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Review Article

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Hemostats in Spine Surgery: Literature Review and Expert Panel Recommendations

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Bleeding in spine surgery is a common occurrence but when bleeding is uncontrolled the consequences can be severe due to the potential for spinal cord compression and damage to the central nervous system. There are many factors that influence bleeding during spine surgery including patient factors and those related to the type of surgery and the surgical approach to bleeding. There are a range of methods that can be employed to both reduce the risk of bleeding and achieve hemostasis, one of which is the adjunct use of hemostatic agents. Hemostatic agents are available in a variety of forms and materials and with considerable variation in cost, but specific evidence to support their use in spine surgery is sparse. A literature review was conducted to identify the pre-, peri-, and postsurgical considerations around bleeding in spine surgery. The review generated a set of recommendations that were discussed and ratified by a wider expert group of spine surgeons. The results are intended to provide a practical guide to the selection of hemostats for specific bleeding situations that may be encountered in spine surgery.

Keywords: Spine surgery, Hemostasis, Hemostatics/therapeutic use, Lumbar vertebrae, Cervical vertebrae, Blood loss

INTRODUCTION

Most surgery carries the risk of complications, when the surgery involves the spine and spinal cord, these complications (i.e., uncontrolled bleeding) can be severe, as the development of an epidural hematoma can cause spinal cord compression and irreversible damage to the central nervous system.[1]

Bleeding is a common occurrence in spine surgery,[2] and substantial blood loss can be considered routine for some procedures that require significant exposure of vertebrae which are prone to bleeding if untreated.[3] Spine surgery involves a wide range of techniques and procedures with varying degrees of complexity and the level of 'invasiveness' has a significant impact on the surgical outcomes (including blood loss).[4] For example, it has been shown that for lumbar decompression and arthrodesis the volume of blood loss increases with the number of spine segments involved.[5,6]

Achieving hemostasis is of critical importance in spine surgery where only a few milliliters within the spinal canal may cause devastating neurological damage; bleeding may also obscure the field of view for the surgeon leading to potential surgical risk.[7] Inadequate hemostasis can lead to complications such as postoperative hematoma and increased resource utilization such as perioperative blood transfusions and hospital length of stay (LOS).[8]

MATERIALS AND METHODS

We performed a narrative review of the literature on surgical bleeding and hemostatic methods used in spine surgery, this was performed though search of the PubMed database using MeSH (medical subject headings) terms in various combinations, supplemented with free text.

Example search terms included "classification," "bleeding scale," "bleeding grade," "topical hemostat classification," "local hemostatic agents," "clotting cascade," "bleeding management," "spine surgery," "fusion," "laminectomy," "costs," "risk," "microfibrillar collagen," "flowable," "powder," "foam."

After manual screening, relevant randomized controlled trials (RCTs), prospective cohort studies, meta-analyses, case reports, and review articles concerning the management of bleeding in spine surgery and topical hemostat use were included.

The results of the review were discussed and refined by 3 senior spine surgeons (JCLH, PS, SL) with 15 to 25 years of practice (academic, hospital practice, and private practice) via remote meeting (Microsoft Teams), and a draft working document was produced. This draft document was then shared with a further 9 surgeons (specializing in spine surgery) from Europe and the Middle East (RP, BD, AJB, SA, AES, NFB, KSH, AMB, DV).

Two identical remote meetings (Microsoft Teams) were held in April & May 2021 to ensure that each surgeon was able to at-

Table 1. Expert panel recommendations and agreement levels

No.	Statement	Agreement
1	The use of hemostat is not a substitute for good surgical technique and proper application of conventional procedures for hemostasis.	100%
2	The choice of hemostat should take into consideration whether bone fusion is needed or not.	83%
3	Bone wax is a suitable hemostatic adjuvant for bone bleeds where the flow of blood is low.	92%
4	If used when fusion is needed, bone wax should be used in the minimum quantity needed and should be removed from spinal canal and fusion sites prior to closure.	92%
5	ORC or MFC sponges may be used in bone bleeds where the bleed is an ooze.	100%
6	MFC or flowable hemostat may be used in bone bleeds where the bleed is moderate.	100%
7	Attempts should be made to remove ORC before closure, since it will swell and could exert unwanted pressure, and to minimize the possibility of a foreign body reaction which may mimic artifacts on radiographic images, resulting in diagnostic errors and possible reoperation.	92%
8	Experience with MFC has shown it is safe to use in spine surgery as it does not swell, and cases of inflammatory reaction are very rare*.	100%
9	Flowable hemostats with thrombin or MFC are appropriate to stop moderate epidural bleeding including in patients with coagulation disorders.	100%
10	The potential consequences of severe epidural bleeding dictate immediate action to achieve hemostasis.	100%
11	Flowable hemostats with thrombin are appropriate to stop severe epidural bleeds, especially in patients with coagulation disorders.	100%
12	Flowable hemostats made of microfibrillar collagen are also appropriate to stop most severe epidural bleeds.	100%
13	Excess flowable hemostat should be removed by gentle irrigation from the site of application.	92%
14	Hemostatic powders are suitable to use before closure on large muscular beds to potentially decrease postoperative bleeds.	83%
15	In some instances, hemostatic powders are suitable to use throughout surgery on large muscular beds to dry the field intraoperatively	83%
16	Any life-threatening bleeding should be addressed immediately using appropriate surgical technique.	100%

ORC, oxidized regenerated cellulose; MFC, microfibrillar collagen.

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tend at least one. These meetings allowed the wider group of 12 to review the draft document and agree changes based on their own experiences of using hemostats in spine surgery. The group developed an initial set of recommendations.

