Perioperative Management of Adult Patients with External Ventricular and Lumbar Drains

Guidelines from the Society for Neuroscience in Anesthesiology and Critical Care

SNACC Task Force for developing guidelines for “Perioperative Management of the External Ventricular and Lumbar Drain”

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Abstract:

External ventricular drains (EVD) and lumbar drains (LD) are commonly used to divert cerebrospinal fluid as well as to measure cerebrospinal fluid (CSF) pressure. Although commonly encountered in the perioperative setting and critical for the care of neurosurgical patients, there are no guidelines regarding their management in the perioperative period. To address this gap in the literature, The Society for Neuroscience in Anesthesiology & Critical Care (SNACC) tasked an expert group to generate evidence based guidelines. The document generated targets clinicians involved in perioperative care of patients with indwelling external ventricular and lumbar drains.
I. **Introduction**

External ventricular drains (EVD) and lumbar drains (LD) are temporary devices placed into the lateral ventricles of the brain and lumbar subarachnoid space respectively, to facilitate external cerebrospinal fluid (CSF) drainage and to monitor CSF pressure. Their placement is considered one of the most frequently performed procedures in neurologically critically ill patients,\(^1\)\(^3\) with the majority placed in patients with subarachnoid hemorrhage, intracerebral hemorrhage and obstructive hydrocephalus.\(^4\) Although the world-wide incidence of placement of EVD and LD is largely unknown, it is estimated that 500,000 ventriculostomies were placed in the United States alone between 1988 and 2010.\(^4\) Since its first placement in 1744, EVDs have undergone numerous changes in materials, techniques, and indications.\(^5\)\(^-\)\(^7\)

EVDs are commonly encountered in perioperative care by clinicians, specifically the anesthesia providers that might have limited experience in their management. Furthermore, mismanagement of EVDs can have catastrophic consequences. Despite their importance, there are currently no guidelines for the perioperative management of EVD and LD.

II. **Methodology**

**Purpose of the guidelines**

These evidence-based guidelines aim to provide recommendations related to EVD and LD regarding (1) common indications, contraindications,
complications and patient preparation for placement and maintenance; (2) preoperative assessment of patients; (3) transporting patients; (4) intraoperative management including monitoring and CSF drainage; (5) management of these drains under special circumstances; and (6) creating a perioperative checklist, clinical competency, and continued medical education.

**Application**

These guidelines are intended for the use by clinicians involved in perioperative care of adult patients with EVDs and LDs.

**Task Force Members**

The initial concept and design of “Society for Neuroscience in Anesthesiology & Critical Care (SNACC) EVD/LD project” began in November of 2015, and an EVD/LD task force was finalized in December of 2015. This task force comprised of ten neuroanesthesiologists and neurointensivists practicing at academic medical centers across the U.S and Canada. These ten individuals were chosen after an e-mail invitation was sent to all active SNACC members seeking project membership. Applicants were required to have published peer-reviewed neuroscience research or have documented experience in the care of patients with EVD and LD. The task-force members agreed on criteria for evidence and then evaluated peer-reviewed studies pertaining to EVD and LD (search strategies described in next section). The document was compiled of six sections, with each section equally co-authored by two project members, and was subsequently reviewed and approved by all members of the task force. The
completed draft was submitted to the SNACC Board of Directors. After incorporating the inputs and suggestions from the SNACC Board of Directors, the approved version was placed on the SNACC website (www.snacc.org) for member review and comments for a period of one-month, with the final version of the guideline confirmed after incorporating member input.

III. Availability and Strength of Evidence

The task force worked with a medical librarian to create a systematic strategy to search PubMed: (external ventricular drain*[tw] OR external ventricle drain*[tw] OR extraventricular drain*[tw] OR extra ventricular drain*[tw] OR ventricular catheter*[tw] OR ventricular access device*[tw] OR lumbar drain*[tw] OR cerebrospinal fluid drain*[tw] OR csf drain*[tw]) OR (ventriculostom*[tw] AND (drain*[tw] OR catheter*[tw])). The format of this search was adapted for Embase via Elsevier. Search results were limited to journal articles and conference papers published in English and last updated on October 8, 2016. The total search results (7936 references) were downloaded to Endnote. After 2729 duplicates were removed, 5207 articles were imported to a Covidence database for team review. Authors had previously identified 119 additional articles, and 91 articles were found by the authors including checks of reference lists as the review progressed.

Several rounds of screening were conducted, with review of each of the titles and abstracts from the original search by two reviewers. Inclusion criteria were all study types in adults, and exclusion criteria were nonhuman studies,
laboratory investigations, and pediatric literature. References addressing infectious complications and prevention strategies published prior to the 2015 Neurocritical Care Society guidelines and those addressing CSF drainage for spinal cord protection published prior to the 2010 ACC guidelines were eliminated. Ultimately a pool of 646 references were identified and organized by topic for the individual section authors to draw upon in construction of the guidelines.

Recommendations are proposed and the quality of evidence that supports the recommendation graded using the methodology used by the American Heart Association.

(Table 1)

**Table 1**

**Summary of Class (Strength) of Recommendation and Level (Quality) of Evidence**

<table>
<thead>
<tr>
<th>Class (Strength) Of Recommendation</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Class I (Strong) Benefit &gt;&gt;&gt; Risk</td>
<td></td>
</tr>
<tr>
<td>Class IIa (Moderate) Benefit &gt;&gt; Risk</td>
<td></td>
</tr>
<tr>
<td>Class IIb (Weak) Benefit &gt; Risk</td>
<td></td>
</tr>
<tr>
<td>Class III: No benefit (Benefit = Risk)</td>
<td></td>
</tr>
<tr>
<td>Class III: Harm (Strong) Risk &gt; Benefit</td>
<td></td>
</tr>
<tr>
<td>Level (Quality of Evidence)</td>
<td>Requirements</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------</td>
</tr>
</tbody>
</table>
| **Level A**               | - High-quality evidence‡ from more than 1 RCTs  
                          - Meta-analyses of high-quality RCTs  
                          - One or more RCTs corroborated by high-quality registry studies |
| **Level B-Randomized**    | - Moderate-quality evidence‡ from 1 or more RCTs  
                          - Meta-analyses of moderate-quality RCTs |
| **Level B- Non Randomized** | - Moderate-quality evidence‡ from 1 or more well-designed, well-executed nonrandomized studies, observational studies, or registry studies  
                          - Meta-analyses of such studies |
| **Level C**               | - Randomized or nonrandomized observational or registry studies with limitations of design or execution  
                          - Meta-analyses of such studies  
                          - Physiological or mechanistic studies in human subjects |
| **Level E**               | - Consensus of expert opinion based on clinical experience when evidence is insufficient, vague, or conflicting |

**Section 1: Introduction to External Ventricular and Lumbar Drains**

(1.1) Common indications for placement of EVDs and LDs
EVDs function as ICP monitors and as conduits for external CSF diversion. Lumbar drains on the other hand, function primarily as a conduit for external CSF drainage, and are not used for ICP monitoring. While both parenchymal ICP monitors and EVDs provide reliable and accurate ICP data, EVD are preferred in patients with hydrocephalus.\textsuperscript{11}

Major indications for placement of EVD and LD are presented in Table 2.

**Table 2: Major Indications for Placement of External Ventricular and Lumbar Drains**

**2a External ventricular drains**

<table>
<thead>
<tr>
<th>Acute symptomatic hydrocephalus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aneurysmal SAH\textsuperscript{12-14}</td>
</tr>
<tr>
<td>ICH and IVH with decreased level of consciousness\textsuperscript{15}</td>
</tr>
<tr>
<td>Acute ischemic cerebellar stroke in concurrence with decompressive cranietomy\textsuperscript{16,17}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ICP monitoring in TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBI with post resuscitation GCS of 3-8, and abnormal computed tomography (CT) scan defined as one with hematomas, contusions, swelling, herniation or compressed basal cisterns\textsuperscript{18-20}</td>
</tr>
<tr>
<td>Severe TBI with a normal CT scan if two or more of the following features are noted on admission (age over 40 yrs., unilateral or bilateral motor posturing, or SBP &lt; 90 mmHg\textsuperscript{18,19}</td>
</tr>
</tbody>
</table>
### Management of patients with intracranial hypertension after TBI

- Malfunctioning or infected ventriculo-peritoneal shunts, and other neurological emergencies occurring due to infective, and neoplastic diseases

### Facilitation of intraoperative brain relaxation

### Targeted therapeutic interventions

- rTPA in patients with IVH (efficacy and safety uncertain) and in patients with SAH

- Treatment of vasospasm after aneurysmal SAH

- Antibiotics in management of central nervous system infections

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### 2b Lumbar drains

### Acute symptomatic hydrocephalus in SAH

### Spinal cord protective strategy in open and endovascular thoracic aortic repair for patients at high risk of spinal cord injury

### Active CSF leak (due to craniofacial trauma) or those at risk for CSF leak during skull base procedures, however lumbar drains do not prevent postoperative CSF leaks

### Facilitate intraoperative brain relaxation and intraoperative exposure

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### Abbreviations

score, CT: computerized tomography, SBP: systolic blood pressure, CSF: cerebrospinal fluid, r TPA: recombinant tissue plasminogen activator
(1.2) Placement of EVDs and LDs

EVDs are frequently inserted emergently at bedside rather than in the operating room (OR). The frontal horn of the right lateral ventricle is the preferred destination as this is assumed to be in the non-dominant side for speech and language in the majority of patients. While different techniques for EVD placement have been described in the literature, anatomical landmarks are frequently used and the drain is placed free handed.

