Iatrogenic cerebral venous sinus occlusion with flowable topical hemostatic matrix

Clinical article

Richard H. Singleton, M.D., Ph.D., Brian T. Jankowitz, M.D., Daniel A. Wecht, M.D., and Paul A. Gardner, M.D.

Department of Neurological Surgery, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania

Object. The use of commercially available topical hemostatic adjuncts has increased the safety profile of surgery as a whole. Cranial surgery has also benefited from the development of numerous agents designed to permit more rapid achievement of hemostasis. Flowable topical hemostatic agents applied via syringe injection are now commonly employed in many neurosurgical procedures, including cranial surgery. Intravascular use of these strongly thrombogenic agents is contraindicated, but in certain settings, inadvertent intravascular administration can occur, resulting in vascular occlusion, thrombosis, and potential dissemination. To date, there have no reports detailing the presence and incidence of this complication.

Methods. The authors conducted a retrospective review of all cranial surgeries performed at Presbyterian University Hospital by members of the University of Pittsburgh Medical Center’s Department of Neurological Surgery between 2007 and 2009. Cases complicated by vascular occlusion due to inadvertent intravascular administration of flowable topical hemostatic matrix (FTHM) were identified and analyzed.

Results. Iatrogenic vascular occlusion induced by FTHM was identified in 5 (0.1%) of 3969 cranial surgery cases. None of these events occurred in 3318 supratentorial cases, whereas 5 cases of cerebral venous sinus occlusion occurred in 651 infratentorial cases (0.8%). The risk of accidental vessel occlusion was significantly associated with infratentorial surgery, and all events occurred in the transverse and/or sigmoid sinus. No episodes of inadvertent vascular occlusion occurred during endoscopic surgery. No cases of arterial occlusion were identified. Of the 5 patients with FTHM-related cerebral venous sinus occlusion, none developed long-term neurological sequelae referable to the event.

Conclusions. Inadvertent intravascular administration of FTHM is a rare complication associated with cranial surgery that occurs most commonly during infratentorial procedures around the transverse and/or sigmoid sinuses. Modifications in the choice of when to use an FTHM and the method of application may help prevent accidental venous sinus administration. (DOI: 10.3171/2011.3.JNS10881)

KEY WORDS • cerebral venous sinus thrombosis • cerebral venous sinus occlusion • Surgifoam • thrombin • flowable topical hemostatic matrix • complication • surgical technique

Although some of the progress in local hemostatic agent development has been in the generation of matrices that support the development and maintenance of a clot, equally important advancements have been made in the application of factors designed to activate the coagulation cascade. The use of these adjuncts, either separately or in combination, has reduced the time it takes to stop bleeding. Further advancements have been made in the development of gelatin-based FTHMs that better conform to irregular surfaces than preformed collagen or gelatin sponges. These agents can be easily applied via syringe injection, facilitating their introduction into narrow spaces or into areas where bleeding sources cannot be readily identified. Several different versions of these gelatin-matrix hemostatic agents are commercially available, including Surgifoam and Surgiflo (Ethicon), as well as Floseal (Baxter). These agents can be used either with or without thrombin based on the level of thrombogenicity desired.

Technological advancements in surgical hemostasis have allowed for reductions in blood loss in a broad range of procedures. This has resulted in a decreased need for blood product transfusion, which is associated with a variety of complications, including allergic reaction, increased rates of wound and systemic infections, acute lung injury, increased perioperative mortality rate, and transfusion error. Numerous biologically derived and synthetic adjuncts are currently available for use, ranging from injectable therapeutic drugs designed to correct global coagulopathy to topical agents intended for control of local bleeding.

