For the purpose of this report we will define endoneuro-
surgery as intradural surgery performed using parallel rod-
lens endoscopy as the sole visualization tool, in contradis-
tinction to through-channel endoscopy (ventriculoscopy)
or microsurgery. Endoneurosurgery can be classified into
expanded endonasal approaches or endoport surgery de-
pending on the corridor used; that is, paranasal sinus or
transcortical approaches, respectively.\textsuperscript{1,2}

We will discuss
the techniques used to achieve hemostasis in each of these
endoneurosurgical approaches together because they are
identical, relying on the concept of corridor surgery. With
the increasing popularity of expanded endonasal approach-
es over the past decade, the ability to achieve intraoperative
hemostasis is one of the greatest concerns for surgeons
contemplating endoneurosurgical procedures. It is essential
that surgeons specializing in endoscopy become comfort-
able with a variety of hemostatic techniques before per-
forming intradural procedures.

Prevention of bleeding is obviously the best solution.
Dissection techniques that minimize the risk of vessel injury
during tumor removal should be adopted. The principles of
endoneurosurgical dissection are identical to those of
microsurgical dissection; specifically, tumor debulking, ex-
tracapsular sharp dissection, and countertraction using gen-
tle suction. The absolute avoidance of pulling takes prec-
edence over all other considerations, including the extent of
tumor removal. Nevertheless, vascular injuries may occur

\textsuperscript{not only because of excessive pulling on tumor tissues but
also from inadequate visualization of dissection planes,
blind instrumentation, direct or indirect injury (thermal in-
jury) from powered instruments (drills, microdebriders, ul-
trasonic aspirators), and tumor vascularity. Despite applica-
tion of an ideal technique, bleeding is often unavoidable and
hemostasis is required to deal with both planned and un-
planned events.

We have found it useful to categorize bleeding based on
two factors; the source (venous or arterial) and the rate
(high-flow or low-flow bleeding). Venous bleeding can in-
volve low flow, as is the case of diffuse generalized oozing
from the mucosa, or it can be high-flow focal bleeding
from the cavernous sinus. Similarly, arterial bleeding can
be low flow, as occurs from small perforating vessels, or
high flow, as is the case with carotid artery injuries.

The choice of hemostatic techniques not only depends
on the source and rate of the hemorrhage but is also influ-
enced by factors such as the type of tissue (mucosa, bone,
and tumor); the proximity of neurovascular structures; and
the area (extradural or intradural) of dissection. At the out-
set it is important to mention that the principles of endoneu-
rosurgical hemostasis are identical to those of microsurgi-
cal hemostasis, and the reader may find these to be obvious
and repetitive. We do not wish to redevelop these time-test-
ed principles, however, but to rather to demonstrate that
they are completely applicable and, with some modifica-
tions, are effective in establishing endoneurosurgical hemo-
stasis. In this paper we will present an algorithm for endo-
zeurosurgical hemostasis based on the factors discussed
earlier and our learning curve over the past 7 years.

ENDONEUROSURGICAL HEMOSTASIS

Equipment and Hemostatic Materials

Before discussing hemostatic techniques it is important
to be aware of the equipment and materials available. The
most important equipment for the endoneurosurgeon is the
bipolar electrocautery. Standard bayonet designs are too
large for a transnasal route, especially for expanded endo-
oral approaches; instead, a pistol-grip design should be
used. There are five endobipolar cautery devices available,
which vary based on the fineness and configuration of the
distal tip (Fig. 1). Therefore, the appropriate bipolar device
can be selected based on the geometry of the vessel, its site,
caliber, and proximity to critical neurovascular structures.
This allows selective cauterization of tissues with minimal
thermal spread to surrounding areas. Monopolar cautery
can be used only on intranasal tissues and should not be us-
ed within the sphenoidal sinus, on the skull base, or intra-
cranially. The risk of thermal dispersion in these confined
areas, and of creating neurovascular injuries, is significant.
Special hemoclip appliers are available that are designed
for endoscopic use.

A variety of hemostatic materials are available. All of
these products require direct contact with the bleeding tis-
sues and work by promoting platelet aggregation and
formation of a stable clot. Examples of such hemostatic
materials include Avitene (Ethicon [Johnson and John-
son], Somerville, NJ), Floseal (Baxter International, Inc.,
Deerfield, IL), and Syvek (Marine Polymer, Boston, MA).
These materials are most effective for venous hemostasis
and low-flow arterial bleeding. An important consideration
in selecting and delivering the specific agent is the need to
maintain visualization within these corridors. We have
found that the application of dry Avitene to the bleeding
site with gentle pressure is the most effective means of
achieving hemostasis without interfering with visualization
of the rest of the surgical field.

