Infection Prevention Measures to Reduce External Ventricular Device-Related Surgical Meningitis and Ventriculitis

by

Saniya Sandeep Sabnis

BS in Chemistry, University of Pittsburgh, 2015

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This essay is submitted

by

Saniya Sandeep Sabnis

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and approved by

Essay Advisor:
Jeremy Martinson, DPhil, Assistant Professor, Department of Infectious Diseases and Microbiology, Graduate School of Public Health, University of Pittsburgh

Mohamed H. Yassin, MD, PhD, Associate Professor, School of Medicine, University of Pittsburgh

Jeremy Martinson, DPhil

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Saniya Sandeep Sabnis, MPH

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Abstract

Introduction: Healthcare-associated infections (HAIs) are serious public health problems with significant morbidity and mortality. The reduction of intra-cranial pressure using external ventricular drains (EVDs) is a life saving measure. Unfortunately, infection is a major complication of this procedure. Therefore, reducing surgical meningitis and ventriculitis, or EVD-related infection, is an important goal for healthcare infection prevention teams.

Methods: This is a single center study performed at an academic medical center reviewing all EVD-related infections between January 2014 and October 2018. This is a pre- and post-study comparing the rates of meningitis and ventriculitis after EVD placement before and after application of infection prevention. The patients were selected using procedure ICD codes via electronic medical records (EMR). A confirmed infection was defined as a positive microbiological culture of the cerebrospinal fluid (CSF); a possible infection was defined as a high white blood cell count (>100 cells/ ml) and/ or a low glucose count (<40 mg/dl) in CSF.

Results: During the study period, there were 106 procedures performed with 85 before and 20 after the prevention. Infection occurred in 44 with 7 confirmed and 37 possible infections. There were 36 infections before and 8 infections after application of the infection prevention bundle. The

number of EVD days, EVD placement procedure (bedside vs. operation room), and CSF specimen source (EVD bag vs. buretrol) were associated with increased risk of infection.

Conclusion: An EVD-related infection is a serious life-threatening HAI. Multiple risk factors were identified in this study including duration of EVD, EVD placement procedure, and CSF specimen source. The application of an effective evidence-based infection prevention bundle to reduce EVD-related surgical meningitis and ventriculitis is an essential intervention.

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1.0 Background

1.1 Hospital Associated Infections

Healthcare-associated infections (HAIs) are a serious growing health concern on a global level; they increase morbidity and mortality of the patients, often reducing quality of life, and they usually elicit an economic burden on the hospital administration and healthcare workers, insurance companies, and patient, as well. The Centers for Disease Control and Prevention's (CDC) Division of Healthcare Quality Promotion (DHQP) utilizes the National Healthcare Safety Network (NHSN) for passive HAI surveillance. Hospitals from all 50 states, Washington, D.C., and Puerto Rico all report HAIs to the NHSN. NHSN's estimates for annual HAIs are as high as 1.7 million in all healthcare settings (Magill, et al., 2014). In the most recent multi-state study published by the CDC which spanned across 183 acute care hospitals, approximately 4% of patients out of over 11,000 contracted at least 1 HAI. These numbers when applied to the national population indicate that on any day, 1 in 25 inpatients in acute care hospitals develop at least 1 HAI (Magill, et al., 2014). The most recent NHSN numbers show that nearly 150,000 HAIs happened in acute care hospitals in 2017. When inpatient rehabilitation facilities, long-term acute care hospitals, and other healthcare facilities are taken into account, this number increases significantly, creating a significant burden on the healthcare system. Deaths associated with HAIs are nearly as high as 100,000 per year (Klevens, et al., 2007). The massive amounts of HAIs that occur nationally cause a serious burden on the U.S. healthcare system that can be in the billions of dollars range. The CDC published numbers indicating that the annual direct medical costs of HAIs range between $28.4 billion to $45 billion (Scott, 2009). Surveillance can help to reduce HAIs by monitoring