Abbreviations used in this paper: bThrombin = bovine thrombin; FTHM = flowable topical hemostatic matrix; rhThrombin = recombinant human thrombin.
Venous sinus occlusion with Surgifoam/thrombin

Surgery over or adjacent to cerebrovascular structures can be problematic because of persistent oozing that can take time to control or even transgression of a vessel that can result in large-volume hemorrhage. In such situations, a rapidly acting hemostatic matrix with or without the addition of thrombogenic factors is an attractive adjunct in minimizing blood loss and the time needed to achieve durable hemostasis. The use of a syringe-injectable FTHM is an option for controlling such hemorrhage. Unfortunately, the high pressures generated by syringe injection and/or application in areas where the bleeding point(s) cannot be visualized may result in matrix flow into unintended areas, including the vasculature. To better define the incidence of this potential problem, we conducted a retrospective review of our cranial surgery population to identify surgical cases complicated by FTHM-induced vascular occlusion.

Methods

Case Identification

This study was performed in compliance with the procedures set forth by the University of Pittsburgh institutional review board. A retrospective review of all cranial surgery cases performed at Presbyterian University Hospital from the years 2007 and 2009 was performed. This academic tertiary care referral facility is the primary operative hospital for the University of Pittsburgh Medical Center’s Department of Neurological Surgery. Inclusion criteria were age 18 years of age or older, cranial surgery performed at Presbyterian University Hospital between 2007 and 2009, postoperative cranial imaging (CT or MR imaging) within 1 month of surgery, and availability of postoperative follow-up material documenting patient outcome. Both open and endoscopic cranial surgery cases were included. Those patients in whom the cranial surgery was performed exclusively via a bur hole were excluded because FTHMs are typically not employed in such cases. Other cranial surgeries in which an FTHM was not used were also excluded. Suspected cases were first identified through electronic searches of operative reports and postoperative imaging reports for key words indicative of vascular occlusion. The results of this search were then cross-referenced with a prospectively maintained neurosurgical complication database to identify patients with intra- or postoperatively recognized FTHM-induced vascular occlusion. To identify those cases in which the complication was not perioperatively recognized, the postoperative images of the remaining electronically identified suspected cases was reviewed for evidence of intravascular FTHM adjacent to the operative site that was associated with vessel occlusion. Those cases with clear evidence of an intravascular FTHM in tandem with vessel occlusion/thrombosis were included in the final cohort. Patients with vascular occlusion that did not demonstrate adjacent FTHM (that is, spontaneous thrombosis) were excluded. Operative reports, postoperative neuroimages, and postoperative inpatient and outpatient progress records were then obtained and reviewed for all confirmed cases. The follow-up period ranged from 6 to 31 months.

Hemostatic Agent

The specific flowable hemostatic matrix used was Surgifoam absorbable gelatin powder (Ethicon) mixed with either bThrombin (Thrombin-JMI, King Pharmaceuticals) or rhThrombin (Recotherm, ZymoGenetics) and sterile normal saline. At our institution preparation of Surgifoam/thrombin differs slightly from the manufacturer’s recommendations. Reconstitution of 5000 U of thrombin with 7 ml of sterile saline is first done for open cranial cases (thrombin concentration 714 U/ml) or 10 ml sterile saline for endoscopic cases (thrombin concentration 500 U/ml). The thrombin solution is then mixed with a 1-g container of Surgifoam powder. The resulting FTHM is then placed in a 20-ml syringe. For application during an open craniotomy, a 14-gauge angiocatheter is attached to the syringe; for endoscopic approaches, a Frazier suction tip is attached to the syringe, and the thumb hole is securely covered with bone wax. Bovine thrombin was used previously but our institution has transitioned to using rhThrombin because of its similar efficacy in obtaining hemostasis with reduced immunogeneity.4,8,24 For open cases, we have found that using an additional 2 ml of saline to reconstitute the thrombin added to the Surgifoam powder (for a total of 7 ml; 5 ml is recommended) results in a thick suspension that will remain in place in the face of significant oozing while more easily facilitating flow out of the syringe. For endoscopic endonasal cases, the amount of extra saline diluent is increased to 5 ml (10 ml total) to create a slightly thinner suspension that flows more easily out of the long Frazier applicator. We have trialed a related FTHM, Surgiflo (porcine gelatin powder, Ethicon), which is similar to Surgifoam but includes a proprietary foaming agent designed to make application easier (a patent application has been submitted). However, we have found that the Surgiflo suspension is thinner than Surgifoam and that it does not remain in place as well after application. Once applied, cottonoids may be added over the Surgifoam-thrombin mixture to provide additional mechanical tamponade to aid in hemostasis.