LDs are placed in a manner similar to a lumbar puncture, epidural, or intrathecal catheter placement. Placement of an LD may be done preoperatively in an awake patient, or after the induction of anesthesia. Coagulation profile, anticoagulation medications should be reviewed and anticoagulants held per current American Society of Regional Anesthesia and Pain Medicine (ASRA) guidelines (Refer to supplement 1). The patient is placed in the lateral decubitus or sitting position. Using strict aseptic technique, the lumbar catheter is typically inserted at the L3-4 or L4-5 level via a 14G Tuohy needle. A special, kink resistant, flexible catheter is passed through the Tuohy needle into the intrathecal space. The catheter with the guide wire is threaded approximately 5-8 cm past the needle into the intrathecal space and secured with a clear dressing. It should be stressed that the catheter should thread easily, similar to an epidural catheter. If resistance is felt, or the catheter is unable to be placed, both the needle and catheter should be removed as a single unit in order to prevent inadvertent
shearing of the catheter. The catheter should be flushed with 10 mL sterile saline flush and connected to a sterile pressure monitoring kit and a closed collection system. The transducer should not be connected to any pressured flushing system. When connecting the transducer to a collection system ensure a continuous fluid column. This can be achieved by allowing CSF to drain back to the stopcock at the transducer. Bloody CSF or aspiration of blood during placement requires avoidance of anticoagulation for 24 hours.

**1.3 Optimizing patients prior to placement of EVDs or LDs**

Contraindications to placement of EVD or LD include coagulopathy and infection at the entry site. LD also need careful screening to rule out non-communicating hydrocephalus, and large intracranial mass lesions. The ASRA guidelines on anticoagulation should be consulted to determine appropriateness of placement and removal of the lumbar drain. It is generally advised to diagnose and promptly correct coagulopathies prior to placement of either monitor.

**1.4 Complications associated with EVDs and LDs**

Complications associated with EVD placement are common requiring revision in 10-22% of cases. Table 3 highlights complications associated with EVDs and LDs. While hemorrhage, infections, and over drainage of CSF are the most recognized complications, clinicians involved in perioperative care must be familiar with other possible complications.

**Table 3: Complications Associated with EVD and LD**
<table>
<thead>
<tr>
<th>Hemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracerebral hemorrhage, tract hematoma or tract hemorrhages (0-41%)</td>
</tr>
<tr>
<td>Neuraxial hematoma (0-3.2%)</td>
</tr>
<tr>
<td>Neural injury</td>
</tr>
<tr>
<td>Infection (0-28% EVD, 0-50% LD)</td>
</tr>
<tr>
<td>Malposition</td>
</tr>
<tr>
<td>Occlusion and malfunction</td>
</tr>
<tr>
<td>Over drainage of CSF</td>
</tr>
<tr>
<td>Subdural or epidural hematoma</td>
</tr>
<tr>
<td>Re-bleeding from a ruptured cerebral aneurysm</td>
</tr>
<tr>
<td>Intracranial hypotension</td>
</tr>
<tr>
<td>Cerebellar tonsillar herniation</td>
</tr>
<tr>
<td>Paradoxical herniation</td>
</tr>
<tr>
<td>Pneumocephalus</td>
</tr>
<tr>
<td>Iatrogenic vascular injury (arteriovenous fistula, cerebral pseudo aneurysm)</td>
</tr>
<tr>
<td>Fracture of catheters, with retained fragment of catheter</td>
</tr>
<tr>
<td>Inadvertent injections of drugs into EVDs</td>
</tr>
<tr>
<td>Postdural puncture headache</td>
</tr>
</tbody>
</table>

Abbreviations
EVD: external ventricular drain
LD: lumbar drain

(1.4.1a) Hemorrhagic complications associated with EVD and LD
There are two main risk factors for hemorrhagic complications; (1) coagulopathy, and (2) over drainage of CSF. Factors such as cerebrovascular disease, size of catheter, use of antiplatelet agents, and INR > 1.6 place patients at risk for ventriculostomy associated hemorrhage. While the majority of these bleeds are clinically insignificant, they can be potentially devastating. Removal of EVD also poses risk for hemorrhage. In a retrospective study of 482 EVDs by Miller et.al, hemorrhage was seen in 22.5% of those patients who underwent post EVD neuro imaging. Factors associated with hemorrhage included bedside placement of EVD. Interestingly the investigators were unable to demonstrate impact of INR value, platelet count, and antiplatelet agents on incidence of hemorrhage. Proposed mechanisms of hemorrhage associated with removal of EVD include; injury to and release of any tamponade effect on a small vessel, tracking of scalp bleeding along EVD track, and possible adherence of EVD to choroid plexus that may be contribute to bleeding on removal. Majority of the hemorrhages in this series were small and asymptomatic.

Hemorrhagic complications associated with chemical prophylaxis against venous thromboembolism

Contrary to popular concern, chemical prophylaxis against venous thromboembolism, started within 24 hours of admission and therapeutic heparinization initiated within 24 hours of placement of the EVD does not increase bleeding risk. The incidence of hemorrhage during removal of EVD
can be higher than during placement, and similar indices of coagulopathy must be maintained prior to removal of EVD.

**Placement of LD in patients requiring systemic anticoagulation**

Placing a LD in an anesthetized patient is safe, even in patients requiring subsequent heparinization and cardiopulmonary bypass. The risk of hematoma and neurological injury is rare, and can be minimized by following certain guidelines, i.e. delaying surgery 24 hours in the event of a traumatic tap (blood freely aspirated), delaying heparinization for more than 60 minutes after catheter insertion, and maintaining tight perioperative control of anticoagulation. Neuraxial hematoma associated with placement or removal of a lumbar drain is a rare but potentially serious complication. The reported incidence of surgical decompression required after epidural catheterization varied between 1/22,189 and 1/4330 in a cohort of 62,450 non-aortic surgery patients. Of note, four of the seven patients who developed a neuraxial hematoma had perioperative anticoagulation management deviated from current ASRA guidelines.

There are limited data on the incidence of neuraxial hematoma associated with lumbar drains during aortic surgery requiring systemic anticoagulation, but has been reported as between 0 and 4%. 67,72,73

A summary of the ASRA guidelines pertinent to lumbar drains and Neurocritical Care Society’s (NCS) consensus statement on management of
EVD can be found in the supplement document attached to the guidelines. (Refer to Supplement 1)

(1.4.2b) Infectious complications

Infections associated with EVD (0-28%) and LD (0-50%) are amongst the most serious of complications. Factors associated with increased infection risk include non-tunneled catheters, non-sterile conditions, intraventricular hemorrhage, frequent sampling, irrigation of catheters, and longer in-situ duration. Adherence to an aseptic technique, i.e. cleansing the insertion site using an antimicrobial agent per local antibiogram, and using a dressing as a part of a management bundle, institution of pre-EVD-insertion antibiotics, using antimicrobial-impregnated catheters whenever possible, avoiding routine CSF sampling, and limited manipulation of the CSF collecting system all feature in the recommendations provided in the recently published NCS consensus statement on EVD insertion and management. To limit potential for clostridium difficile diarrhea and antimicrobial resistant organisms, as well as lack of efficacy, antibiotics are not routinely recommended for the duration of the EVD.

Although there are no guidelines or consensus statements regarding intraoperative peri-procedural administration of antibiotics prior to lumbar drain placement for aortic and non-aortic surgery, this task force recommends
following standards similar to those employed for EVD insertion and management.

(1.4.3) Summary

While there are many indications for the placement of EVD or LD; it is critical to monitor intracerebral or intraspinal pressure. Thorough knowledge of indications, contraindications, complications and cautions associated with the monitoring modality, along with strict adherence to local, national and international standards will likely enhance patient safety.

Prevention of Hemorrhagic and Infectious Complications Associated with External Ventricular and Lumbar Drains. Class of Recommendation and Level of Evidence:

1. Prior to insertion of EVD and LD, prompt diagnosis and correction of coagulopathy utilizing institutional practice guidelines is recommended (Class I Recommendation; Level of Evidence E).

2. Perioperative anticoagulation management with lumbar drain placement and removal during aortic or non-aortic surgery should be performed within the framework of the current ASRA guidelines (Class I Recommendation; Level of Evidence E).

3. Antibiotics should only be administered prior to placement of an EVD and LD with the choice based on institutional practice (Class I Recommendation; Level of Evidence E).
4. It is recommended to practice strict aseptic technique based on national and institutional guidelines (Class I Recommendation; Level of Evidence E).

Section 2: Preoperative Evaluation of Patient with EVD and LD

(2.1) Background

A thorough pre-anesthetic evaluation of patients with EVD and LD is critical for optimal perioperative care. Table 4 describes components of history, physical examination, laboratory, and imaging data that should be incorporated into the preanesthetic assessment.