infection trends and providing warnings for early outbreaks; by providing benchmarking to encourage healthcare workers to collaborate and perform surveillance and to increase their compliance to infection control standards; and by pinpointing potential risk factors associated with HAIs (Li, et al., 2017). By understanding and analyzing HAI data and implementing infection control interventions, savings resulting from stopping preventable infections can save between $5.7 billion to $31.5 billion annually (Scott, 2009). Additionally, the implementation of the Hospital-Acquired Conditions (HACs) Initiative in 2008 was a payment reform from the Centers for Medicare and Medicaid Services, which attempted to incentivize healthcare facilities into reducing HAIs (Waters, et al., 2015). The HACs Initiative stated that hospitals could no longer claim a high-level severity diagnosis to recoup costs for treating a patient who developed one of the eight never events, which include catheter-associated urinary tract infections and central line-associated bloodstream infections (Waters, et al., 2015). This initiative further highlights the necessity for hospitals to want to decrease the incidence of HAIs amongst their patients.

1.1.1 Types of HAIs

HAIs are device-related infections, which include central line-associated bloodstream infections (CLABSI), catheter-associated urinary tract infections (CAUTI), and ventilator-associated pneumonia (VAP) (Centers for Disease Control and Prevention, 2010) (Centers for Disease Control and Prevention, 2015) (Centers for Disease Control and Prevention, 2010). Surgical site infections (SSIs) are device-related infections that stem from EVD-related infections, implant-related infections that originate from prosthetic joint infections, or simply open wound infections that are introduced into the body through the locations where surgery took place (Centers for Disease Control and Prevention, 2010). These infections can be superficial on the skin

only or can be deeper and infect soft tissues, organs, implanted devices and material, and even bones. Nationally, the CDC uses surveillance data from the NHSN and the Emerging Infections Program Healthcare-Associated Infections – Community Interface (EIP HAIC) to track trends in incidence and prevalence on a state-wide basis (Centers for Disease Prevention and Control, 2018). Pneumonia and surgical site infections are the most common HAIs with an annually estimated prevalence of 24.3% each (Magill, et al., 2014). Gastrointestinal infections, urinary tract infections, and bloodstream infections are also frequently seen and estimated to have prevalence at 19.0%, 14.4%, and 11.1%, respectively (Magill, et al., 2014). This study shows that device-associated infections only cause a quarter of the HAIs, whereas half of the HAIs are not caused by devices or operative procedures (Magill, et al., 2014). The importance of the study highlights necessity of refocusing public health initiatives from current efforts on device-associated infections only to include other more pressing infection causes. NHSN's published numbers from 2017 indicate that there were 21,173 CLABSI, 24,865 CAUTI, 24,491 VAE, 20,625 SSI (Centers for Disease Control and Prevention, 2017). The predicted number of infections which are believed to have existed are 25,996, 28,242, 25,731, and 21,967 for CLABSI, CAUTI, VAE, and SSI respectively (Centers for Disease Control and Prevention, 2017). According to the CDC, economically, this translates to $3.22 to $10.07 billion for SSI, $0.59-$2.68 billion for CLABSI, $0.78 to $1.50 billion for VAP, and $0.34 to $0.45 billion for CAUTI (Scott, 2009). A more recent meta-analysis on the impact of HAIs on the U.S. health system, specifically for adult inpatients at acute care hospitals, estimates that the incidence of SSIs are 1.98 per 100, CLABSIs are 1.27 per 100, CAUTIs are 1.87 per 100, and VAEs are 1.33 per 100, resulting in a total HAI incidence of 440,916 patients (Zimlichman, et al., 2013). This study then went on to conclude that the total attributable financial impacts of

HAIs at acute care hospitals to be $3 to $3.6 billion for SSIs, $1.25 to $2.64 billion for CLABSIs, $0.19 to $0.37 billion for CAUTIs, and $2.8 to $3.41 billion for VAEs (Zimlichman, et al., 2013).