Results

Between 2007 and 2009, 3969 cranial operations were performed. Of these, 83.6% (3318) were supratentorial, whereas 16.4% (651) of the total surgeries were infratentorial. Among the entire surgical cohort, 5 cases of FTHM-induced vascular occlusion were identified for an overall incidence of 0.1% (5 of 3969 operations). The incidence of vascular occlusion for supratentorial surgery was 0%, while that for infratentorial surgery was 0.8% (5 cases). All 5 cases of infratentorial FTHM-induced vascular occlusion occurred during open surgery and involved the transverse and/or sigmoid sinus. The details of the 5 identified cases are summarized in Tables 1 and 2. No cases of arterial occlusion were found. We performed statistical analysis of supratentorial compared with infratentorial occlusive events (0 of 3318 vs 5 of 651, respectively) using the Fisher exact test. Infratentorial surgery was associated with a significantly increased risk of FTHM-induced vascular occlusive events (p < 0.001). Given the relatively
small number of patients with FTHM-induced venous sinus occlusion, the specifics of 2 illustrative cases are discussed.

**Illustrative Cases**

**Case 1**

This 55-year-old woman with a history of breast cancer presented with a symptomatic 3.5-cm metastasis in the right cerebellar hemisphere, for which a right-sided image-guided retrosigmoid craniectomy was performed for tumor resection. As the craniectomy was being completed, significant bleeding was observed from underneath the bone edge from a large emissary vein entering the transverse-sigmoid junction. After bipolar electrocautery failed to create hemostasis, a syringe was used to inject Surgifoam/rhThrombin beneath the bone edge and adjacent to the bleeding point. During application, we observed, through the outer dural layer, filling of the sigmoid sinus, at which point the injection was immediately stopped. There were no changes in vital signs or neuromonitoring and no evidence of cerebellar swelling or increased intracranial pressure. After hemostasis was achieved and the mastoid air cells waxed, the dura mater was opened and the tumor resection completed. The patient awoke from surgery without any new neurological deficits. A noncontrast head CT obtained after surgery revealed a hypodensity in the distal transverse and sigmoid sinus under the craniectomy site (Fig. 1A). Attenuation measurements within the hypodense region in the sinuses ranged from −40 to −120 HU. An irregular hyperdensity was also present in the middle third of the transverse sinus, consistent with retrograde sinus thrombosis. On brain windowing (window level 40 HU, window width 90 HU), the hypodensity appeared similar to air (Fig. 1A); however, when the window was adjusted for lower attenuation (window level −10 HU, window width 400 HU), the affected venous sinus showed filling with a loculated, low-density material consistent with Surgifoam (Fig. 1B). Enhanced MR imaging revealed absence of contrast filling in the distal and middle transverse sinus and sigmoid sinus to the level of the jugular bulb (Fig. 1C) in the setting of a more normal-appearing proximal right transverse sinus (Fig. 1D). Preoperative imaging had demonstrated normal contrast filling throughout both transverse and sigmoid sinuses to the level of the jugular bulb (not shown). The right jugular vein appeared to reconstitute and fill from the inferior petrosal sinus. The sagittal sinus and left transverse sinus appeared patent. No evidence of venous infarction was present (not shown). Interestingly, follow-up MR images showed continued occlusion of the right transverse and sigmoid sinus at 2 months (not shown) but partial recanalization at 3 months (Fig. 2).