A Delphi process was carried out to validate the levels of agreement by the steering group with each of the initial recommendations. The recommendations were used to produce a 4-point Likert scale as a Microsoft Forms survey to rate agreement with each statement, ranging across 'strongly disagree,' 'tend to disagree,' 'tend to agree,' and 'strongly agree.'[9] The group predefined agreement for consensus at 75%, a widely accepted threshold[10] and 'very high' at ≥90%. Each member of the group completed the survey, only the project facilitator (Triducive Partners Ltd.) had access to the individual results. The results were extracted from Microsoft Forms and individual scores for each statement analysed (using Microsoft Excel) in line with Delphi methodology. The results were shared with the group via email, and all group members confirmed acceptance of the results and agreement that no further rounds of survey were needed. Thus, the group arrived at a final set of 16 recommendations designed to provide guidance on when and where hemostats should or could be used as adjuncts in spine surgery (Table 1, Fig. 1).

RESULTS

1. Factors That Influence Surgical Bleeding

In addition to the nature and complexity of the procedure, there are a number of patient factors that may also influence the volume of blood loss during surgery, and these include advanced age, higher body mass index (BMI), the presence of osteoporotic bone, neuromuscular scoliosis and bone metastasis.[2,3] Age is a key determinant of blood loss due to the increased likelihood of osteotomy (leading to bleeding from exposed bone surfaces) and the need for surgery involving more vertebral seg-

Type of bleed	Intensity* (qualitative description, visually estimated rate of blood loss [mL/min]): 1 (Mild, >1.0 – 5.0)	2 (Moderate, >5.0 – 10.0)	3 (Severe, >10.0 – 50.0)	4 (Life threatening, >50.0)
Bone	• Bone wax • ORC or MFC foam	• Bone wax • MFC • Flowable hemostat	Potentially complex scenario, approach may vary (and might include compression, electrocautery, etc.)	No indication for hemostats: • Surgical clamp • Massive compression • Suturing
Epidural	• Fabric or foam hemostat • Flowable hemostat with thrombin or MFC		• Flowable hemostat with thrombin or MFC	
Muscular	• Hemostatic powder		Unexpected type of bleed requiring investigation	
Large blood vessels	These tend to be life-threatening due to nature of tissue			No indication for hemostats: • Suturing

Fig. 1. Recommended approach to hemostat use in spine surgery according to type of bleed and bleeding intensity. ORC, oxidized regenerated cellulose; MFC, microfibrillar collagen. *Validated Intraoperative Bleeding Scale.

ments.[3] Revision surgery is also associated with increased bleeding,[11] with reported blood transfusion rates of 8% to 30%.[12-14]

2. Standardized Bleeding Scales

The Mirza Invasiveness Index[15] has been independently validated[4] and counts a maximum of 6 possible interventions on each vertebral level. The Spot Grade, a surface bleeding severity scale has been developed as a visual method for assessing bleeding severity based on quantitative determinations of blood flow.[16] The Validated Intraoperative Bleeding Scale (Vibe Scale) is also used which ranges from 0 (no bleeding) to 4 (unidentified or inaccessible spurting or gush which is life threatening).[17] These standardized scales tend to be used in clinical studies rather than in surgical practice. In complex surgeries, such as idiopathic scoliosis or adult degenerative deformity, systems should be in place to register blood pressure and blood loss regularly. In practice this has demonstrated a tendency that the more important and premature the blood loss, the more difficult it will be to manage during surgery.

3. Uncontrolled Bleeding Impacts the Patient and the Healthcare System

Complications are the main concern of patients and surgeons perioperatively, as they may have personal and economic consequences, affecting the quality of life and future independence of patients.[18] As well as improving patient outcomes, avoiding uncontrolled surgical bleeding also avoids costs to the healthcare system (Table 2).

Table 2. Consequences of bleeding in spine surgery[1,19-21]

Clinical consequences
Anemia
Hemodynamic instability
Seroma
Hypovolemia
Reduced oxygen delivery to tissues
Postoperative spinal epidural hematoma
Deep vein thrombosis
Pulmonary embolism
Neurological damage
Transfusion reactions and infections
System consequences of surgical bleeding
Increased operating room time
Postoperative length of stay in hospital
Intensive care unit days
Treatment of serious postoperative infection
Repeat surgeries

Whilst the costs of methods employed to control bleeding are a consideration, they should be put into the context of the costs involved in managing the consequences of uncontrolled bleeding to both the patient and to the healthcare system. In spinal surgery, the occurrence of bleeding-related consequences is associated with an almost six-fold increase in mean LOS and intensive care unit (ICU) days compared to those with no bleeding-related consequences, and the associated inpatient costs were found to be more than double.[21]

4. Blood Loss Minimization

Hemostats are widely used in spine surgery, where it is often found to be a significant consumer of hemostats in terms of cost. An analysis in a French hospital[22] shows neurosurgery (including spine surgery) is the greatest consumer of surgical hemostats, with the greatest expenditure for a relatively small number of higher cost hemostats. It may be that there is a need to examine how and when hemostats are used in spine surgery in order to maximize surgical and patient outcomes. It is therefore appropriate to consider the specific role of topical hemostats in spine surgery with a targeted approach that considers not only bleed type but the properties of available hemostats.

Evidence of the use of topical hemostats specific to spine surgery is limited and there are many factors to consider. The following analysis is provided to encourage the optimal use of topical hemostats in spine surgery and provide a rationale for their cost-effective use.

5. Types of Bleeding and Associated Complications in Spine Surgery

1) Subcutaneous and muscle bleeding

This bleeding is a diffuse oozing, rarely of high intensity but continuous in nature which generally occurs throughout the whole surgery, from opening to closure. Surgical retractors can limit bleeding during the surgery through compression of tissues, but once released, bleeding may resume. It commonly occurs during posterior approaches of the lumbar and also the cervical spine where muscular vascularization is preponderous. Intensity of bleed is dependent on the magnitude of muscular exposition and therefore on both the number of levels and the muscular mass involved.

2) Bone bleeding

This type of bleeding occurs during bone resection proce-

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dures and may result in oozing of blood from cancellous bone. The significance of this bleeding depends on the surface exposed. During basic surgeries such as recalibration or arthrectomy, the bleeding is limited, but in more complex procedures such as laminectomy and multilevel surgeries, bleeding may be more substantial.