The NHSN uses standardized infection ration (SIR) as a summary statistic to track the spread of HAIs and the success of HAI prevention programs. SIR is a ratio of the number of observed infections over the number of predicted infections for that time period. The SIR helps to determine the change in HAIs from year to year. The SIRs for 2017 were 0.814 for CLABSI, 0.880 for CAUTI, and 0.952 for VAE. The national data for acute care hospitals in 2017 when compared to the national baseline for acute care hospitals in 2016 indicate a 19% decrease in CLABSI, 12% decrease in CAUTI, a 5% decrease in VAP, an 11% decrease in SSIs related to abdominal hysterectomies, and a 9% decrease in SSIs related to colon surgery. All these decreases in infections were significant except the two SSI related results. Specifically, Pennsylvania data for acute care hospitals in 2017 when compared to the national baseline for acute care hospitals in 2017 had a 21% decrease in CLABSI, a 15% decrease in CAUTI, a 7% decrease in VAP, no change in the incidence SSIs related to abdominal hysterectomies, and a 19% decrease in SSIs related to colon surgeries. Events related to CLABSI and CAUTI and were significantly lower in 2017 when compared to Pennsylvania's results in 2016. The rest showed no significant difference when comparing Pennsylvania results in 2016 to 2017.

1.2 Neurosurgery HAIs

Neurosurgery-associated HAIs are an important area that requires additional focus and research because of the severity of associated infections. ICUs generally have an increased rate of HAIs because of the severity of the medical condition of the patient or procedure, the increased

length of stay, and the frequent use of invasive medical devices; in fact, HAI incidence can reach as high as 30%, compared to the average of 1 in 25 patients (Abulhasan, et al., 2018). Based on the studies that are done, the incidence, prevalence, and economic burden of HAIs vary greatly depending on a multitude of factors, including but not limited to database used, infection prevention policies, and procedure- and patient-related aspects (DeAngelis, Murthy, Beyersmann, & Harbarth, 2010). Often times the only costs taken into account are direct costs, both fixed and variable, (e.g., utilities, equipment, medications, treatments and procedures, testing, and supplies) because indirect costs (e.g., lost wages, mortality and morbidity, pain and suffering) are nearly impossible to calculate (Scott, 2009). The types of study can also lead to vast differences in results. For example, a comparative cohort studies can lead to the rise of biases by not taking into account variables that could influence the cost (DeAngelis, Murthy, Beyersmann, & Harbarth, 2010).

Taking these studies' possible shortcomings and cause for variations into account, the chances of contracting HAIs in neurosurgical intensive care units can range between 5.9% to 21.7% (Kupronis, Edwards, Horan, Richards, & Tokars, 2004) (Dasenbrock, et al., 2016) (Celik, 2004) (Orsi, et al., 2006). These included all four classifications of HAIs, (i.e., CLABSI, CAUTI, VAP, and SSI). A study spanning 6 years of medical data in the National Nosocomial Infections Surveillance (NNIS) showed that out of 93,327 patients the most common of these four HAI classifications were VAPs and CAUTIs at 30.8% and 30.4%, respectively (Kupronis, Edwards, Horan, Richards, & Tokars, 2004). Bloodstream infections occurred at 11.9%, lower respiratory infections at 6.6%, surgical site infections at 4.4%, and central nervous system infections at 4.3% (Kupronis, Edwards, Horan, Richards, & Tokars, 2004). Another study confirmed this and found that in patients who had had an aneurysmal subarachnoid hemorrhage, CAUTIs were the most common HAIs (23.9%) (Dasenbrock, et al., 2016). This was followed by VAPs (23.0%),

meningitis/ventriculitis (4.4%), and CLABSIs (1.0%) (Dasenbrock, et al., 2016). A study from Germany showed that the overall incidence of HAIs in the neurosurgical ICU was 20.7 per 100 (Dettenkofer, et al., 1999). The breakdown of this study is also similar to the afore mentioned studies done in the U.S. Pneumonia and urinary tract infections had the highest incidence of 9 per 100 and 7.3 per 100, respectively (Dettenkofer, et al., 1999). Following those were bloodstream infections (1 per 100), urinary tract infections (7.3 per 100), meningitis (1.1 per 100), and others, which contained SSIs, catheter related local infection, bronchitis, and diarrhea grouped into the same category, (1.7 per 100) (Dettenkofer, et al., 1999). Similarly, the largest study on HAIs in Europe studied prevalence in 10,038 patients (Celik, 2004). 20.6% of the patients had a HAIs; of these HAIs, 46.9% was pneumonia, 17.8% were lower respiratory tract infections, 17.6% were urinary tract infections, and 12% were bloodstream infections (Celik, 2004). Another prospective study in Italy found that 32.6% of HAIs were VAPs, 9.1% were CLABSIs, 22.7% were CAUTIs, and 6.8% were SSIs (Orsi, et al., 2006).