**Case 2**

This 33-year-old man had with a history of von Hippel-Lindau disease and multiple midline posterior fossa surgeries for resection of differing hemangioblastomas. After presenting again with a symptomatic midline cerebellar hemangioblastoma, the patient underwent an

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**TABLE 1: Demographic and intraoperative characteristics of patients with FTHM-induced cerebral vascular occlusion**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Indication</th>
<th>Craniectomy Type</th>
<th>Recognized Intraoperatively</th>
<th>Sinus Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55, F</td>
<td>rt cerebellar breast cancer metastasis</td>
<td>rt retrosigmoid</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>2</td>
<td>33, M</td>
<td>recurrent cerebellar hemangioblastoma (VHL)</td>
<td>repeat midline suboccipital</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>3</td>
<td>75, F</td>
<td>lt hemifacial spasm</td>
<td>lt retrosigmoid</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>29, F</td>
<td>rt glossopharyngeal neuralgia</td>
<td>rt retrosigmoid</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>40, F</td>
<td>rt trigeminal neuralgia</td>
<td>rt retrosigmoid</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

* VHL = von Hippel-Lindau disease.

**TABLE 2: Postoperative characteristics in patients with FTHM-induced cerebral vascular occlusion**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Acute Symptoms</th>
<th>Reason for Postop Imaging</th>
<th>FTHM Location</th>
<th>Extent of Thrombosis</th>
<th>Associated Complications</th>
<th>Follow-Up (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>none</td>
<td>intraop recognition of complication</td>
<td>TS, SS</td>
<td>TS, SS</td>
<td>postirradiation CSF leak &amp; meningitis</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>none</td>
<td>intraop recognition of complication</td>
<td>TS, T</td>
<td>TS, SS, SIS, T, SagS</td>
<td>none</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>none</td>
<td>cranial nerve injury</td>
<td>TSJ, SS</td>
<td>TS, SS</td>
<td>1-cm ipsilat cerebellar hemispheric infarction</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>headache</td>
<td>postop headache</td>
<td>TSJ, SS</td>
<td>TS, SS</td>
<td>none</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>none</td>
<td>cranial nerve injury, 2.5-L op blood loss</td>
<td>TSJ, SS</td>
<td>TS, SS</td>
<td>2-cm ipsilat cerebellar hemispheric infarction</td>
<td>31</td>
</tr>
</tbody>
</table>

* SagS = sagittal sinus; SS = sigmoid sinus; SIS = straight sinus; T = torcula; TS = transverse sinus; TSJ = transverse-sigmoid junction.
Venous sinus occlusion with Surgifoam/thrombin

After dissection through the scar from his prior operations, the previous craniectomy was widened. During the course of the bone removal, brisk venous bleeding was encountered along the superior aspect of the widened craniectomy arising from the region of the torcula/right transverse sinus. This was successfully controlled using local Surgifoam/thrombin and cottonoids. After hemangioblastoma resection was completed, significant bleeding from the same region was encountered after removing the cottonoids, which was again managed with syringe injection of Surgifoam/rhThrombin under the bone edge followed by cottonoid placement. During the process of removing both cottonoids and excess hemostatic matrix, a defect in the inferior wall of the transverse sinus/torcula was noted through which Surgifoam extended into the vessel. Given the previous difficulty with hemorrhage, no evidence of brain swelling, and a lack of neuromonitoring or vital sign changes, the Surgifoam was left in place and the wound closed.

After awakening, the patient was alert and able to follow commands with all extremities but exhibited bilateral dysmetria. A noncontrast head CT scan showed a hyperdensity in the torcula extending into the posterior superior sagittal sinus, straight sinus, and left transverse sinus consistent with sinus thrombosis (Fig. 3A and B). An adjacent, irregular hypodensity extending from the torcula to proximal right transverse sinus was also present (Fig. 3B and C). Similar to the first case, the attenuation measurements of the irregular, loculated, low-density material in this area ranged from −40 to −120 HU, consistent with Surgifoam (Fig. 3D). Compared with the preoperative MR images demonstrating a patent cerebral venous sinus system (not shown), the postoperative MR images/MR venograms revealed a lack of flow in all of the aforementioned venous sinuses, with present flow in the anterior and middle superior sagittal sinuses and distal to the right transverse-sigmoid junction, which was fed by the vein of Labbé (Fig. 3E–H); no evidence of venous infarction was present on MR images (not shown). Ophthalmological evaluation did not reveal evidence of papilledema, and except for his incisional pain, the patient did not complain of headache. The patient received conservative therapy with aggressive intravenous hydration and observation and was eventually discharged to a rehabilitation facility. He died 18 months later due to tumor progression without undergoing further surgery. No postmortem examination was performed.