Bleeding may be particularly important and more difficult to control in deformity correction surgeries, such as transpedicular osteotomies or vertebral column resections.

3) Epidural bleeding

This is the most problematic type of bleeding in spine surgery. Epidural venous plexus are thin and fragile, and therefore tend to be damaged as soon as the opening of the spinal canal is initiated. This network surrounds neurological structures making it difficult to control bleeding without involving the nerve roots and dural sheath. Epidural bleeding can cause compressive hematomas with disastrous consequences on neurological structures. Even in the form of venous bleeding normally handled by tamponade, the bleed site may be difficult to reach or located around structures which cannot be compressed.

Although predominantly a low-pressure type of bleeding, particular conditions (such as obesity and abdominal hypertension) can significantly increase venous pressure and consequently the bleeding rate.

4) Large blood vessel bleeding

This is a rare event caused by complication during anterior lumbar approaches or, exceptionally during lumbar discectomies, by transfixion of the anterior longitudinal ligament. These wounds cause catastrophic bleeding (spurting) that requires quick control, often by direct suture of the damaged blood vessel.

APPROACHES TO MANAGING BLEEDING IN SPINE SURGERY

To minimize the occurrence and severity of bleeding in spine surgery, a multimodal approach involving preoperative prevention and intraoperative management is often employed, with postoperative correction/care as appropriate.

1. Preoperative Prevention

1) Withdrawal of drugs that increase intraoperative bleeding risk

Nonsteroidal anti-inflammatory drugs (NSAIDs) decrease the production of thromboxane A2, a key upstream trigger of platelet activation and aggregation. Withdrawal of NSAIDS should be carried out based on the half-life of the drug and only if the risk-benefit of withdrawal is considered positive. Whilst aspirin is a NSAID, evidence to date does not demonstrate a significant effect of withdrawal on bleeding or complication rates in spine surgery.[2,23-25]

Anticoagulant drugs (i.e., warfarin, dabigatran, apixaban etc.) should be stopped 3–5 days prior to surgery according to individual drug requirements and bridging therapy (i.e., heparin) should be used where necessary to mitigate the risk of stroke or other consequence of withdrawal.[2]

Whilst withdrawal of antiplatelet agents other than NSAIDS (e.g., clopidogrel, prasugrel) is generally recommended by spine surgeons,[26] evidence suggests that it is generally safe to continue these agents prior to spine surgery unless there is a considerable risk of significant blood loss.[7,27]

Herbal or naturalistic supplements, notably ginseng, ginkgo, and vitamin E among others, can also increase bleeding and should be managed prior to surgery.[3]

2) Preoperative autologous blood transfusion

Preoperative autologous blood transfusion (PABD) has been proposed to reduce transfusion risks in elective cases with anticipated high blood loss. Evidence suggests that a significant number (40%) of patients who undergo PABD still require transfusion of allogenic blood products[28] which has led to PABD falling out of favor over time.

2. Intraoperative Management

1) Anesthetic approach

Hypotensive anesthesia may be used to improve the surgical field and to reduce blood loss during major spinal surgery. A mean arterial blood pressure (MAP) reduction of 30% from baseline is recommended. The systolic blood pressure is reduced to 80–90 mmHg and the MAP is reduced to 50–65 mmHg in normotensive patients. Good anesthetic technique should be employed to avoid tachycardia and any reduction in the MAP or systolic blood pressure below the expected range should be managed with vasoactive drugs.[29,30]

In patients undergoing lumbar spinal surgery, caudal epidural anesthesia has also been shown to reduce surgical bleeding by as much as 50%, lower pain scores, and increase levels of patients satisfaction when compared with general anesthesia. However, this approach is unsuitable for operations involving the thoracic and cervical spine and may hinder early postoperative neurological assessment. Use of regional anesthesia in spine surgery also requires the patient to maintain a prone position

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for extended periods, making it unsuitable for longer procedures.[29,31]

Excellent cooperation is required between the surgeon and the anesthesiologist in the control of intraoperative bleeding and continual adjustment is required to maintain tight control during surgery.

2) Surgical positioning

It is important to consider both the relative positions of the surgical site and right atrium and the intra-abdominal pressure (IAP). Prone positioning is a common body position for spine surgery to allow access to the surgical site, alternative body positions may be considered including the Trendelburg position (for surgeries on the lumber and lower thoracic spine) or the reverse Trendelburg (for cervical procedures) to reduce pressure on the inferior vena cava. As pelvic and abdominal compression can increase IAP, the use of conventional surgical tables may thereby increase the risk of bleeding, particularly in patients with a high BMI.[32,33] To reduce the occurrence and extent of elevated IAP, chest rolls and the use of a Jackson table or Wilson frame with wide interpad spacing can be used to allow the abdomen to hang freely without compression. In the absence of this equipment, a jackknife position can reduce IAP and blood loss compared with standard prone positioning for single level lumbar surgery.[2]

3) Maintaining core temperature

Studies from surgical fields other than spine surgery suggest that reducing the patient's core temperature may increase total blood loss,[34] but evidence in spine surgery does not currently support this,[35,36] however, caution is advised as unintentional hypothermia is associated with an increased risk of complications.[37]

4) Use of antifibrinolytic agents

The 2 main antifibrinolytic agents in clinical practice are tranexamic acid (TXA) and ε-aminocaproic acid (EACA), both of which have been shown to reduce blood loss during surgery:

- Systemic (intravenous) use of TXA is considered a mainstay of reducing blood loss in surgery and has been shown to reduce perioperative hemorrhage and the need for blood transfusions by one third in major surgery (including spinal surgery). TXA does not appear to be associated with an increased incidence of pulmonary embolism (PE), deep vein thrombosis, or myocardial infarction.[20,38] Continuous low-dose postoperative TXA for 24 hours after spinal deformity surgery in 147 patients was not associated with significantly reduced drain output and allogenic transfusion requirements, the use of high-dose TXA in this manner requires investigation.[39] Topical use of TXA has also been explored and systemic review suggests similar hemostatic efficacy compared with intravenous TXA.[20] A metanalysis of the use of TXA in spine surgery found that topical application of TXA in spinal surgery decreases the total blood loss and drainage volume without increasing the risk of wound infection, hematoma, DVT, and PE.[40]
- Multiple RCTs have demonstrated the safety and efficacy of EACA. Findings suggest a significantly lower estimated blood loss with use of EACA without any associated difference in complications between groups.[41-44]