Parts of evaluation that are unique to EVDs include reviewing indication for placement, relevant history, medications given, ICP trends, qualitative evaluation of components of ICP waveforms, and any data available from EVD clamp trials. P1: P2 wave form evaluation would be significant to understand ICP compliance curve, and EVD clamp trial data would be significant to understand impact of EVD clamping on ICP during patient transport.

Table 4

Preoperative Assessment of Patients with External Ventricular and Lumbar Drain

<table>
<thead>
<tr>
<th>History</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis</td>
<td>SAH, ICH, IVH, AIS, TBI, skull base</td>
</tr>
<tr>
<td><strong>Medications</strong></td>
<td>Anticoagulant drugs, antiplatelet drugs</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td><strong>Liver or renal disease</strong></td>
<td>Associated with coagulopathy</td>
</tr>
<tr>
<td><strong>Cancer or hematological disorders</strong></td>
<td>Associated with coagulopathy</td>
</tr>
<tr>
<td><strong>Physical examination</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Vital signs</strong></td>
<td>SpO2, PO2, EtCO2, PCO2, MAP, CPP</td>
</tr>
<tr>
<td><strong>ICP data</strong></td>
<td>ICP range, ICP waveform, P1: P2 ratio</td>
</tr>
<tr>
<td></td>
<td>EVD clamp trial results</td>
</tr>
<tr>
<td><strong>CSF data</strong></td>
<td>Hourly CSF output, output over 24 hours,</td>
</tr>
<tr>
<td></td>
<td>Color of CSF (clear, xanthochromia, bloody, etc.)</td>
</tr>
<tr>
<td><strong>Multimodal monitoring data</strong></td>
<td>Pbto2, micro dialysis, and autoregulation studies</td>
</tr>
<tr>
<td><strong>Focused neurological examination</strong></td>
<td>GCS, FOUR score, cranial nerve paresis brain stem reflexes, presence or absence of focal neuro deficits</td>
</tr>
<tr>
<td><strong>Inspection of EVD or LD system</strong></td>
<td>Tunneled catheter system</td>
</tr>
<tr>
<td></td>
<td>Setting of EVD with reference to zero</td>
</tr>
<tr>
<td></td>
<td>Leveling of EVD at EAM</td>
</tr>
<tr>
<td></td>
<td>Leveling of LD at phlebostatic axis / EAM</td>
</tr>
<tr>
<td><strong>Laboratory data</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Complete blood count</strong></td>
<td>Correct thrombocytopenia</td>
</tr>
</tbody>
</table>
### Abbreviations


### (2.2) Inspection of the EVD or LD system

Inspection of EVD and LD system must be performed to provide information regarding (1) integrity of the system, (2) color, consistency of CSF, and (3) leveling and zeroing of the transducer system.

Baseline color, consistency of CSF, presence of air bubbles or debris, should be noted in the catheter and the burette (rather than the collecting bag),

<table>
<thead>
<tr>
<th><strong>PT, INR, PTT</strong></th>
<th>Prompt reversal of coagulopathy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Imaging data</strong></td>
<td></td>
</tr>
<tr>
<td>CT or MRI findings</td>
<td>Site and location of EVD</td>
</tr>
<tr>
<td></td>
<td>Midline shift, cerebral edema</td>
</tr>
</tbody>
</table>
and sudden change in color of CSF at any given time deserves attention (see section 5 for further details).

EVDs are leveled at the external auditory meatus using either a Carpenter’s bubble or a laser level. Lumbar drains on the other hand are leveled at the right atrium (phlebostatic axis) or at the lumbar catheter insertion site.

(2.3) Understanding “drain dynamics” or “setting of EVD and LD”

CSF drainage via EVD and LD is performed under controlled conditions to prevent over drainage. Establishing CSF drain volume goals is an important part of this with a goal of 10-20 milliliters/hour as this is the typical hourly CSF production and volume that resides in the ventricular system.\textsuperscript{126} To avoid over-drainage, bridging vein tear, and ultimately subdural bleed, drainage of EVD/LD greater than 15-20 ml in any hour should accompany consultation of a neurosurgeon. The bedside notes should clearly indicate if the goals are hourly drainage of certain predetermined CSF volume or if ICP data are allowed to drive the drainage volume.

Setting of EVD depends upon indication for placing catheters. In patients with aneurysmal SAH, EVDs are typically set at + 20 cm H20, prior to clipping or coiling of ruptured cerebral aneurysm, and EVD setting is lowered to + 10 cm H20 after aneurysm repair has been completed. While these are arbitrary numbers, clinicians involved in perioperative care must familiarize themselves to their respective institutional practices. Sudden over drainage of CSF in a patient with unsecured ruptured cerebral aneurysm predisposes to rebleeding due to
sudden widening of transmural pressure gradient (MAP-ICP) across the aneurysm wall.  

In patients with ICH, EVDs are set to provide drainage so that an intra-ventricular clot does not develop by stasis, and thus avoids blocking ventricular system passages and egresses that lead to non-communicating hydrocephalus and impending herniation.  

(2.4) Results of clamping trials

EVDs and LDs are routinely clamped during change in patient positioning, such as occurring during turning patients in the intensive care unit, getting patients out of bed to chair or during ambulation, and remains the recommended standard of practice.  

Tolerance of patients to any period of clamping depends upon the primary reason for placement of EVD or LD, ICP trends, and dependency on external CSF diversion. Patients at risk for clamp failure include those dependent on external CSF diversion, such as occurring with acute hydrocephalus, and in situations of elevated intracranial pressure.  

The preoperative evaluation of all patients with an indwelling EVD/LD should also include clinical (worsening headache, depressed level of consciousness, cranial nerve deficits, ICP elevation) and radiographic findings (worsening hydrocephalus) that confirm clamping trial tolerance.
While clamping trials are performed periodically, they are not standardized, and initiation and frequency of such trials vary in different institutions. It is imperative that any clamping trial data be sought for and documented in the preoperative evaluation to ensure that clamping can be safely done during patient transport to and from the operating room, and in the operating room.

(2.5) Importance of ICP and Multimodality Monitoring Data

Often, ICP monitoring and CSF drainage is part of a multi-modal monitoring plan, that includes brain tissue oxygenation, brain temperature, and continuous electroencephalography (c-EEG).

The analysis of the continuous ICP waveform can give indications of cerebral dysfunction. Normal ICP waveform has three components; P1 (percussion wave), P2 (tidal wave), and P3 (dicrotic wave). The P1 wave is the tallest and the sharpest wave, and results from arterial pressure being transmitted from the choroid plexus. The P2 wave follows P2, and is usually 80% as tall as the P1 wave, and correlates to brain compliance. The P3 wave is caused by closure of the aortic valve. (Refer to figure 1a)

Figure 1a

Normal ICP waveforms
P1 Percussion wave, reflections off choroid plexus

P2 Tidal wave, indicates brain compliance

P3 Dicrotic wave, correlates to closure of aortic valve

P1 wave is the tallest, sharpest wave

P2 wave is no greater than 80% of the P1 wave

**Figure 1 b**

**Abnormal ICP waveforms**
Note here that P2 wave is higher than P1, which may indicate reduced cerebral compliance.

**Abbreviations:**

*ICP*: intracranial pressure

Certain patients may have an abnormally high P2 waveform (refer to figure 1b) demonstrating poor compliance. In this case, the compensatory mechanism defined by the compliance curve in the Monro-Kellie doctrine may be exhausted at a lower ICP than expected. Certain patients may have an abnormally high P2 waveform demonstrating poor compliance requiring therapy. In this case, the compensatory mechanism defined by the compliance curve in the Monro-Kellie doctrine may be exhausted at a lower ICP than expected. In the noncompliant brain, this reflection is stronger than the initial energy pulse P1 where as a normally compliant brain will absorb the energy generating a less intense P2 response. Dampened waveform can be observed in patients with cerebral vasospasm, post-craniectiontomy, and other skull-fusion defects.

The preoperative evaluation of all patients with an indwelling EVD/LD should include recent ICP values, trends, indices, and relationship with CPP and other multimodality values made available.

*(2.6) Summary*

To safely conduct an anesthetic on a patient with CNS injury or risk thereof, a thorough preoperative evaluation should include any and all important details of
the EVD and LD management. Communication with the intensive care / ward staff and a thorough investigation of the ICP and other multi-modal monitoring data and EVD / LD drain settings is paramount.

Preoperative Assessment of Patients with External Ventricular and Lumbar Drains. Class of Recommendation and Level of Evidence:

1. A thorough preoperative evaluation should be performed in all patients with an indwelling EVD and LD that includes a focused history and physical exam (*Class I Recommendation; Level of Evidence E*).

2. Recommended preoperative evaluation of all patients with an indwelling EVD and LD should include all of the following (*Class I Recommendation; Level of Evidence E*).
   
   a. CSF color and consistency.
   
   b. ICP values, ICP trends, autoregulation indices, and relationship with CPP and other multimodal monitoring data.
   
   c. Clinical (worsening headache, depressed level of consciousness, cranial nerve deficits, ICP elevation) and radiographic evidence of clamp trial tolerance (worsening hydrocephalus).