Discussion

Previous Reports

To date, no previous cranial complications and only one spinal surgery complication involving the use of an FTHM have been reported. In this case, a young patient undergoing extensive spinal surgery for posterior correction of a scoliotic deformity suffered a cardiac arrest shortly after Surgifoam mixed with rhThrombin was injected into and around a bleeding lumbar pedicle. After resuscitation, the patient was hypotensive, requiring vasopressor support, and was experiencing right heart failure,
with pulmonary emboli and disseminated intravascular coagulation, but ultimately made a good recovery after treatment. The authors hypothesized that intravascular injection of the Surgifoam/bThrombin caused the complication, based on the timing of the event and evidence of multiple right atrial and ventricular emboli noted on intraoperative transesophageal echocardiography, although no direct evidence of intravascular Surgifoam/bThrombin injection could be provided. Significant morbidity and mortality has also been reported after inappropriate infusion of thrombin alone. As indicated in their respective package inserts, intentional intravascular administration of both Surgifoam as well as all thrombin formulations is contraindicated. In fact, both materials can be used off-label as thrombotic and/or embolic agents.

Identification of Sinus Occlusion

Inadvertent intravascular administration of Surgifoam/thrombin resulting in cerebral venous sinus occlusion was directly observed in 2 of our patients (Cases 1 and 2), and this correlated with findings on postoperative imaging. In the other 3 cases, venous sinus occlusion was not recognized intraoperatively and was discovered on the basis of imaging alone. Postoperative imaging was performed in Cases 1 and 2 due to intraoperative recognition of the complication. Of the 3 occult cases (Cases 3–5), images were obtained in Cases 3 and 5 due to cranial neuropathy thought to be related to surgical manipulation and not to suspicion of a vascular problem. Only the patient in Case 4 demonstrated any acute symptoms of sinus occlusion (headache), which prompted radiographic evaluation.

Localized intravascular FTHM is best appreciated on CT imaging. In comparison with cerebral venous sinus thrombosis, which appears as a hyperdensity within cerebral venous sinuses on noncontrast images, Surgifoam appears hypodense. This is consistent with the significant amount of air that comprises the material. When viewed through a brain window alone (window level 40 HU, window width 90 HU); however, if the window is set for lower attenuation (window level –10 HU, window width 400 HU), the distinction becomes more apparent. Magnetic resonance imaging can be helpful in identifying areas of vascular occlusion, either by loss of intravascular contrast signal on an enhanced T1-weighted sequence or lack of flow on MR venography, but MR imaging is not as sensitive as CT at detecting intravascular Surgifoam. Diffusion-weighted imaging can also identify any related venous infarction, but it is similarly insensitive in detecting intravascular Surgifoam. Given the transiently mild to asymptomatic nature of the venous sinus occlusions in the patients described in this study, diagnostic angiography was not performed; however, if a patient developed...
significant symptoms, angiography could prove useful in not only providing detailed information about the exact nature and extent of the thrombus/occlusion, but also in allowing for intervention either via mechanical means or thrombolysis.\textsuperscript{15}

\textbf{Clinical Consequences and Management of FTHM-Mediated Sinus Occlusion}

Fortunately, none of the patients in this series developed acute or delayed sequelae of venous hypertension, with the exception of the transient headache in Case 4. No patients developed clinical signs of pseudotumor cerebri, which has been linked to venous sinus thrombosis and stenosis.\textsuperscript{14} Indeed, it is remarkable that one patient in this series suffered an occlusion of the torcular without clinical sequelae (Case 2). Other complications occurred, but were not clearly associated with venous sinus occlusion. In Case 1, the delayed CSF leak may have been a consequence of elevated intracranial pressure due to venous occlusion, but more likely it resulted from meningitis after postirradiation wound dehiscence in a patient receiving chemotherapy. In Cases 3 and 5, the small cerebellar infarctions adjacent to the operative site could have been related to venous hypertension but may also have resulted from cerebellar retraction.