5) Electrocautery

Standard electrocautery is a technique employs high temperatures (up to 400°C) to seal small blood vessels, it is commonly used in spine surgery to prevent bleeding in the operative field to maintain clear visibility.[45]

An additional technique has been developed to use a bipolar sealer which applies a saline-irrigated radiofrequency to induce hemostatic sealing and coagulation of soft tissue. This technique maintains a tissue temperature below 100°C and so may reduce tissue trauma.[2] Wang et al.[46] found the use of a bipolar sealer to reduce operation time, intraoperative blood loss, rate of allogenic transfusion, and mean transfusion requirement. It is also possible to use plasma cautery to reduce muscle damage as the temperature increase is limited to within a few microns.[47]

Hemostatic agents including topical and flowable agents are often preferable to electrocautery in intraspinal procedures, as they control bleeding without occluding the vessel lumen or causing thermal injury to adjacent structures.[48]

6) Blood transfusion and cell salvage

Intravenous blood transfusion is a method used to replace blood lost from significant bleeding during surgery and is effective in maintaining blood pressure and tissue perfusion. The blood products used may be autologous or allogenic. The use of allogenic blood carries increased risks to the patient including infection, contamination, immune system compromise, and transfusion-related acute lung injury. As a consequence, allogenic blood transfusion use is associated with increased length of ICU care.[3,19]

Intraoperative cell salvage is a method where blood is drained from the dissection cavity during the surgery and filtered to

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produce a red blood cell enriched unit that is then returned to the patient.[2] This is commonly used in spine surgery and has been shown to reduce the rate of allogenic blood transfusion from 55% to 6%.[49]

7) Topical hemostatic agents

The use of topical hemostats adjuvant to manual pressure, cautery and suture is generally indicated for bleeding of low to moderate intensity. Topical hemostats may take several forms, from traditional patches and foams (sponge) to powders and flowable hemostats. Within these broad categories are differences according to composition and the presence of active compounds (e.g., thrombin derived from either bovine, human, or recombinant sources).[19]

Topical hemostats may be classified by their nature as mechanical, active, flowable, or sealant.[50] Mechanical agents (also referred to as passive agents) are generally considered most effective for low intensity bleeding and act by forming a barrier to the flow of blood and providing a surface that allows the blood to clot more rapidly. Active hemostats contain substances that biologically assist in the clotting process to achieve hemostasis.[51] Dry fibrin dressings and liquid fibrin sealants contain fibrinogen and thrombin in varying proportions according to individual product.[52] Active hemostats provide greater hemostatic efficacy than purely mechanical options in patients with coagulation disorders but tend to have a greater acquisition price.[53] Hemostats containing animal or human products carry the risk of development of immunogenicity and viral contamination. Animal thrombin is also associated with antibody formation, potentially leading to coagulopathy and anaphylaxis in rare cases.[51] Pooled human plasma thrombin is associated with a potential risk of viral or prion transmission. Recombinant thrombin has a reduced risk of antibody formation compared with bovine thrombin although allergic reactions are possible.[50,52,53]

3. Materials Used in Topical Hemostats

Bone wax works via mechanical intercalation within trabecular bone. Bone wax has a local proinflammatory effect and may elicit an allergic reaction in some patients.[2,54] Bone wax should be used sparingly for minimal bleeding and should never be left in place in fusion sites or within the spinal canal.[54]

Gelatin-based agents contain either porcine or bovine-derived gelatin, they act by absorbing blood exerting a hemostatic effect through mechanical swelling[53,55] whilst the gelatin provides a matrix for clot formation.[53] The swelling associated with gelatin products in the spinal canal has been linked with severe neurological consequences.[56]

Oxidized regenerated cellulose (ORC) based hemostats exhibit favorable biocompatibility and bactericidal properties, and act by swelling and compression. It can be useful for the control of oozing from large surfaces, and also pressed under osteoplastic flaps or used to stop oozing from dural surfaces. When ORC is used in proximity to nerve structures in the spinal cord, nerve compression may result. Although ORC is absorbed over time, excess material may cause granulation formation, leading to complications.[53]

Some hemostats are based on a matrix of microfibrillar collagen (MFC), often in the form of a classic 'flour' or compressed into sheets. MFC adheres well to blood vessels and forms an effective barrier without swelling. Platelets adhere strongly to MFC, thereby promoting clotting through platelet aggregation, but this may not be effective in patients with severe thrombocytopenia.[54] Idiopathic inflammatory reaction to MFC is a possibility (although rare) and should be considered when seizures or radiological appearance consistent with tumor or abscess formation arise shortly after surgery.[57,58]

Polysaccharide hemostats are derived from plant matter and are completely absorbable, thus limiting granuloma formation or infection.[58] Microporous polysaccharide hemospheres (MPH) are starch particles formed into 10-200-μm spheres.[59] Other types of polysaccharide hemostats exist, including chitosan, cellulose, alginate, dextran, and hyaluronic acid, they share some properties with MPH including excellent biocompatibility and biodegradability.[60]

Polyethylene glycol (PEG) polymers can be used as a sealant to achieve hemostasis, forming a hydrogel matrix on contact with tissue, the resulting network also acts as a barrier to adhesion formulation.[53] Swelling is the most common safety risk associated with PEG sealants, which can swell up to 400% and cause nerve compression,[19] for this reason use in spine surgery is not recommended.