3. Incorporate all information pertinent to the EVD and LD into a standardized preoperative handoff between intensive care unit / ward providers and anesthesia providers (*Class I Recommendation. Level of Evidence E.*)
Section 3: Transporting Patients with External Ventricular Drains (EVD)

(3.1) Introduction

Neurocritically ill patients with indwelling EVDs frequently require transport from the intensive care unit to other sites for diagnostic and/or therapeutic procedures. These patients may be at risk of intracranial complications such as high intracranial pressure (ICP) during intrahospital transport (IHT) because of direct patient movement and stimulation and/or discontinuation of ICP treatment. However, change in patient position can also lead to CSF overdrainage and result in complications such as re-bleeding of intracranial aneurysm \(^{130-132}\), subdural hemorrhage from disruption of bridging veins \(^{80-82}\) and reverse brain herniation. \(^{92}\) Anesthesiology providers are often involved in the transport of these patients to and from the ICU and to angiography and or to and from the operating room. There are no guidelines regarding EVD management during IHT.

(3.2) Background

The majority of guidelines for the transport of critically ill patients, including those with ICP monitoring lack recommendations specific to EVD management. \(^{133-137}\) The American Association of Neuroscience Nurses Guideline recommends routine clamping of EVD prior to and during IHT to prevent CSF overdrainage but does not address ICP monitoring or documentation during IHT.
The lack of recommendations regarding EVD management is problematic because published studies document several complications associated with IHT of neurocritically ill patients, including unwanted alteration in systemic blood pressure, respiration and neurologic conditions.\textsuperscript{138-141} Andrews et al. prospectively observed 50 IHTs of patients with traumatic brain injury who underwent computed tomography scanning, magnetic resonance imaging, and transport to the operating room. Investigators reported high ICP as the most common secondary insult (16\%) during IHT.\textsuperscript{142} Picetti et al. conducted a prospective observational study of 160 neurocritically ill patients undergoing 288 CT transports; 32\% of these IHTs were associated with EVDs.\textsuperscript{143} Although ICP was monitored in only 32 of the 127 patients with pre-transport ICP monitoring, the incidence of ICP > 20mmHg was high (66\%). However, neither of these two studies distinguished between ICP monitoring types. Moreover, in a case series of 7 patients with indwelling EVDs who were transported for CT, there was a 27\% increase in average ICP from the initial value, and the highest ICP noted during CT exam was 35 mmHg. Kleffmann et al. recently published a prospective observational study of 56 IHTs to CT of 43 patients with ICP monitoring (50\% were EVD).\textsuperscript{144} The authors reported an 85 \% increase in average ICP from baseline during CT scan and ICP therapy was required in 26\% of IHTs. Recently, Chaikittisilpa et al. reported on the largest series of 178 IHTs among 19 neurocritically ill cerebrovascular patients whose EVD were clamped prior to IHT.\textsuperscript{145} They reported that 12\% of IHTs were associated with post-IHT high ICP.\textsuperscript{21} ICP complications were only observed among IHTs of patients who had an open
EVD setting in the intensive care unit prior to transport. Pre-IHT ICP values 15-19 mmHg (odds ratio, 3.4 (1.08-10.76), Pre-IHT ICP values greater than or equal to 20 mmHg (odds ratio, 12.94 (4.08-41.01), IHT for therapeutic procedure (odds ratio, 5.82 (1.76-19.19) and high hourly CSF output (odds ratio for every ml/hour, 1.11 (1.01-1.23)), are risk factors for ICP-related complications during IHT.

While these guideline focuses on perioperative management, the transport recommendations should be applicable to all IHTs. Personnel accompanying patient during transport should be trained and competent in management of intracranial hemodynamic perturbations such as intracranial hypertension and cerebral hypoperfusion.

(3.3) Summary

Best evidence from observational studies suggests that neurocritically ill patients with indwelling EVDs are at risk of intracranial hypertension during IHT. Routine clamping of EVD for IHT may predispose the patients to intracranial complications, particularly in patients with open EVD status prior to IHT, and those with pre transport ICP greater than 15 mmHg, and high hourly CSF output in the intensive care unit. Patients with lumbar drains may experience similar complications but there are no data specific to IHT among patients with lumbar drains.

Transporting Patients with Indwelling External Ventricular Drains. Class of Recommendation and Level of Evidence:
1. While transporting patients with EVD and LD, it’s recommended to use a dedicated intravenous pole to mount the transducer and drainage system (Class I Recommendation; Level of Evidence E).

2. Do not routinely clamp EVD during intrahospital transport. The decision whether to open or clamp EVD for intrahospital transport should be individualized. Factors in pre-transport evaluation that may influence decision to travel with EVD open or clamped to cerebrospinal drainage (CSF) include: (1) hourly and daily CSF output and setting of EVD; (2) EVD clamp status in the intensive care unit; (3) patient’s tolerance to clamping of EVD in intensive care unit, and (4) reason transport is undertaken (diagnostic vs. therapeutic procedure). Test tolerance to EVD clamping prior to making clamping decision as patients at high risk for high ICP may benefit from opening of EVD during intrahospital transport (Class I Recommendation; Level of Evidence B-NR).

3. If the EVD is clamped during transport, clamping should be undertaken at two sites (1) proximal port on the EVD, and (2) distal port on collecting system of EVD (Class I recommendation, Level of Evidence E).

4. It is recommended to continue all pre-transport intensive care unit monitoring, including intermittent clamping of EVD for accurate ICP monitoring, and documentation of ICP and other vital signs including
end-tidal carbon dioxide during intrahospital transport (*Class I Recommendation; Level of Evidence B-NR*).

5. Transport personnel should be prepared to treat intracranial hypertension in patients with indwelling EVDs during intrahospital transport (*Class I Recommendation; Level of Evidence E*).

Section 4: Intraoperative Management of EVD and LD

(4.1) Introduction

EVD and LD function as diagnostic and therapeutic devices, and planning for a procedure requires knowledge of the basic goals of management. Addition of a pressure transducer allows monitoring and waveform display of the ICP or intraspinal pressure (ISP).

(4.2) Setting up an EVD or LD System in the Operating Room

Some aspects of EVD or LD use can be idiosyncratic for the specific device (Figures 2a and 2b). Consistency within an institution is important for choices such as the reference level and measurement scale. The reference level is most commonly the external auditory meatus for external ventricular drains. However, this convention is not followed rigorously in clinical practice and published studies 94,146 which can lead to significant measurement errors if the head of the bed is elevated above zero degrees 147. For vascular surgery patients with lumbar drains, common reference levels include the right atrium (phlebostatic axis) or lumbar catheter insertion site. The reference level is the zero pressure point for both any attached transducer and also the EVD/LD. The device is leveled by
aligning the zero pressure point on the device with the reference level on the patient; this is more accurate when a Carpenter's (bubble) or laser level is utilized.\textsuperscript{148,149}

A flushless pressure transducer (Figure 2b) is used with EVD/LD that is connected to the patient via a fluid column. This is the most common configuration with the transducer located externally on the device and measurement of the ICP or ISP via the fluid column in the drainage catheter.\textsuperscript{150,151} In stark contrast to commonly used transducer based monitoring systems such as invasive arterial blood pressure, central venous or pulmonary artery catheter, this flushless system is not pressurized in any way. Under no circumstances should a pressure transducer system with a pressure bag be assembled or used in conjunction with EVD or LD.

**Figure 2a**

**Components of an External Ventricular Drain** (A representative example of anti-microbial impregnated external ventricular drain)
Figure 2 b

CSF Collecting System
Extra catheter systems are increasingly available and separate the pressure transducer from the drainage catheter by placing the transducer at the tip of the catheter. \textsuperscript{152,153} Intracranial pressure can also be measured separately from the EVD at a variety of anatomic sites utilizing several available technologies. \textsuperscript{11,150,151,154-156}

The following steps can be followed when setting up an EVD or LD intraoperatively: (Refer to educational document that accompanies this article)

1. Choose the appropriate reference level and measurement scale (cm H\textsubscript{2}O).

   The reference level is most commonly the external auditory meatus for external ventricular drains or the right atrium (phlebostatic axis) for vascular surgery patients who have lumbar drains.
2. Mount the device upright\textsuperscript{157} by attaching to an intravenous pole or to the patient’s bed. Make appropriate changes to the drainage system when the patient’s position changes relative to the drainage system. It is good practice to clamp the EVD or LD during changes in the position of the patient until it can be re-leveled.\textsuperscript{155,158}

3. Level the device by aligning the zero point of the device and the reference level on the patient either visually or using a Carpenter’s (bubble) or laser level.\textsuperscript{148}

4. Monitor ICP via EVD or ISP via LD with an attached transducer, if possible.

5. Adjust the collection chamber to the specified height based on the requirements of the procedure.

6. The fluid path of the EVD/LD is a sterile system. There should be a careful assessment of the risks/benefits before opening any of these systems to reduce the risk of infectious complications.

(4.3) EVD/LD Management during Changes in Position

The orientation of the patient can alter the ICP\textsuperscript{159-161} which must be accounted for in the management of EVD/LD. Intraoperatively there are frequent changes in the position of the patient such as moving the height of the table, altering the head elevation and others. In addition, there may be times when the position of the device is moved relative to the patient such as from one pole to
another. During such changes, it is good practice to clamp the EVD/LD if clinically feasible until the device and any attached transducer can be re-leveled. If changes in position are not accounted for then there is the risk of both over-drainage & under-drainage of CSF as well as inaccurate pressure measurements. Nevertheless, there are clinical situations such as impending herniation where it is not feasible to clamp the EVD/LD even briefly for position changes.