In comparison with the previously published case report\textsuperscript{16} in which spinal surgery was performed, none of the patients in the present series developed signs of either immediate or delayed systemic collapse, coagulopathy, or hypercoagulable state. This may be attributed to the relatively thick consistency of the Surgifoam suspension, which may be more likely to remain in place and form a local clot if accidentally injected into an intravascular space, thus preventing further dissemination of either the Surgifoam or thrombin. In contrast, a more liquid and flowable suspension, such as Surgiflo, or a more dilute suspension of Surgifoam powder may be more prone to intravenous dissemination with resulting systemic morbidity. In addition, the tortuosity of the sigmoid sinus and jugular bulb may limit embolization.

Although the recommended treatment for spontaneous cerebral venous sinus thrombosis is initial anticoagulation with either intravenous heparin or subcutaneous low-molecular-weight heparin followed by oral warfarin,\textsuperscript{9} none of the patients in this series received any of these agents, although one patient (Case 5) was started on aspirin. Neurointerventional procedures, such as mechanical thrombectomy or intravascular thrombolysis, are also treatment strategies for venous thrombosis, but they are usually reserved for situations in which anticoagulation proves unsuccessful\textsuperscript{17} and were not pursued in these cases. These strategies may be less effective in the setting of FTHM-induced venous sinus occlusion, given the mechanical nature of the Surgifoam thrombosis coupled with the significant thrombogenicity associated with the coadministered thrombin.

\textit{Supratentorial Versus Infratentorial Surgery}

The significantly increased risk of iatrogenic sinus occlusion with posterior fossa compared with supratentorial surgery is likely a result of the increased venous sinus exposure that occurs as a necessary part of some infratentorial approaches (for example, exposure up to the transverse and sigmoid sinuses for a retrosigmoid approach\textsuperscript{21}). This increases the risk of venous sinus transgression and the need for subsequent hemostasis. Another study evaluating the incidence of procedure-related, symptomatic sinus thrombosis after translabyrinthine and suboccipital approaches for tumor resection found an overall rate of 4.6%, which was attributed to a variety of factors, including mechanical occlusion of the sinus due to retraction, sinus desiccation and shrinkage from exposure, and dehydration.\textsuperscript{14} The comparatively lower incidence of FTHM-induced vascular occlusion reported in the current work would indicate that sinus occlusion caused by misapplication of FTHM likely accounts for only a fraction of the overall sinus thrombotic events experienced by the patients in our series. In contrast to infratentorial surgery, the sinuses are avoided, if possible, for most supratentorial approaches. Supratentorial exposures that extend to or cross the midline and expose the sagittal sinus are a notable exception and would theoretically be at similar risk of a sinus injury and possible hemostasis-related occlusion if an FTHM is used.

\textit{Why Does This Complication Occur?}

The reasons for the accidental injection of FTHM into the venous sinuses in these cases were likely multifactorial. Bleeding from the venous sinuses occurred at or under the bone edge, making visualization of the sinus breach difficult due to bony obstruction combined with the high blood flow out of the sinus. Next, the tip of the syringe applicator was placed under the bone edge near the vessel breach point to apply the hemostatic matrix locally. The injection occurred through a relatively small opening at the end of a short 14-gauge angiocatheter, resulting in a high local infusion pressure within a confined space. When a flowable hemostatic matrix is injected into an enclosed space, a typical sign to cease injection is backflow of the material out of the space. In the setting of a sinus injury, the high pressure of the injection may have caused the hemostatic matrix to enter the sinus through the defect after filling of the dead space. This could delay or extend the time until the expected backflow occurs, signaling that the injection should be stopped. The result would be a supranormal amount of hemostatic matrix being injected, with some entry into the intravascular space. In addition, the possibility exists that while Surgifoam may have played a role in the observed cases of sinus occlusion, the direct injury to the venous sinuses that occurred in 4 of the 5 cases may also have been a primary factor resulting in occlusion.