Bovine albumin and glutaraldehyde can be used as a sealant or adhesive and can be used to seal large blood vessel anastomosis, however, it is associated with the risk of toxicity from glutaraldehyde.[19]

The materials above can be used in varying combinations to produce a range of materials for application in different situations, including as patches, foams (sponge), fabrics, powders, and flowable (liquid) hemostats. Patch, foam, and fabric hemostats provide a physical barrier and are useful for applying direct pressure to a bleed site where access is not limited.

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1) Patch hemostats

Patches tend to be made from ORC, collagen or polysaccharide, these patches require minimal preparation and may be cut into shape to facilitate compression on the bleeding site or packing a body cavity. Modern patches tend to consist of a sheet-like backing and a self-adhering surface. Fibrin patches (TachoSil, Evarrest) and synthetic or protein-reactive sealant patches (Hemopatch, Veriset) are commonly used.[61] Polysaccharide patches (Heamocer patch) are also available which dehydrate the blood to concentrate clotting agents locally.[62]

2) Foam hemostats

Foam (sometimes referred to as sponge) hemostats can be cut to size and easily manipulated to the bleed site, once in place they provide a mechanical barrier and a matrix for clot formation. Sabel and Stummer (2004) discussed the use of Surgicel (ORC) and Surgifoam (absorbable porcine gelatin) hemostats in spine surgery, suggesting that they are both effective for the control of bleeding when bipolar cautery is either ineffective or dangerous.[48] A comparison of different hemostatic sponges in 92 patients found that hemostatic collagen sponge demonstrated better hemostasis effects with lower postoperative drainage volume and blood loss in posterior spinal fusion surgery than gelatin sponge.[63] Use of absorbable gelatin sponges in spine surgery is associated with some drawbacks, for example, blood-soaked gelatin tends to stick to surgical instruments, and gelatin sponges may be easily dislodged. Whilst ORC based foams may have superior handling characteristics in this regard, the potential for ORC to pass through the intervertebral foramen and cause spinal cord compression is a key consideration.[48]

3) Fabric hemostats

Although ORC hemostat (Surgicel Fibrillar) is absorbable, it has been linked to postoperative complications where masses of the hemostat have been found to compress the dural sac, for this reason, it is suggested that it is removed once hemostasis is achieved.[64]

4) Powder hemostats

Powder hemostats are commonly constructed from ORC (Surgicel), collagen (Hemoblast), or starch polysaccharides (Arista AH, Haemocer, Perclot, StarSil). They provide broad surface coverage to address diffuse bleeding on rough or difficult to reach surfaces.

MPH hemostats absorb water from the blood, resulting in an increased localised concentration of platelets and clotting proteins and thereby reducing time to hemostasis. In cardiothoracic surgery they are associated with reduced postoperative chest drain output and transfusion requirement.[53] Polysaccharide powder hemostat has demonstrated efficacy in 33 patients undergoing neurological microsurgical tumor resection surgery, and hemostasis generally persisted after only a single application with no associated adverse reactions.[65] MPH is also associated with significantly less postoperative bleeding after endoscopic sinus surgery, and reduction in use of bipolar coagulation surgery time in cerebral procedures.[66,67] Powder hemostats can be easily spread over a large surface area and are often used to manage low-pressure bleeds across large surgical surfaces. Similar to flowable hemostats, powder hemostats are able adhere to rough surfaces but may be completely absorbed in 24 to 48 hours.[68]

5) Flowable hemostats

Flowable hemostats may be effective for localised bleeding and providing thorough coverage of the bleed site using a substance that easily conforms to the topography of the underlying tissues.[19] Evidence suggests that flowable fibrin sealant may be more effective than a combination of gelatin foam and thrombin.[19] Adjunctive use of flowable gelatin-thrombin hemostat (Floseal) has been shown to reduce both intraoperative blood loss (by 30%) and postoperative decrease in hemoglobin concentration in adolescents undergoing posterior spinal fusion for idiopathic scoliosis.[69] Application of Floseal at the end of anterior cervical discectomy and fusion has also been shown to significantly reduce occurrence of postoperative hemorrhage.[70] Analysis of 2 flowable hemostats found that surgery time, risk of blood transfusion, and amount of hemostat used is lower with Floseal patients in comparison to Surgiflo.[71] Where bleeds are situated deep in tissue with limited access, a flowable hemostat may be considered an appropriate option to achieve hemostasis although it must be noted that they do not flow against the direction of gravity.

4. Postoperative Correction and Care

1) Postoperative drain use

Postoperative blood loss may be responsible for up to 47% of the total blood loss and this 'hidden' blood loss can contribute to the need for postoperative blood transfusion. The use of drainage can contribute to increased incisional drainage and surgical site hematoma.[2,72] For this reason, use is not a general recommendation but should be individualised for each patient.[73] There is a lack of guidance on the use of drains in spine surgery, and

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there is a clear need to properly correlate drain use in spine surgery with the key complications associated with the presence of drains (such as wound infection, intracranial hypotension, and delayed hemorrhage from pulling the drain), and those complications associated with the absence of drains (including hematoma formation with neurological sequelae, and wound dehiscence with subsequent infection).[74] For short-segment and less invasive fusion surgeries, the use of a drain is associated with delayed ambulation and more pain at the surgical site, routine wound drainage is therefore not recommended for short-segment lumbar fusion surgery.[75]

2) Postoperative spinal epidural hematomas

Whilst rare, postoperative spinal epidural hematomas (PSEH) is one of the most common early complications of spine surgery which can cause neurological complications requiring prompt treatment. Patients with spinal stenosis have increased risk of bleeding from rupture of the venous plexus during decompression surgery, due to their relative thinness.[76] Multilevel surgical procedures and the presence of a preoperative coagulopathy are established significant risk factors for the development of PSEH.[77] Significant PSEH may cause spinal cord compression and neurological symptoms, requiring urgent surgical recovery supported by accurate imaging.[77,78] Immediate (e.g., within 6 hours but sooner if possible) surgical decompression is recommended to prevent/minimize neurological sequelae.[79,80] If the patient is symptomatic in the recovery room, then an immediate revisit to the operating theatre for surgical decompression should be considered with imaging carried out as quickly as possible to support the clinical decision. Surgical decompression usually involves laminectomy followed by evacuation of the hematoma, hemostasis of any bleeding, inspection of the dura, and closure.[81]

DISCUSSION

Spine surgery is complex, with a number of different procedures and approaches, all of which can influence the optimal choice of topical hemostat. The nature of the spine often prevents the use of direct pressure and ligature, and while electrocautery is an option, it is associated with some drawbacks. Additional to the intrinsic risks associated with uncontrolled bleeding, spine surgery carries the risk of nerve damage and/or paralysis.