Positioning the patient for an intraoperative procedure is a unique phase of the case. The final patient position during the intraoperative procedure may be quite different from that in the intensive care unit or the ward. In addition, there are very significant and dynamic changes in CSF pressure with postural changes as might occur as the patient is moved between beds, turned prone and others to meet the requirements of the procedure. The EVD/LD should be closed to drainage during positioning if clinically feasible, and the management reassessed once in the intraoperative position.

(4.4) Inaccurate Pressure Measurements with Simultaneous Drainage

Transducers that measure pressure via the fluid column in the drainage catheter are always inaccurate if the EVD or LD is simultaneously open for drainage. For fluid-coupled systems, accurate pressure measurements require a static fluid column without simultaneous drainage allowing the transducer to directly interface with the patient line. This concern is relevant to transducers that are mounted externally as well as
transducers placed within the tip of the drainage catheter. While a value for ICP can be trended while the device is simultaneously draining, the EVD/LD should be closed for accurate measurement at least hourly. In some situations such as an anesthetized patient with elevated ICP, it would be indicated to obtain accurate pressure measurements more frequently than hourly.

Dramatic measurement errors are possible with transducers that measure with fluid-coupling while at the same time draining. Notable situations reported or discussed in the literature are compressed or slit ventricles, catheter blockage by debris or catheter dislodgement into the parenchyma. Accurately measuring the pressure by stopping drainage and connecting the transducer directly to the patient line can sometimes overcome this limitation.

(4.5) Continuous Drainage versus Continuous Monitoring

A common management decision is whether to utilize continuous drainage with intermittent monitoring (open EVD) versus continuous monitoring with intermittent drainage (monitor EVD). Continuous drainage impacts the ability of the EVD as a monitor to detect trends. The decision to choose a specific management option is dependent on the indication for drain placement and close consultation with the surgical team is important. In adult severe TBI, continuous drainage (open EVD) has been associated with better ICP control, but in patients with aneurysmal SAH, open EVD management is associated with a higher rate of complications.
(4.6) Documentation on anesthesia record for patients with EVD or LD

There are five items that should be documented in the anesthesia record in patients with EVD or LD.

1. Pressure = ICP / CPP or intraspinal pressure (ISP)/ spinal cord perfusion pressure (SCPP)

2. Amount of CSF drainage (expressed in ml)

3. Color of CSF and any change in color of CSF observed during the procedure

4. Drain height relative to the reference level

5. EVD / LD status as set by the stopcocks in the device (i.e. open, clamped)

These items should be recorded at least hourly, however, it is reasonable that frequency of ICP documentation follow clinical situations, since, changes in ventilation, exposure to anesthetics and hemodynamic changes all cause frequent perturbations in ICP and CPP. In such clinical scenarios, it may be desirable to document ICP more frequently such as every 5 to 15 minutes. CSF characteristics such as color, and any sudden change in color including the presence of blood should also be documented. 128,155,172,173

With an electronic health record that automatically imports patient data, care should be exercised to prevent inaccuracies. 170  This may occur due to
technical issues with the monitoring system or if automatic systems continue to import inaccurate data such as when the EVD system is open for continuous drainage.

(4.6) Summary

Intraoperative management of EVD and LD includes review of basic management goals, knowledge of the device in use, and the ability to make accurate measurements. This section includes recommendations for preparing the EVD/LD, device management during positioning, and best practice for documentation in the anesthetic record. There is also a discussion of inaccuracies that arise with traditional fluid-coupled systems if simultaneously open for drainage, and evidence that is accumulating for various management strategies.

Intraoperative Management of Patients with External Ventricular and Lumbar Drains. Class of Recommendation and Level of Evidence:

1. Anesthesia providers should be knowledgeable about the specific EVD and LD device in use locally as details vary- *(Class I Recommendation; Level of Evidence E).*

2. It is recommended to set up your anesthetizing location following the standards of your institution including a consistent choice of reference
level and measurement scale (*Class I Recommendation; Level of Evidence E*).

3. It is recommended to level EVD or LD using a Carpenter’s (bubble) or laser level rather than by visual inspection (*Class I Recommendation; Level of Evidence B-NR*).

4. It is recommended to close the EVD/LD to drainage during any changes in position if clinically feasible (*Class I Recommendation, Level of Evidence C*).

5. It is recommended to re-level the transducer after changing patient position to ensure accurate monitoring of intracranial pressure and adequate drainage of cerebrospinal fluid (*Class I Recommendation; Level of Evidence C*).

6. It is recommended to monitor intracranial or intraspinal pressure with an attached transducer that is appropriately leveled and zeroed according to manufacturer guidelines (*Class I Recommendation; Level of Evidence E*).

7. A pressure bag and pressurized flush system should not be attached to the EVD/LD (*Class III; Level of Evidence E*).

8. Pressure measurements should not be made while the EVD or LD is simultaneously draining. Accurate pressure measurements require a static fluid column from the monitoring site to the externally mounted transducers without simultaneous drainage (*Class III Recommendation; Level of Evidence B-NR*).
9. If open for continuous drainage, it is recommended to close the EVD or LD to measure pressure at least once per hour or more often if clinically indicated (Class I Recommendation; Level of Evidence E).

10. The decision for either continuous drainage or continuous monitoring should be made in consultation with the surgical team. Continuous monitoring with intermittent drainage may be considered in patients with aneurysmal SAH, and continuous drainage may be considered for adults with severe TBI (Class IIb Recommendation: Level of Evidence B-R).

11. It is recommended to document the following information pertinent to EVD and LD on the anesthesia record at least hourly: (Class I Recommendation: Level of Evidence E) (1) Pressure = ICP/CPP or intraspinal pressure (ISP)/ spinal cord perfusion pressure (SCPP), (2) Amount of CSF drainage (expressed in ml), (3) Color of CSF and any change in color of CSF observed during the procedure, (4) Drain height relative to the reference level, and (5) EVD / LD status as set by the stopcocks in the device (i.e. open, clamped)

Section 5: Management of EVD and LD in Special Clinical Scenarios

(5.1) Background

Despite careful maintenance and vigilance, complications may arise given the invasive nature of the devices. EVD and LD need monitoring with the same
attention provided to other invasive monitoring devices. Safety can be enhanced through the use of dedicated protocols and bundles that standardize the handling of EVD and LD.

(5.2) Accidental Disconnection of EVD and LD

As an immune privileged organ, the brain is at high risk for infections from bacterial contamination of drainage devices. Standardized bundles for EVD placement have significantly reduced rates of ventriculitis/meningitis associated with EVD placement.\textsuperscript{174,175} Relevant guidelines were recently published by the Society for Neurocritical Care and emphasize the importance of maintaining a closed, sterile drainage system.\textsuperscript{8} If drains become inadvertently disconnected, the most immediate threat to the patient is from uncontrolled leakage of CSF as discussed below. A clamp should immediately be put on the free end of the catheter to stop leakage. As the system becomes contaminated by disconnection, all distal parts should be replaced with new, sterile tubing.\textsuperscript{128} As replacement of the proximal catheter carries new procedural risk\textsuperscript{128} it will not routinely be replaced after accidental disconnection. There is no evidence to support empiric antibiotic treatment after disconnection of an EVD or LD system. After a new system is connected, patency must be confirmed, especially in situations where the catheter may have been displaced. In doubt, CT imaging can confirm appropriate position of an EVD catheter.

(5.3) Drain Occlusion and Troubleshooting
No studies exist in the literature that compares methods to troubleshoot EVD or LD. Published recommendations represent expert opinion and practice surveys.\textsuperscript{128,149,175} Sudden reduction in the hourly volume of CSF drained can indicate an obstruction in the drainage system. Similarly, if the ICP waveform is dampened, the EVD may be occluded.\textsuperscript{176} Patency can be tested by briefly lowering the drainage system. This may also be sufficient to remove small amounts of material such as air bubbles, blood clots, or tissue that may obstruct the tubing. If patency is not restored by briefly lowering the system, troubleshooting should continue by examining the drainage tubing distal to the patient. If any occluding material is present, the tubing can be flushed away from the patient to remove the debris. Alternatively, the entire drainage system can be changed, if necessary. Occlusion of the proximal catheter can sometimes be resolved by flushing the catheter towards the patient. This may increase intracranial pressure (ICP), as the irrigation solution adds to the intracranial volume. In patients with poor intracranial compliance, irrigation with even small volumes can create disproportionately large and dangerous increases of ICP, possibly causing brain herniation. Proximal flushing should only be attempted after discussion with the neurosurgeon. Volumes of 0.5-2 mL of sterile, preservative free isotonic sodium chloride solution can be used to flush the EVD catheter, although a variety of antibiotic solutions are sometimes used as well.\textsuperscript{177} Maintaining aseptic conditions are essential. The technique should be guided by institutional protocol and include, as a minimum, sterile gloves, mask and hair
The drainage system should be re-leveled and re-zeroed after manipulation.