\textit{Complication Avoidance}

In retrospect, the best way to avoid inadvertent infusion of flowable hemostatic matrix into vascular structures is to avoid its use in situations in which there has been clear violation of vessel integrity and instead use noninjectable topical hemostatic agents such as microfibrillar collagen or a gelatin sponge. In our opinion, if a
flowable matrix is to be used in the setting of venous sinus compromise, the surgeon should be vigilant to apply it under low pressure over the bleeding site; if visualization of the bleeding site is obstructed, the hemostatic matrix should be applied to an adjacent location where it can be clearly visualized and then moved over the area where hemostasis is desired using cottonoids. The FTHM-mediated venous sinus occlusion that occurred in Case 4, however, is of special concern; despite a lack of an overt sinus injury, FTHM still managed to reach the intravascular space, perhaps either through an occult vessel tear that was tamponaded under the bone edge or through a communication in the diploe.

Limitations

It is possible that this retrospective evaluation may underestimate the incidence of flowable hemostatic matrix–related sinus occlusion, given that only 1 of 5 patients had acute symptoms of venous hypertension or infarction. Three of the 5 reported episodes of sinus occlusion in this series occurred during microvascular decompression cases, in which postoperative images are not routinely obtained at our institution if the operative and postoperative courses are uncomplicated. In this setting, an asymptomatic patient with FTHM-induced vascular occlusion would go unrecognized. In other asymptomatic patients with postoperative imaging, lack of physician familiarity with the radiographic appearance of intravascular Surgifoam may cause some cases to go unnoticed. Additionally, we were only able to assess for local intravascular administration of Surgifoam/thrombin. The patients with possible subclinical remote dissemination of FTHM could not be identified. In patients with a postoperatively noted vascular occlusion, only individuals with the characteristic hypodense, loculated appearance of intravascular Surgifoam in association with a hyperdense thrombus on CT were included in the study. The possibility exists that not all FTHM-mediated vascular occlusive events share this imaging characteristic and could therefore have been missed.

Conclusions

Inadvertent cerebral venous sinus occlusion due to FTHM application is a rare complication of cranial surgery (0.1%) that is significantly associated with infratentorial approaches compared with supratentorial approaches. Surgery adjacent to the transverse and/or sigmoid sinuses appears to confer the greatest risk (0.8%). The risk of an occlusive event appears to be lower for endoscopic surgery. Intravascular administration of FTHM may be recognized intraoperatively, but it may also be occult and asymptomatic. Given this, the risk of FTHM-related sinus occlusion described in this report may underestimate the true incidence of the complication. Given the lack of severe acute neurological sequelae in patients with cerebral venous sinus occlusion, medical and neurointerventional measures to limit associated thrombosis or attempt thrombolysis/thrombectomy were not used in the current report. However, if neurological deterioration should occur in the setting of iatrogenic cerebral venous sinus occlusion with an FTHM, more aggressive measures to restore vessel patency may be warranted. When performing surgery around the transverse or sigmoid sinus, FTHM should be used with caution.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Singleton. Acquisition of data: Singleton, Jankowitz, Wecht. Analysis and interpretation of data: Singleton. Drafting the article: Singleton. Critically revising the article: Gardner, Singleton, Jankowitz. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Singleton. Study supervision: Gardner.

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Address correspondence to: Paul Gardner, M.D., Department of Neurological Surgery, University of Pittsburgh Medical Center, Suite B-400, 200 Lothrop Street, Pittsburgh, Pennsylvania 15213. email: gardpa@upmc.edu.