Topical hemostats are used as an adjunct to manage the diffuse capillary oozing characteristic of many intraspinal pathologies. The choice of topical hemostat should therefore consider both the nature of the procedure and the properties of the hemostatic agent.

As spine surgery is a major consumer of hemostatic agents, it is important to consider their judicious use not only to optimize patient outcomes but also to ensure cost-effective use. Based on the expert opinion of 12 surgeons across Europe and the Middle East, we present 16 recommendations for consideration when selecting a hemostat for adjunct use in spine surgery.

NOTES

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REFERENCES

1. Pirkle S, Cook DJ, Kaskovich S, et al. Comparing bleeding and thrombotic rates in spine surgery: an analysis of 119 patients. Global Spine J 2021;11:161-6.
2. Mikhail C, Pennington Z, Arnold PM, et al. Minimizing blood loss in spine surgery. Global Spine J 2020;10(1 Suppl):71S-83S.
3. Hu SS. Blood loss in adult spinal surgery. Eur Spine J 2004;13 Suppl 1(Suppl 1):S3-5.
4. Holzer EM, Aghayev E, O'Riordan D, et al. Validation of a surgical invasiveness index in patients with lumbar spinal disorders registered in the Spine Tango registry. Eur Spine J 2021;30:1-12.
5. Cassinelli EH, Eubanks J, Vogt M, et al. Risk factors for the development of perioperative complications in elderly patients undergoing lumbar decompression and arthrodesis for spinal stenosis: an analysis of 166 patients. Spine (Phila Pa 1976) 2007;32:230-5.
6. Nuttall GA, Horlocker TT, Santrach PJ, et al. Predictors of blood transfusions in spinal instrumentation and fusion surgery. Spine (Phila Pa 1976) 2000;25:596-601.

7. Columbo JA, Lambour AJ, Sundling RA, et al. A meta-analysis of the impact of aspirin, clopidogrel, and dual antiplatelet therapy on bleeding complications in noncardiac surgery. Ann Surg 2018;267:1-10.
8. Ramirez MG, Niu X, Epstein J, et al. Cost-consequence analysis of a hemostatic matrix alone or in combination for spine surgery patients. J Med Econ 2018;21:1041-6.
9. Dalkey N, Helmer O. An experimental application of the Delphi method to the use of experts. Manag Sci 1963;9:458-67.
10. Diamond IR, Grant RC, Feldman BM, et al. Defining consensus: a systematic review recommends methodologic criteria for reporting of Delphi studies. J Clin Epidemiol 2014;67:401-9.
11. Zheng F, Cammisa FP Jr, Sandhu HS, et al. Factors predicting hospital stay, operative time, blood loss, and transfusion in patients undergoing revision posterior lumbar spine decompression, fusion, and segmental instrumentation. Spine (Phila Pa 1976) 2002;27:818-24.
12. Basques BA, Anandasivam NS, Webb ML, et al. Risk factors for blood transfusion with primary posterior lumbar fusion. Spine (Phila Pa 1976) 2015;40:1792-7.
13. Berenholtz SM, Pronovost PJ, Mullany D, et al. Predictors of transfusion for spinal surgery in Maryland, 1997 to 2000. Transfusion 2002;42:183-9.
14. Butler JS, Burke JP, Dolan RT, et al. Risk analysis of blood transfusion requirements in emergency and elective spinal surgery. Eur Spine J 2011;20:753-8.
15. Mirza SK, Deyo RA, Heagerty PJ, et al. Development of an index to characterize the "invasiveness" of spine surgery: validation by comparison to blood loss and operative time. Spine (Phila Pa 1976) 2008;33:2651-61; discussion 2662.
16. Gaizo DJD, Spotnitz WD, Hoffman RW, et al. SPOT GRADE II: clinical validation of a new method for reproducibly quantifying surgical wound bleeding: prospective, multicenter, multispecialty, single-arm study. Clin Appl Thromb Hemost 2020;26:1076029620936340.
17. Lewis KM, Li Q, Jones DS, et al. Development and validation of an intraoperative bleeding severity scale for use in clinical studies of hemostatic agents. Surgery 2017;161:771-81.
18. Reis RC, de Oliveira MF, Rotta JM, et al. Risk of complications in spine surgery: a prospective study. Open Orthop J 2015;9:20-5.
19. Neveleff DJ. Optimizing hemostatic practices: matching the appropriate hemostat to the clinical situation. AORN J 2012;96:S1-17.
20. Winter SF, Santaguida C, Wong J, et al. Systemic and topical use of tranexamic acid in spinal surgery: a systematic review. Global Spine J 2016;6:284-95.
21. Stokes ME, Ye X, Shah M, et al. Impact of bleeding-related complications and/or blood product transfusions on hospital costs in inpatient surgical patients. BMC Health Serv Res 2011;11:135.
22. Almeida M. Exercise thesis: use of surgical hemostatics: medico-economic study at the Limoges University Hospital. Limoges (France): Limoges University; 2018.
23. Zhang C, Wang G, Liu X, et al. Safety of continuing aspirin therapy during spinal surgery: a systematic review and meta-analysis. Medicine (Baltimore) 2017;96:e8603.
24. Cuellar JM, Petrizzo A, Vaswani R, et al. Does aspirin administration increase perioperative morbidity in patients with cardiac stents undergoing spinal surgery? Spine (Phila Pa 1976) 2015;40:629-35.
25. Goes R, Muskens IS, Smith TR, et al. Risk of aspirin continuation in spinal surgery: a systematic review and meta-analysis. Spine J 2017;17:1939-46.
26. Baschera D, Oberle J, Grubhofer F, et al. Perioperative use of anticoagulant and platelet-inhibiting medications for elective spine surgery: results of a nationwide survey. J Neurol Surg A Cent Eur Neurosurg 2018;79:398-407.
27. Chu EW, Chernoguz A, Divino CM. The evaluation of clopidogrel use in perioperative general surgery patients: a prospective randomized controlled trial. Am J Surg 2016;211:1019-25.
28. Cha CW, Deible C, Muzzonigro T, et al. Allogeneic transfusion requirements after autologous donations in posterior lumbar surgeries. Spine (Phila Pa 1976) 2002;27:99-104.
29. Raw DA, Beattie JK, Hunter JM. Anaesthesia for spinal surgery in adults. Br J Anaesth 2003;91:886-904.
30. Tegegne SS, Gebregzi AH, Arefayne NR. Deliberate hypotension as a mechanism to decrease intraoperative surgical site blood loss in resource limited setting: a systematic review and guideline. Int J Surg Open 2021;29:55-65.
31. Lee JK, Park JH, Hyun SJ, et al. Regional anesthesia for lumbar spine surgery: can it be a standard in the future? Neurospine 2021;18:733-40.
32. Park CK. The effect of patient positioning on intraabdominal pressure and blood loss in spinal surgery. Anesth Analg 2000;91:552-7.
33. Kwee MM, Ho YH, Rozen WM. The prone position during surgery and its complications: a systematic review and evi-