(5.4) Over Drainage of Cerebrospinal Fluid

Rapid drainage of large volumes of CSF from the ventricles (i.e. more than the 15-20 ml produced in an hour) can collapse the ventricles (especially when communication to the extra ventricular subarachnoid space is compromised, as in non-communicating hydrocephalus), thus shrinking the cerebral hemispheres away from the skull and dura. This creates tension on the bridging veins and can cause acute subdural hematomas. In patients with aneurysmal subarachnoid hemorrhage and an unsecured aneurysm, rapid drainage of CSF while the dura is closed can increase the transmural pressure of the aneurysm and provoke re-bleeding. Over drainage from an EVD occurs most commonly when the patient’s position is changed (e.g. the head of the bed or operating table is raised) without simultaneously adjusting the position of the EVD drainage system. Drainage systems should be clamped whenever patient position is changed. Patients with critically elevated intracranial pressure may not tolerate even brief clamping of their EVD during transport, in which case extra care needs to be taken to secure the drainage system to the bed, and to monitor output. Once a new position is achieved, the drain should be re-leveled and re-zeroed.

Inadvertent over drainage of significant amounts of CSF is a more common problem with lumbar drains, as they are more prone to covert leakage of CSF around the drain or through a persistent dural defect after removal. There are
many case reports describing complications from over drainage related to lumbar drains. The most serious complication is herniation, which is more likely to occur when there is a differential in intracranial and spinal CSF pressure. Acute herniation from lumbar over drainage of CSF can present with cranial nerve deficits, hypertension, or bradycardia, and can lead to brainstem hemorrhage. It can often be corrected by lowering the head of the bed to Trendelenburg position. Injection of sterile isotonic saline solution into the lumbar drain to replace lost CSF has also been used as an emergency intervention. Patients after decompressive hemicraniectomy are at increased risk for paradoxical herniation from lumbar drainage of CSF. Their skull defect exposes the brain to ambient pressure, so that relatively small decreases in CSF pressure can cause significant brain sag and herniation (“syndrome of the trephined”). Tension pneumocephalus and subdural hematoma from brain sag have also been described as complications from lumbar drains.

(5.5) Cerebrospinal fluid drainage at different points during a case (e.g. before craniotomy bone flap, before dural reflection, post durotomy, or after dural closure)

Lumbar drains are often placed electively for procedures that carry a risk of postoperative CSF leak, such as skull base surgery. They are used to drain CSF and improve exposure during the procedure, and 10-20 mL of CSF are usually drained immediately before durotomy to “relax” the brain, while the drain remains clamped for the rest of the procedure. Lumbar drains are also used to reduce CSF pressure and optimize spinal cord perfusion pressure during repair
of thoracoabdominal aortic aneurysms (TAAA). CSF is usually drained to a pressure goal, e.g. 10 mmHg of CSF pressure (zeroed at the right atrium). Use of CSF drainage for spinal cord protection during TAAA repair has recently been reviewed\textsuperscript{195,196}, and is not the focus of the current document.

EVDs are not commonly placed for intraoperative CSF drainage, but rather to treat ICP elevation caused by non-communicating hydrocephalus. Most patients will come from the intensive care unit with an EVD in place. CSF can be drained from an EVD to reduce intracranial pressure and improve surgical conditions, similar to a lumbar drain, with the difference that if the patient has non-communicating hydrocephalus, CSF will be removed only from the intraventricular space. Rapid removal of a large volume of CSF will cause sudden decrease in ICP and can cause subdural hematoma, as discussed above. In patients with aneurysmal subarachnoid hemorrhage, sudden CSF drainage before durotomy in patients can result in precipitous decrease in ICP and widening of transmural pressure gradient and can cause fatal re-rupture of cerebral aneurysm and should be avoided.\textsuperscript{197}

\textbf{(5.6) Monitoring, and Patient Safety}

Changes in EVD output can provide important clues into changes in patient condition. Increasing output can indicate an increase in intracranial volume from edema or hemorrhage, or rising intracranial pressure. Bright red output from an EVD suggests an intraventricular or subarachnoid hemorrhage, such as from re-rupture of an unsecured aneurysm. This is a life-threatening emergency, and
thus should be communicated immediately to the surgical team. Alternatively, blood from a previous intraventricular hemorrhage may have been mobilized and transiently color the CSF more brightly red. While this is a much more benign scenario, suspicion should remain high for a fresh hemorrhage, especially if there are changes in vital signs, such as hypertension or bradycardia, or if ICP increases. Close communication is key to safe management.

(5.7) Avoiding accidental injections into EVD or LD

EVD tubing routinely has at least one three-way stopcock that allows access to the system. Commonly used EVD systems use the Luer-lock standard and most EVD tubing is not specifically marked to differentiate it from intravenous tubing. This creates the opportunity for providers to inadvertently inject drugs into the ventricular system that are meant for intravenous use. There are many case reports and case series that describe accidental intrathecal injection of agents as varied as anesthetic drugs, antibiotics, chemotherapeutic agents, or gadolinium contrast, frequently with devastating or fatal consequences. Care should be taken to prevent this severe complication by carefully labeling EVD tubing and access ports, and using color-coded caps (Please refer to educational document that accompanies this publication). In the future, manufacturers should design access ports that cannot be confused with intravenous access ports, similar to the safety pin system used for anesthetic gases. Treatment of accidental intrathecal injection is supportive. Aspiration of CSF and replacement with isotonic sodium chloride to “lavage” the intrathecal space has been suggested as an emergent intervention to reduce neurotoxicity,
especially when caustic agents such as chemotherapeutic drugs have been injected inadvertently.\textsuperscript{100,101} No controlled studies exist, however, and success of this intervention is mixed in reported cases.

*Intrathecal injection of fluorescein dye for CSF leak*

Intrathecal injection of fluorescein dye through the lumbar drain is sometimes indicated intraoperatively during repair of cerebrospinal fluid leaks to identify the location of actual defect. In addition, it is useful to assist in locating additional leak sites and also to confirm the watertight closure of the defect. Though it has been used worldwide for this purpose, the intrathecal fluorescein is an off-label use of the product; hence, informed consent is required in many centers.

The usual dose range used is 10-50 mg (0.1-0.5 ml of 10\% fluorescein with 9.5 ml of CSF) injected over 30 minutes.\textsuperscript{198} Complications are mostly related to meningeal irritation that include headache, nausea and vomiting, dizziness, nuchal pain, limb weakness, generalized seizures\textsuperscript{199} and cranial nerve palsy. Most complications are dose related and transient; typically resolve within 7-10 days. Limited evidence suggests that fluorescein injection should be avoided in patients with history of seizures, hydrocephalus, spinal stenosis and cerebral edema. We strongly recommend that individual institutions should develop their own protocols for intrathecal administration of fluorescein.

(5.8) **Summary of Management of External Ventricular and Lumbar Drains in Special Clinical Scenarios**
Due to invasive nature of these devices, complications that occur perioperatively that include accidental disconnection, drain occlusion, over drainage and inadvertent administration of drugs into the drains. Extra vigilance, clear labeling of the drains and the development of standardized protocol on the handling of EVD/LDs are some of the measures that can minimize these complications.

Management of EVD and LD in Special Clinical Scenarios. Class of Recommendation and Level of Evidence:

1. EVD or LD tubing that is accidently disconnected should be clamped immediately to prevent overdrainage of cerebrospinal fluid (Class I Recommendation; Level of Evidence C).

2. If the EVD or LD systems are contaminated by disconnection, all distal parts should be replaced with new sterile tubing (Class IIa Recommendation; Level of Evidence E).

3. Routine flushing of the EVD or LD catheter should not be performed (Class III Recommendation; Level of Evidence E).

4. In patients with ruptured cerebral aneurysm, sudden excessive drainage of cerebrospinal fluid prior to securing the aneurysm can provoke aneurysm re-rupture and should be avoided (Class III Recommendation: Level of Evidence C).
5. Identification of EVD or LD tubing by appropriate labels and use of other visual aids is recommended to prevent confusion with intravenous ports (Class I Recommendation; Level of Evidence E).

6. Accidental intrathecal injection should be recognized and reported to the neurosurgeon (Class Ila Recommendation; Level of Evidence E).

7. Lavage of the intrathecal space after accidental injection is not recommended (Class III Recommendation; Level of Evidence C).

8. Establish institutional standards to ensure safe intrathecal injection of fluorescein dye via lumbar drain in patients with suspected cerebrospinal fluid leak (Class I Level of Recommendation, Level of Evidence E).

Section 6: Perioperative Checklist, Developing Clinical Competencies for EVD/ LD and Continued Medical Education

(6.1) Use of a Perioperative EVD and LD checklist

The material presented above provides a framework from which a perioperative checklist can be constructed. Such a checklist (Table 5) incorporated into a shared mental model \(^{200-202}\) is intended to reduce systematic errors during perioperative management of patients with EVD or LD. This perioperative checklist can be used for all patients undergoing perioperative care, and may be included in pre-operative handoffs between intensive care unit (ICU)
/ ward providers and anesthesia providers, and during intraoperative handoffs between various anesthesia providers. Checklist can be modified and used during intrahospital transport of neurocritically ill patients.