Special mention should be made of warm water irriga-
tion. It is a common misconception that cold water irriga-
tion provides the best hemostasis. Nevertheless, the amount
of vascular constriction that occurs with cold water is insuf-
ficient to provide effective hemostasis. Clinical trials of hot
water irrigation, in contrast, show that it is nearly as effec-
tive as surgical techniques for the treatment of epistaxis.3
The ideal temperature for coagulation has been determined
to be approximately 40˚C.4 We have found, however, that
irrigation with saline that is just warm to the touch is ade-
quate. A number of different mechanisms for this method
of hemostasis have been proposed, including activation of
platelet aggregation, enhanced coagulation, and interstitial
edema. Warm saline irrigation is performed whenever there
is diffuse oozing, either from traumatized nasal mucosa,
dened bone surface, or the dissected surface of the tumor
or brain. Gentle irrigation of the brain surface with a soft
catheter is effective in clearing the field so that bleeding
sites can be visualized and selectively cauterized or com-
pressed with a hemostatic material. Care should be taken to

Fig. 1. Intraoperative views demonstrating the different types of
donal bipolar cautery devices. A: Endoscopic view obtained
during endonasal resection of an olfactory groove meningioma.
The bipolar devices used have the two blades placed along a verti-
cal plane with insulation close to the distal end. These devices
are most useful for coagulating the tumor capsule (TC) during the
dissection. The suction (S) is brought close to the target to provide
good visualization. B: Endonasal view obtained during endo-
nasal resection of a clival chordoma, demonstrating a more ag-
gressive bipolar cautery with the blades oriented along a horizon-
tal plane and bent approximately 30˚ to improve visualization. The
devices are not fully insulated up to the distal tip, and in sealing the
tear (T) in the vessel the tissue between the uninsulated portion of
the proximal tips is also coagulated. C: Endoscopic view demon-
strating the fine endoscopic bipolars. Note the insulation extends to
allow for focal exposure of the fine tips preventing heat dispersion.
Endoneurosurgical hemostasis techniques: lessons from 400 cases

avoid excessive irrigation pressures because hydrodissection of the tissues could occur.

Specific hemostasis techniques have been developed for both venous and arterial bleeding that is encountered during expanded endonasal approaches. These techniques are as follows.

VENOUS HEMOSTASIS

Low-Flow Bleeding

Diffuse venous bleeding from mucosa and bone responds very well to warm saline irrigation, and this is our preferred method. For extradural application, this is delivered with a bulb syringe; for intradural application, an external ventricular drain catheter or similar soft catheter is used. Focal bleeding from bone may be controlled by drilling with a diamond burr or application of bone wax with a pledget.

Focal venous bleeding from the cavernous or another venous sinus can be quite brisk and the rapidity of blood loss can be underestimated because of the clearance of blood with the suction device. Constant communication with the anesthesiologist is essential so that volume loss can be anticipated and blood replacement can be instituted. It is sometimes necessary to work through the blood loss until tumor dissection in the cavernous sinus is completed. We believe that focal bleeding from the cavernous sinus is best controlled with precision application of Avitene on a pledget. The pledget must be dry, with the Avitene placed on the inside, creating a “sandwich” of the substance (Fig. 2). This is applied directly to the bleeding point and may need to be replaced with exchanges multiple times until bleeding is controlled.

The technique for the exchange requires two surgeons, because Avitene can only be effective if it is directly and precisely applied over the focal site of the bleeding. The surgeon performing the dissection brings the “sandwich” into the field and prepares it for positioning. Once it is close to the target, the surgeon handling the endoscope then removes the previous “sandwich,” allowing the surgeon performing the dissection to use a suction device with one hand while laying the replacement “sandwich” on the target (Fig. 2, Video 1). It is best to treat each bleeding source as it arises rather than trying to deal with multiple bleeding sites at the same time. Venous bleeding from large veins is halted using the technique for low-flow arterial bleeding described later.

Video 1. Technique for Avitene “sandwich” exchange. (Click here to view with Windows Media Player and a broadband connection, here to view with a dial-up connection, or here to view with RealPlayer.)