dence-based guidelines. Int Surg 2015;100:292-303.
34. Rajagopalan S, Mascha E, Na J, et al. The effects of mild perioperative hypothermia on blood loss and transfusion requirement. Anesthesiology 2008;108:71-7.
35. Schur MD, Blumstein GW, Seehausen DA, et al. Intraoperative hypothermia is common, but not associated with blood loss or transfusion in pediatric posterior spinal fusion. J Pediatr Orthop 2018;38:450-4.
36. Tedesco NS, Korpi FP, Pazdernik VK, et al. Relationship between hypothermia and blood loss in adult patients undergoing open lumbar spine surgery. J Am Osteopath Assoc 2014;114:828-38.
37. Billeter AT, Hohmann SF, Druen D, et al. Unintentional perioperative hypothermia is associated with severe complications and high mortality in elective operations. Surgery 2014; 156:1245-52.
38. Cheriyan T, Maier SP 2nd, Bianco K, et al. Efficacy of tranexamic acid on surgical bleeding in spine surgery: a meta-analysis. Spine J 2015;15:752-61.
39. Dunn LK, Chen CJ, Taylor DG, et al. Postoperative low-dose tranexamic acid after major spine surgery: a matched cohort analysis. Neurospine 2020;17:888-95.
40. Luo W, Sun RX, Jiang H, et al. The efficacy and safety of topical administration of tranexamic acid in spine surgery: a meta-analysis. J Orthop Surg Res 2018;13:96.
41. Berenholtz SM, Pham JC, Garrett-Mayer E, et al. Effect of epsilon aminocaproic acid on red-cell transfusion requirements in major spinal surgery. Spine (Phila Pa 1976) 2009; 34:2096-103.
42. Peters A, Verma K, Slobodyanyuk K, et al. Antifibrinolytics reduce blood loss in adult spinal deformity surgery: a prospective, randomized controlled trial. Spine (Phila Pa 1976) 2015;40:E443-9.
43. Urban MK, Beckman J, Gordon M, et al. The efficacy of antifibrinolytics in the reduction of blood loss during complex adult reconstructive spine surgery. Spine (Phila Pa 1976) 2001; 26:1152-6.
44. Florentino-Pineda I, Thompson GH, Poe-Kochert C, et al. The effect of amicar on perioperative blood loss in idiopathic scoliosis: the results of a prospective, randomized double-blind study. Spine (Phila Pa 1976) 2004;29:233-8.
45. Lu D, Ding WG, Sheng HF, et al. The efficacy and safety of using a bipolar sealer to prevent blood loss in spine surgery: a meta-analysis. Int J Surg 2017;46:37-46.
46. Wang X, Sun G, Sun R, et al. Bipolar sealer device reduces blood loss and transfusion requirements in posterior spinal fusion for degenerative lumbar scoliosis: a randomized control trial. Clin Spine Surg 2016;29:E107-11.
47. Piazzolla A, Bizzoca D, Solarino G, et al. Plasma technology reduces blood loss in adolescent idiopathic scoliosis surgery: a prospective randomized clinical trial. Global Spine J 2021; 11:874-80.
48. Sabel M, Stummer W. The use of local agents: surgicel and surgifoam. Eur Spine J 2004;13 Suppl 1(Suppl 1):S97-101.
49. Bowen RE, Gardner S, Scaduto AA, et al. Efficacy of intraoperative cell salvage systems in pediatric idiopathic scoliosis patients undergoing posterior spinal fusion with segmental spinal instrumentation. Spine (Phila Pa 1976) 2010;35: 246-51.
50. Spotnitz WD, Burks S. State-of-the-art review: Hemostats, sealants, and adhesives II: Update as well as how and when to use the components of the surgical toolbox. Clin Appl Thromb Hemost 2010;16:497-514.
51. Vyas KS, Saha SP. Comparison of hemostatic agents used in vascular surgery. Expert Opin Biol Ther 2013;13:1663-72.
52. Hickman DA, Pawlowski CL, Sekhon UDS, et al. Biomaterials and advanced technologies for hemostatic management of bleeding. Adv Mater 2018;30:10.1002/adma.201700859.
53. Huang L, Liu GL, Kaye AD, et al. Advances in topical hemostatic agent therapies: a comprehensive update. Adv Ther 2020;37:4132-48.
54. Schonauer C, Tessitore E, Barbagallo G, et al. The use of local agents: bone wax, gelatin, collagen, oxidized cellulose. Eur Spine J 2004;13 Suppl 1(Suppl 1):S89-96.
55. Chiara O, Cimbanassi S, Bellanova G, et al. A systematic review on the use of topical hemostats in trauma and emergency surgery. BMC Surg 2018;18:68.
56. Szpalski M, Gunzburg R, Sztern B. An overview of blood-sparing techniques used in spine surgery during the perioperative period. Eur Spine J 2004;13 Suppl 1(Suppl 1):S18-27.
57. Apel-Sarid L, Cochrane DD, Steinbok P, et al. Microfibrillar collagen hemostat-induced necrotizing granulomatous inflammation developing after craniotomy: a pediatric case series. J Neurosurg Pediatr 2010;6:385-92.
58. O'Shaughnessy BA, Schafernak KT, DiPatri AJ Jr, et al. A granulomatous reaction to Avitene mimicking recurrence of a medulloblastoma. Case report. J Neurosurg 2006;104(1 Suppl):33-6.
59. Seyednejad H, Imani M, Jamieson T, et al. Topical haemostatic agents. Br J Surg 2008;95:1197-225.
60. Li D, Chen J, Wang X, et al. Recent advances on synthetic and polysaccharide adhesives for biological hemostatic ap-