**Table 5**

**Perioperative Checklist for Patients with External Ventricular and Lumbar Drain**

<table>
<thead>
<tr>
<th>Preoperative assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Obtain baseline neurological examination</td>
</tr>
<tr>
<td>☐ Review EVD (cmH20) &amp; LD setting (in ml/hr of CSF drained)</td>
</tr>
<tr>
<td>☐ Review hourly CSF output to obtain baseline</td>
</tr>
<tr>
<td>☐ Review baseline ICP mmHg, ICP trends, and available multimodal monitoring data</td>
</tr>
<tr>
<td>☐ Review baseline CSF color and consistency</td>
</tr>
<tr>
<td>☐ Review clamp trials data if available</td>
</tr>
<tr>
<td>☐ Review coagulopathy profile</td>
</tr>
<tr>
<td>☐ Review antibiotic plan if anticipating new EVD /LD insertion in the operating room</td>
</tr>
<tr>
<td>☐ Provide EVD and LD details during pre-operative handoff between intensive care / ward providers and the anesthesia providers.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transporting patients with EVD and LD</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Confirm decision to travel with EVD or LD clamp vs. open</td>
</tr>
<tr>
<td>☐ If travelling with EVD clamp, ensure clamping at both proximal port on EVD and distal port on CSF collecting system</td>
</tr>
<tr>
<td>☐ Confirm HOB status during transport</td>
</tr>
<tr>
<td>☐ Confirm availability of dedicated intravenous pole for EVD / LD mount</td>
</tr>
</tbody>
</table>
- Confirm leveling EVD at external auditory meatus & LD at phlebostatic axis or at lumbar catheter insertion site
- Enable ICP monitoring during transport
- Confirm availability of medications needed to treat intracranial hypertension during transport

**Intraoperative management of indwelling drains**

- Prepare transducer cable
- Identify EVD/ LD tubing by appropriate unique labeling
- Confirm HOB status during surgical procedure
- Confirm leveling of EVD at external auditory meatus & LD at phlebostatic axis
- Obtain ICP waveform & baseline ICP value
- Record q 1-hour EVD /LD setting
- Record at least q 1-hour ICP values (recorded with EVD closed to drain)
- Record at least q 1-hour EVD /LD drain output (expressed in ml)
- Provide EVD and LD details during intraoperative handoffs between anesthesia providers

**Inform surgeon if any one or more of the following**

- Sudden decline in CSF drainage or no drainage from EVD or LD, or occlusion of EVD or LD
- If drain output is greater than 15-20 ml at any time or in any given hour
- Sudden change in CSF color
- Dampening or loss of ICP waveform

**Abbreviations:**
EVD: external ventricular drain, LD: lumbar drain, ICP: intracranial pressure, CSF: cerebrospinal fluid, HOB: head-of-bed, cmH20: centimeters of water

(6.2) Clinical Competence and Continued Medical Education related to Management of Patients with EVD / LD

For clinicians involved in perioperative care of patients, one of the core competencies is the ability to administer safe and reliable care on a consistent basis. In relationship to patients with EVD and LD, this translates to acquiring knowledge about the basics of EVD and LD relevant to the perioperative period, at the same time, possessing essentially same skills as neuroscience nursing while managing these drains within confines of perioperative care.

While management of patients with EVD and LD may be expected from all clinicians involved in perioperative care of patients, there are lack of published perioperative guidelines and standards. However, there are various educational materials that are available on the World Wide Web that provide institutional guidance to practitioners regarding EVD and ICP monitoring. A comprehensive clinical competency checklist can be found in table 6.

Table 6

External Ventricular and Lumbar Drain Clinical Competency Checklist for Clinicians involved in Perioperative Care

<table>
<thead>
<tr>
<th>Name of Provider</th>
<th>Date</th>
<th>Validated by</th>
<th>Date / Initials of Validator</th>
</tr>
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<tbody>
<tr>
<td></td>
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<table>
<thead>
<tr>
<th>Steps</th>
<th>Date / Initials of Validator</th>
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</thead>
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<td></td>
<td></td>
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</tbody>
</table>
Has the anesthesia technician already tightened the connection between the bottom of the burette and the bag (loose from the manufacturer, similar to pressure tubing for arterial lines) and primed the system using sterile technique (wearing face mask, making sure not to touch sterile connections with bare hands or only clean gloves)? Only a flushless transducer system is used for EVD and LD.

**Leveling and zeroing external ventricular drainage system**

- Level flushless transducer and red “0” on drainage system at external auditory meatus (EAM). State why EAM level is typically chosen for neurosurgical CSF drainage systems (Answer: approximate level of Foramen of Monro, drainage channel between lateral ventricles).
- Raise burette to desired level (EAM or EAM+/- _____ cm H2O). State rationale (Answer: ICP must rise above pressure level indicator of drip chamber to drain CSF).
- Turn stopcocks on patient line off until ready to connect and drain.
- Use sterile technique to connect ventricular catheter with CSF drainage system (face mask and sterile gloves).
- Once system is attached to ventricular catheter, attach pressure cable to flushless transducer. Open panel mount (reference) stopcock port to the right of the flushless transducer (remove injection cap); turn stopcock off to the patient and open the system to air. Press, “zero” on bedside monitor. When monitor says “0,” return stopcock, upright, and replace injection cap.

**Monitoring Intracranial Pressure and Draining CSF**

- Demonstrate correct position of stopcock to monitor true ICP (not trend); (Answers: stopcock should be at 12 o’clock) state requirements of for true ICP determination (Answer: corresponding waveform and numeric display; ICP is a mean value in mm Hg).
- Demonstrate correct position of stopcock to trend ICP (not true ICP) and
<table>
<thead>
<tr>
<th>Complications of External Ventricular Drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ State common complications of external ventricular drainage:</td>
</tr>
<tr>
<td>◦ (Answer: under drainage; overdrainage, infection, possibly rebleeding. Overdrainage may result in subdural hematoma or herniation)</td>
</tr>
<tr>
<td>□ State the usual recommended CSF drainage rate. (Answer 20 ml/hr.; adults make 500 ml/24 hours which is 22 ml/hr.; so drain the amount that is made in an hour)</td>
</tr>
<tr>
<td>□ State normal intracranial pressure. (Answer: less than 20 mm Hg)</td>
</tr>
<tr>
<td>□ State calculation of Cerebral Perfusion Pressure (CPP). (Answer: MAP-ICP = CPP. 60 mm Hg is generally considered acceptable.)</td>
</tr>
<tr>
<td>□ State that CSF drainage may be desired continuously or intermittently. Defer to neurosurgery; however, do not drain, in general over 20 ml/hr.</td>
</tr>
<tr>
<td>□ Record ICP/CPP and CSF output at least hourly in electronic record.</td>
</tr>
<tr>
<td>□ Why would it be bad practice to attach the transducer to a pressure bag setup? If so, the answer of course would be, you will deliver 3 ml/hr of fluid to an already tight space and if someone activates the fast flush, you could have sustained ICPs with herniation (EVD) or if a LD for Aortic Aneurysm repair, possibly create/increase spinal cord ischemia with paraplegia</td>
</tr>
</tbody>
</table>

**Transport**

□ Demonstrate position of CSF drainage system during transport and position of stopcock (Answer: CSF drainage system upright on IV pole, leveled;
flushless transducer zeroed with transport monitor and stopcock at 12 o’clock to allow accurate monitoring of ICP in transport but no drainage during transport) Only leave CSF drainage system open to transport if herniation is pending. If left open during transport must observe CSF drainage constantly and avoid overdrainage)
Has the anesthesia technician already tightened the connection between the bottom of the burette and the bag (loose from the manufacturer, similar to pressure tubing for arterial lines) and primed the system using sterile technique (wearing face mask, making sure not to touch sterile connections with bare hands or only clean gloves) Only a flushless transducer system is used for EVD and LD

**Leveling external lumbar drainage system**

- Level the red “0” on drainage system at phlebostatic axis.
- Raise burette to desired level (EAM or EAM +/- _____ cm H2O). State rationale (Answer: ICP must rise above reference level of drip chamber to drain CSF)
- Turn stopcocks on patient line off until ready to connect and drain.
- Use sterile technique to connect lumbar catheter with CSF drainage system.

**Draining CSF**

- Demonstrate correct position of stopcock to drain CSF
  - (Answer: 3 o’clock or 9 o’clock)
- Demonstrate correct position of stopcock to prevent drainage
  - (Answer: 6 o’clock and may also turn stopcock toward head at port on patient line closest to lumbar catheter).

**Complications of Lumbar Drainage**

- State common complications of lumbar drainage:
  - (Answer: under drainage; overdrainage, infection, possibly rebleeding.
    Overdrainage may result in subdural hematoma or herniation)
- State the usual recommended CSF drainage rate.
(Answer 10-15 ml/hr.; for a lumbar drain; the risk of herniation may be greater than with a lumbar drain related to downward pull of CSF drainage at the lumbar level)

- Record CSF output at least hourly in electronic record.
- Why would it be bad practice to attach the transducer to a pressure bag set up? If so, the answer of course would be, you will deliver 3 ml/hr of fluid to an already tight space and if someone activates the fast flush, you could have sustained ICPs with herniation (EVD) or if a LD for Aortic Aneurysm repair, possibly create/increase spinal cord ischemia with paraplegia.

### Transport

- Demonstrate position of CSF drainage system during transport and position leveled at EAM and turned off to drainage, stopcock at 12 or 6 o’clock).