ARTERIAL HEMOSTASIS

High-Flow Arterial Bleeding

In the case of high-flow bleeding it is critical to confine the flow to a specific portion of the artery to allow for the direct application of bipolar coagulation. Blood has a tremendous capacity for heat dispersion; therefore, diffuse cauterization without identifying the small segment of the vessel with the laceration will not be effective. The suction device is used to isolate the bleeding site by maintaining a dry field and directing the stream of blood away from the tip of the endoscope. Once the hole in the artery can be seen clearly, the bipolar electrocautery is applied along the sidewall of the vessel (Fig. 3). The specific type of endoneurosurgical bipolar device chosen will vary depending on the factors previously discussed. Gentle irrigation with saline helps prevent sticking of the bipolar electrocautery blades to the vessel.

A critical difference in comparison with microsurgery is the ability to maintain visualization by using the endoscope during the course of this type of bleeding. This requires a significant amount of collective experience among the team members to be able to navigate through the bleeding and maintain vision. Although the principles are the same, with the surgeon who is performing the dissection managing the two primary suction devices while the endoscopist uses a third one to follow the flow of blood to the focal site, a key difference is the need for two surgeons to maintain visualization (Video 2).

Video 2. Technique for bipolar cautery in high-flow arterial bleeding. (Click here to view with Windows Media Player and a broadband connection, here to view with a dial-up connection, or here to view with RealPlayer.)

In cases involving these larger vessels with high-flow hemorrhage, the immediate and delayed consequences of
the thermal injury to the vessel wall that occurs during the coagulation needs to be borne in mind. The probability of immediate occlusion of the vessel is extremely high and the tolerance of the distal circulation will be contingent on the collateral supply. Therefore, an assessment of this eventual-ity must be considered during perioperative and intraoperative planning. The surgeon must be very vigilant for the delayed sequelae of thermal injury and the development of a pseudoaneurysm. Therefore, early and delayed postoperative arteriograms are important.

Low-Flow Arterial Bleeding

For low-flow bleeding from small arterioles, the technique is similar, with selective use of bipolar electrocautery. One should bear in mind, however, that small vessels such as perforating arteries from which this type of bleeding is often sustained are in critical locations, and so heat dispersion to adjacent structures becomes a paramount issue. Continued irrigation with saline during coagulation helps disperse the heat. In these low-flow hemorrhages, isolated segmental packing can be judiciously used. There are a variety of hemostatic materials such as Avitene and Syvek (off-label indication) that we have found useful. Nevertheless, extreme caution must be exercised here. We do not favor this approach unless the packing can be applied focally with no possibility that the vessel will retract or allow bleeding to continue in a retrograde fashion into the adjacent brain. This will inevitably lead to parenchymal hemorrhage, with devastating consequences. Therefore, we rarely use this technique and do so only when these contraindications are not present. Furthermore, if packing is required it is positioned just on the affected vessel to allow visualization of all of the surrounding neural tissue. Only enough pressure is maintained to tamponade the bleeding while still being able to see the normal physiological pulsations in the surrounding brain (Video 3).

Video 3. Technique for halting low-flow bleeding from arterioles (P, perforating artery). (Click here to view with Windows Media Player and a broadband connection, here to view with a dial-up connection, or here to view with RealPlayer.)

ADDITIONAL SPECIAL CONSIDERATIONS

Carotid Artery Injury

When a major carotid artery injury occurs, the immediate concern is maintaining visualization so that the actual defect can be seen. This requires the active participation of both surgeons with the use of two suction devices in addition to the endoscope and dissection instrument. Pressure is applied with a pledget to achieve immediate control. The anesthesiologist takes appropriate measures to maintain blood pressure and restore intravascular volume. A hypertensive state should be avoided; the blood pressure should be high enough to maintain collateral cerebral perfusion. Neurophysiological monitoring may provide early evidence of inadequate perfusion.

In our opinion, every effort should be made to control the bleeding intraoperatively. Indiscriminate packing should be avoided because this will not prevent bleeding intracranially. The edge of the bleeding site is then cauterized with bipolar electrocautery as the pledget is moved aside. Only if the bleeding cannot be stopped with these measures is the site packed focally and the patient transported to the angiography suite for placement of a stent if possible or permanent occlusion of the vessel if not. If adequate collateral circulation is not present, a vascular bypass procedure is performed in the same session.

Devascularization of Tumor Tissues

Preoperative strategies include devascularization of the
tumor by angiographically guided embolization of the vascular bed when possible. The majority of tumors in this location receive their blood supply from small feeding vessels that can be difficult to cannulate for direct embolization with particulate matter. In the absence of direct cannulation, the use of alcohol embolization has been suggested. Based on our experience, we have abandoned the use of intraarterial infiltration of the tumor bed with alcohol. Although it is effective, we have observed a number of complications related to diffusion of the alcohol to critical vascular territories; these include secondary strokes of the cortex and ischemic injury to the contents of the cavernous sinus.