plications. Front Bioeng Biotechnol 2020;8:926.
61. Slezak P, Monforte X, Ferguson J, et al. Properties of collagen-based hemostatic patch compared to oxidized cellulose-based patch. J Mater Sci Mater Med 2018;29:71.
62. Watanabe J, Ohtori S, Orita S, et al. Efficacy of tachosil, a fibrin-based hemostat, for anterior lumbar spine surgery. Asian Spine J 2016;10:930-4.
63. Xu D, Ren Z, Chen X, et al. A randomized controlled trial on effects of different hemostatic sponges in posterior spinal fusion surgeries. BMC Surg 2016;16:80.
64. Menovsky T, Plazier M, Rasschaert R, et al. Massive swelling of Surgicel® Fibrillar™ hemostat after spinal surgery. Case report and a review of the literature. Minim Invasive Neurosurg 2011;54:257-9.
65. Tschan CA, Nie M, Schwandt E, et al. Safety and efficacy of microporous polysaccharide hemospheres in neurosurgery. Neurosurgery 2011;69(1 Suppl Operative):ons49-63.
66. Antisdel JL, West-Denning JL, Sindwani R. Effect of microporous polysaccharide hemospheres (MPH) on bleeding after endoscopic sinus surgery: randomized controlled study. Otolaryngol Head Neck Surg 2009;141:353-7.
67. Galarza M, Porcar OP, Gazzeri R, et al. Microporous polysaccharide hemospheres (MPH) for cerebral hemostasis: a preliminary report. World Neurosurg 2011;75:491-4.
68. Bruckner BA, Blau LN, Rodriguez L, et al. Microporous polysaccharide hemosphere absorbable hemostat use in cardiothoracic surgical procedures. J Cardiothorac Surg 2014;9:134.
69. Helenius I, Keskinen H, Syvänen J, et al. Gelatine matrix with human thrombin decreases blood loss in adolescents undergoing posterior spinal fusion for idiopathic scoliosis: a multicentre, randomised clinical trial. Bone Joint J 2016;98-B:395-401.
70. Li QY, Lee O, Han HS, et al. Efficacy of a topical gelatin-thrombin matrix sealant in reducing postoperative drainage following anterior cervical discectomy and fusion. Asian Spine J 2015;9:909-15.
71. Price JS, Tackett S, Patel V. Observational evaluation of outcomes and resource utilization from hemostatic matrices in spine surgery. J Med Econ 2015;18:777-86.
72. Smorgick Y, Baker KC, Bachison CC, et al. hidden blood loss during posterior spine fusion surgery. Spine J 2013;13:877-81.
73. Liu JM, Chen WZ, Fu BQ, et al. The use of closed suction drainage in lumbar spinal surgery: is it really necessary? World Neurosurg 2016;90:109-15.
74. von Eckardstein KL, Dohmes JE, Rohde V. Use of closed suction devices and other drains in spinal surgery: results of an online, Germany-wide questionnaire. Eur Spine J 2016;25:708-15.
75. Debono B, Wainwright TW, Wang MY, et al. Consensus statement for perioperative care in lumbar spinal fusion: Enhanced Recovery After Surgery (ERAS®) Society recommendations. Spine J 2021;21:729-52.
76. Kim JE, Yoo HS, Choi DJ, et al. Effectiveness of gelatin-thrombin matrix sealants (floseal®) on postoperative spinal epidural hematoma during single-level lumbar decompression using biportal endoscopic spine surgery: clinical and magnetic resonance image study. Biomed Res Int 2020;2020:4801641.
77. Yi S, Yoon DH, Kim KN, et al. Postoperative spinal epidural hematoma: risk factor and clinical outcome. Yonsei Med J 2006;47:326-32.
78. Raasck K, Habis AA, Aoude A, et al. Spontaneous spinal epidural hematoma management: a case series and literature review. Spinal Cord Ser Cases 2017;3:16043.
79. Kamoda H, Ishikawa T, Miyagi M, et al. Delayed postoperative epidural hematoma presenting only with vesicorectal disturbance. Case Rep Orthop 2013;2013:861961.
80. Lawton MT, Porter RW, Heiserman JE, et al. Surgical management of spinal epidural hematoma: relationship between surgical timing and neurological outcome. J Neurosurg 1995;83:1-7.
81. Nelson A, Benzon HT, Jabri RS. Diagnosis and management of spinal and peripheral nerve hematoma. In: Hadzic A, editor. Hadzic's textbook of regional anesthesia and acute pain management. 2nd ed. New York: McGraw Hill; 2017.

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