This or a modification of this checklist may be used by institutions to establish competency standards for clinicians involved in perioperative care of patients with EVD and LD. It is recommended that institutions establish an annual evaluation of competency, a continued medical education program and a refresher course for all clinicians involved in perioperative care of patients with EVD and LD.

### (6.2) Summary

A clinical competency checklist comprising setting up and maintenance of EVD or LD, along with a comprehensive checklist covering pre-operative...
assessment, transporting patients, intraoperative management and evaluation of patient under special circumstances provides a framework to clinicians involved in perioperative care of patients with EVD or LD.

**Perioperative Checklist, Clinical Competency, and Continued Medical Education. Class of Recommendation and Level of Evidence:**

1. It is recommended that clinicians involved in perioperative care of patients must familiarize themselves with information regarding indications, contraindications, leveling, zeroing of transducer, and current standards related to transporting and intraoperative care of patients with EVD or LD (*Class I Recommendation; Level of Evidence E*).

2. It is reasonable to provide educational material aimed at perioperative management of EVD and LD in form of text and or multimedia to all clinicians involved in perioperative care of patients (*Class IIa Recommendation; Level of Evidence E*).

3. To standardize care of patients with EVD and LD, and to promote a shared mental model, use of a perioperative checklist is recommended (*Class I Recommendation; Level of Evidence E*).

4. It is recommended that institutions set up competency standards for clinicians involved in perioperative care of patients with EVD and LD (*Class I Recommendation; Level of Evidence E*).
Supplement 1

Summary of the American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (Third Edition) for Regional Anesthesia in the Patient Receiving Antithrombotic or Thrombolytic Therapy and Neurocritical Care Society’s Evidence Based Consensus Statement on Insertion and Management of External Ventricular Drains

The American Society of Regional Anesthesia and Pain Medicine (ARSA) Evidence-Based Guidelines (Third Edition) for Regional Anesthesia in the Patient Receiving Antithrombotic or Thrombolytic Therapy and Neurocritical Care Society’s (NCS) Insertion and Management of External Ventricular Drains: An Evidence-Based Consensus Statement have been summarized with reference to neuraxial and external ventricular catheter placement in patients with potential abnormalities in coagulation. The goals of the guidelines are to reduce the risk of hemorrhagic complications associated with placement of ventricular and neuraxial catheters. The ARSA guidelines are applicable to placement of a lumbar drain while the NCS guidelines are specific for insertion of an external ventricular drain. It is important to note that the ASRA guidelines are in the process of being updated and the practitioner is encouraged to use the most updated guidelines. Current complete guidelines are available at:

1. Lumbar Drain Placement

1.1 Fibrinolytic and Thrombolytic Therapy

1.1.1 In patients who received fibrinolytic or thrombolytic drugs the guidelines recommend against performance of a neuraxial puncture.

1.1.2 For those patients who received fibrinolytic or thrombolytic drugs at or near the time of neuraxial puncture, close neurological monitoring (not more than 2 hours between checks) is recommend.

1.1.3 No definitive recommendations exist for removal of catheters in those patients who unexpectedly received fibrinolytic or thrombolytic drugs. The guidelines recommend evaluation of fibrinogen level to assess for residual fibrinolytic or thrombolytic effect.

1.2 Unfractionated Heparin

1.2.1 No contraindication exists for neuraxial technique in patients receiving subcutaneous heparin 5000 U twice daily. Administering heparin after placement of the drain placement reduces the risk of spinal hematoma.
1.2.2 The safety of patients receiving greater than 10 000 U/day subcutaneous heparin or three times a day dosing has not been established. Careful monitoring is advocated.

1.2.3 Time of lumbar drain placement to systemic intravenous heparinization should be greater than 60 minutes.

1.2.4 Lumbar drains should be removed 2-4 hours after the last heparin dose and after the coagulation status has been assessed. Re-initiate heparin 1-hour after catheter removal.

1.3 Low-molecular Weight Heparin (LMWH)

1.3.1 The anti-Xa levels are not predictive of bleeding and the guidelines recommend against the routine monitoring of this variable.

1.3.2 Concomitant use of LMWH and other antithrombotic agents is not recommended.

1.3.3 The presence of blood with either catheter or needle placement does not necessitate postponement of surgery. However LMWH should be delayed for at least 24 hours after postoperatively.

**Preoperative LMWH**

1.3.4 Patients receiving preoperative thromboprophylaxis with LMWH should have neuraxial puncture delayed for 10-12 hours after the last dose.
1.3.5 Patients receiving higher doses of LMWH (treatment doses) should have neuraxial puncture delayed for 24 hours after the last dose.

1.3.6 Neuraxial puncture is not recommended if LMWH has been administered 2 hours preoperatively.

Postoperative LMWH

1.3.7 Twice daily dosing: If a catheter is left in place, the guidelines recommend removal of the catheter prior to initiation of treatment. LMWH should be delayed for 2 hours after catheter removal. The first dose of LMWH should be administered no earlier than 24 hours postoperatively and in the presence of adequate hemostasis.

1.3.8 Single-daily dosing: First postoperative dose should be administered 6-8 hours postoperatively with the second dose not occurring sooner than 24 hours after the first dose. Catheters can be continued with the single daily dosing however a minimum period of 10-12 hours is required from the last dose prior to removal. LMWH should be delayed for 2 hours after catheter removal.

1.4 Warfarin
1.4.1 Anticoagulation therapy should be stopped 4-5 days before the procedure with normalization of the International Normalized Ratio (INR) prior to neuraxial puncture.

1.4.2 Concomitant use of other antithrombotic agents is not recommended.

1.4.3 Patients who have received a dose of warfarin prior to neuraxial puncture should have an INR checked.

1.4.4 Patients receiving low-dose warfarin therapy with a neuraxial catheter in place should have their INR monitored daily.

1.4.5 Neuraxial catheters should be removed when the INR is less than 1.5. The guidelines suggest ongoing neurological evaluation for 24 hours after removal of catheters.

1.4.6 In patients with an INR between 1.5 and 3, removal of the catheter should be done with caution with careful monitoring of the neurological status. Careful review of other concomitant anti-thrombotic administration should be performed.

1.4.7 In patients with an INR greater than 3, warfarin should be held or reduced. The guidelines do not make definitive recommendations regarding the management to facilitate removal of neuraxial catheters in these patients.

1.5 Antiplatelet Medication
1.5.1 Nonsteroidal anti-inflammatory drugs alone confer no added risk during neuraxial puncture. The guidelines however highlight the increased risk of neuraxial hematoma associated with combing nonsteroidal anti-inflammatory and other anti-thrombotic drugs.

1.5.2 Ticlopidine, clopidogrel, prasugrel and ticagrelor should be discontinued 14, 7, 7-10 and 5-7 days respectively before neuraxial puncture. Normalization of platelet function should be documented.

1.5.3 With platelet GP IIb/IIIa inhibitors, neuraxial techniques should be avoided until platelet function has recovered. The time to normal platelet aggregation is 24 to 48 hrs. for abciximab and 4 to 8 hrs for eptifibatide and tirofiban.

1.6 Direct Thrombin Inhibitors

1.6.1 In patients receiving direct thrombin inhibitors (Desirudin, Lepirudin, Bivalirudin, and Argatroban) neuraxial puncture is not recommended.

1.6.2 Dabigatran should be stopped 5 days before neuraxial puncture.

1.7 Oral Factor Xa Inhibitors
1.7.1 Neuraxial puncture with fondaparinux should occur under conditions used in clinical trials (single-needle pass, atraumatic needle placement, avoidance of indwelling neuraxial catheters)

1.7.2 Apixaban and Rivaroxaban should be stopped 3 days before neuraxial puncture

1.8 Herbal Medications

1.8.1 There does not appear to be an increased risk of neuraxial hematoma associated with the use of herbal medications (garlic, gingko and ginseng). The guidelines recommend against mandatory discontinuation of these medications or avoidance of neuraxial techniques in these patients

2. External Ventricular Drain

The NCS guidelines suggest that coagulopathy should be corrected prior to insertion of an EVD, except under emergent conditions. As no specific thresholds for International Normalized Ratio (INR), activated Partial Thromboplastin Time (a-PTT), and platelet count are currently recommended, providers are encouraged to follow current institutional protocols for correction of the coagulopathy.
Author contributions:

Abhijit Vijay Lele, M.B.B.S, M.D., M.S, Manuscript design, manuscript write up, tables 1-6, figures 1a, 1b, 2a, 2b, section 1-6, developing of clinical competencies for EVD/ LD amongst clinicians involved in perioperative care, continued medical education and following a perioperative checklist for management of EVD/LD, review and approve manuscript

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Nina Schloemerkemper, M.D., Dr. med, F.R.C.A., Manuscript write up, Section 1, Introduction, indications and contraindications, review and approve manuscript

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Bhiken Ishwarlal Naik, M.D., Manuscript write up, review and approve manuscript, Section 4, Intraoperative Management of External Ventricular and Lumbar Drains, review and approve manuscript
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Ines Koerner, M.D., Ph.D., Manuscript write up, Section 5, Management of External Ventricular Drains (EVD)/ Lumbar Drains (LD) in special clinical scenarios review and approve manuscript

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