-field control as well as enable the surgeons to

identify the exact point of bleeding. The most common site for injury remains the parasellar ICA. In this situation, proximal control is obtained by exposing the paraclival (vertical petrous) ICA.

The exact source of bleeding should be identified and controlled as quickly as possible, and systemic blood pressure should be ideally maintained in normal to slightly elevated levels to avoid cerebral hypoperfusion if pressure is being held on the artery or proximal clip occlusion is performed. Once identified, it should be categorized as one of two types: direct wall laceration or avulsion of a perforating artery, or main branch, such as the inferior hypophyseal artery because this has an impact on hemostatic technique. Thereafter, a decision has to be made: sacrifice or vessel preservation. Such a decision may be guided preoperatively by a balloon test occlusion. In the absence of these data, intraoperative neurophysiologic monitoring can be invaluable; a decrease in somatosensory-evoked potentials strongly predicts an adverse neurologic outcome.²⁴ However, this must take into account whether or not there is active extravasation that can exaggerate the lack of flow in the ipsilateral hemisphere or due to occlusion or stenosis. Whenever possible, we strive for vessel preservation. To achieve this goal, some tools may be used such as bipolar sealing, vascular clipping (aneurysm clips), and muscle pack occlusion. Which technique is used and its efficacy depends on the size of the opening.

In case of perforator avulsion or a small opening (1–2 mm), we prefer to use bipolar coagulation or clipping. Avitene or muscle packing may be a useful adjuvant in cases of small perforator bleeding. However, for large holes, this technique may not be sufficient and should be replaced by muscle pack occlusion because this maneuver is known to achieve hemostasis.²² Packing should be done carefully at the exact site of bleeding. Overpacking carries an increased risk of morbidity due to vascular stenosis and vasospasm. This can be done in conjunction with an aneurysm clip to try to preserve flow. At no point should flowable materials like Surgifoam be used because these can rapidly embolize distally. There is currently no reliable method for suturing a vessel endonasally. Once control is achieved, immediate postoperative angiography with possible endovascular treatment is indicated.

Delayed Bleeding

Delayed bleeding following EES is a rare but sometimes life-threatening complication. Late massive hemorrhage is commonly associated with arterial injuries. However, sometimes no clear site is determined.²⁵ The internal maxillary artery and its sphenopalatine branch may be damaged during transsphenoidal and transmaxillary approaches, whereas ethmoidal arteries can be the source of bleeding after transethmoidal approaches. Approaches directed toward the cranial base obviously put the ICA or even vertebrobasilar system at risk, especially in extended cases.²³

Arterial injuries may be not promptly recognized or fully controlled during the operation.²⁶ As a result, severe epistaxis, orbital hematoma, and intracranial bleeding can occur a few hours or weeks after surgery. Postoperative epistaxis is

commonly managed initially with nasal packing. However, in case of failure or patients presenting in hypovolemic shock, an angiographic study of both external and ICAs is warranted.^{25,26} Following transclival approaches, the posterior circulation must also be studied. The internal maxillary branch as the source cannot be assumed with approaches that involve dissection of the intracranial vasculature.

Hemorrhagic orbital complications following EES occur in 0.5 to 3% of all cases.²⁷ Violation of the lamina papyracea and periorbita may result in intraorbital bleeding. However, anterior or posterior ethmoidal artery injuries are the most feared given the potential of rapidly evolving optic nerve compression and irreversible blindness. Fortunately, such retrobulbar hematomas are usually recognized in the early postoperative period.²⁸ Thus the presence of preseptal edema, ecchymosis, and ocular proptosis following EES, especially those involving ethmoidal sinus surgery, should raise the suspicion of an orbital hematoma. Urgent CT scan and ophthalmologic consultation are mandatory, and emergent lateral canthotomy for decompression may be necessary.²⁹

Intracranial hemorrhage following EES may present in several forms. Partial resection of giant pituitary adenomas can lead to postoperative apoplexy of the residual tumor that is highly associated with poor outcomes despite treatment. Therefore, as an attempt to increase tumor resection, some authors have proposed a combined and simultaneous transsphenoidal-transventricular approach for these cases.^{22,30–32} We believe that a properly planned endoscopic endonasal approach can avoid using a transcranial approach. The one exception is the rare adenoma that extends into the middle fossa, into which hemorrhage may even be asymptomatic. Subarachnoid hemorrhage and vasospasm can also complicate pituitary apoplexy. Moreover, we always recommend the use of small cottonoids over dural or arachnoid defects to decrease the exchange rate between blood and cerebrospinal fluid during surgery if extensive arachnoid dissection is required. A lumbar drain may be placed to facilitate cerebrospinal fluid (CSF) clearance and potentially decrease the risk of delayed ischemic complications.

One other unusual hemorrhagic complication following EES was reported by Dallan et al. Three months after the resection of a sinonasal malignancy, the patient developed a subdural hematoma as a result of a massive early postoperative CSF leak and subsequent intracranial hypotension.³³ Subdural hematoma can occur intraoperatively as well from excessive CSF drainage. If head pin fixation is used, especially in young patients, epidural hematoma related to skull fracture may also occur. Although very rare, the surgical team must be aware of this possibility. Any unexplained lateralizing change in neurophysiologic monitoring should prompt a surgical pause and emergent CT.

Conclusions

Adequate hemostasis remains as one of the most important surgical principles. For the practice of EES of the cranial base, it is critical for success. The surgical team must be well versed in specific hemostatic techniques given the particularities of

the approach. The selection of appropriate materials and equipment is of paramount importance, and the advantages and limitations of each technique must be understood.

We strongly recommend that surgeons performing EES follow the modular training program previously proposed.⁵ Dealing with hemorrhagic complications requires different surgical skills that can be acquired in a stepwise fashion according to the level of complexity of the procedures. Likewise, understanding the indications and current limitations of EES may increase safety and minimize the risks of a catastrophic hemorrhagic complication.

Conflict of Interest

The authors have nothing to disclose concerning the materials or methods used in this study or the findings specified here.

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