With the use of the expanded endonasal approach, we have been able to gain circumferential access to these lesions, obviating the need for this type of embolization in the majority of cases, even in tumors that are known for being hypervascular (angiobromas, meningiomas, paragangliomas). With large intranasal lesions, debulking of the tumor to the level of the skull base may be necessary to obtain access to the remaining blood supply. Devascularization of tumors can be achieved by ligation of feeding arteries. For tumors in the sinonasal space, the key arterial supply is from the internal maxillary artery and its branches. The critical branches are the sphenopalatine and posterior nasal arteries, which can be accessed early. These vessels exit the sphenopalatine foramen at the posterior–superior corner of the maxillary sinus, deep to the attachment of the middle turbinate. A maxillary antrostomy is made and a subperisteal dissection is performed to identify the foramen. Overlying bone is removed with a 1-mm angled Kerrison rongeur to expose the main trunk of the vessel before the branching point, and a hemoclip is placed.

Tumors that involve the anterior cranial base often receive the majority of their blood supply from the anterior and posterior ethmoid arteries. A complete ethmoidectomy is first necessary to expose the roof of the ethmoid sinus. The anterior ethmoid artery crosses the skull base just posterior to the nasofrontal recess. The thin lamina papyracea of the medial orbital wall is fractured and removed up to the plane of the cranial base. Further elevation of the perios- teum on the orbital side exposes the vessel where it leaves the orbit, and a hemoclip can be placed (Fig. 4). The posterior ethmoid artery is similarly ligated in the roof of the posterior ethmoid air cells.

The expanded endonasal approach provides early exposure of the dural base, facilitating further devascularization in the case of anterior base lesions. The best example of this is anterior base meningiomas, which receive a blood supply from the dural base in addition to the ethmoid arteries. It is not uncommon in anterior skull base meningiomas to find an additional feeding artery arising from the distal portion of this paraclinoid carotid at the level of the opticocarotid recess. This vessel should be specifically identified and coagulated. Care should be taken to prevent the proximal stump from bleeding and retracting into the orbit, resulting in a retrobulbar hematoma.

DISCUSSION

The principles discussed earlier are identical to those applied in achieving hemostasis when using an operating microscope. In this paper we have provided some important considerations that are important in executing these principles when using an endoscope to achieve hemostasis. The most common concerns raised when discussing the ability to effect endoneurosurgical hemostasis have centered on the lack of true three-dimensional visualization and the necessity of working in a relatively narrow corridor at a distance. Together these concerns have raised questions about the ability to maintain visualization, particularly during high-flow arterial bleeding.

To address these questions, several key endoneurosurgical principles and critical equipment used in the procedure have been emphasized throughout this paper. The most important of these is the concept of team surgery, which represents perhaps the most fundamental difference from microsurgery. It is our opinion that in situations in which bleeding is likely to be encountered, team surgery is mandatory. The value of having a team of surgeons working simultaneously is most evident when a vascular crisis occurs. A single surgeon cannot hold an endoscope, suction blood, and achieve hemostasis without help. A stationary
endoscope holder may suffice during uncomplicated dissection but is woefully inadequate if an artery is squirting toward the end of the endoscope. With profuse hemorrhage, it may even be necessary to use two suction devices simultaneously to maintain visualization. An inexperienced assistant is unlikely to be helpful in such a situation.

Currently the most significant limitation of endoneuro-surgical hemostasis is the inability to repair large arteries primarily. Endoscopic suturing techniques are not yet available to reconstruct tears in large vessels primarily. This represents a major difference when compared with microsurgery. Endoneurosurgical techniques for application of vascular clips, including encircling clips, are currently available. Nevertheless, we will need to develop techniques and instruments to reconstruct large vessels in those rare situations in which this is warranted.

CONCLUSIONS

Endoscopic hemostatic techniques must be mastered to perform effective and safe endoneurosurgery. The risk of vascular complications is minimized with adequate preoperative preparation, sound anatomical knowledge, proper dissection techniques, familiarity with hemostatic materials, and treatment algorithms for emergency situations.

Based on our experience with 400 cases between 1998 and 2005, we have found the algorithm described to be an effective means of securing hemostasis during endoscopic endonasal surgery for both intra- and extradural lesions.

References


Manuscript received June 8, 2005. Accepted in final form June 28, 2005.
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