The CDC also has particular diseases and organisms it monitors because of their severity or their association with being spread primarily in a healthcare setting. These include *Acinetobacter*, *Burkholderia cepacia*, *Candida auris*, *Clostridium difficile* (*C. difficile*), *Clostridium sordellii*, carbapenem-resistant Enterobacteriaceae, gram-negative bacteria, hepatitis, HIV/AIDS, influenza, *Klebsiella*, methicillin-resistant *Staphylococcus aureus* (MRSA), *Mycobacterium abscessus*, norovirus, *Pseudomonas aeruginosa* (*P. aeruginosa*), *Staphylococcus aureus* (*S. aureus*), tuberculosis, vancomycin-intermediate and vancomycin-resistant *Staphylococcus aureus* (VRSA), and vancomycin-resistant Enterococci (Centers for Disease Control and Prevention, 2019). The most commonly seen disease-causing organisms according to the CDC's multi-state study on HAIs are *C. difficile* (12.1%), *S. aureus* and MRSA (10.7%),

Klebsiella family organisms (10.3%), *Escherichia coli* (*E. coli*) (93.3%), organisms from the Enterococci family (8.7%), and organisms from the *P. aeruginosa* (7.1%) (Magill, et al., 2014). The NHSN focuses specifically on MRSA and *C. difficile* and their relevance in contributing to HAIs. In the most recent NHSN report, approximately 8,000 hospital-onset MRSA events and approximately 82,000 hospital-onset *C. difficile* events were reported. Comparisons between SIRs in the national data for acute care hospitals in 2017 and the national baseline for acute care hospitals in 2016 indicated a 14% decrease in MRSA and a 20% decrease in *C. difficile*, both of which were significant. Pennsylvania's data for acute care hospitals in 2017 when compared to the national baseline for acute care hospitals in 2017 showed a 22% decrease in MRSA and a 18% decrease in *C. difficile*. Only the decrease in *C. difficile*-related HAIs was significantly lower in 2017 when compared to Pennsylvania's results in 2016; the decrease in MRSA was not significant. In particular, SSIs that are most common in neurosurgery ICUs include *S. aureus*, coagulase-negative Staphylococci (CNS), *P. aeruginosa*, *Klebsiella pneumoniae* (*K. pneumoniae*), and other gram-positive bacteria (Orsi, et al., 2006). Meningitis infections which are associated with EVDs are *S. aureus*, Staphylococci, *Enterococcus faecalis*, *P. aeruginosa*, *K. pneumoniae*, and other gram-positive bacteria (Orsi, et al., 2006). According to another study, ventriculostomy-associated infections are often caused by *S. epidermidis*, *Candida*, and both gram-negative and gram-positive bacteria (Abulhasan, et al., 2018). Moreover, yet another study concluded that CNS, Streptococci, Corynebacterium spp., and herpesvirus are also associated with meningitis and ventriculitis in neurosurgery ICUs (Dettenkofer, et al., 1999).

While SSIs are generally the least prevalent HAIs, they cause the most economic burden and more severely increase the morbidity and mortality in healthcare settings. Neurosurgical associated HAIs include SSIs (superficial or deep) after cranial or spinal surgery as well as surgical

meningitis and ventriculitis associated with EVD or shunt-related infection. Patients in the neurosurgical ICUs come with their own distinctive array of issues which further increase the morbidity of any contracted SSIs. There are many associated risk factors, both patient-related and procedure-related, that can increase the incidence of meningitis or ventriculitis as a result of SSIs. Commonly found patient-related risk factors include male sex, age of 70 or higher, non-trauma related procedure, and a higher American Society of Anesthesiologists (ASA) score. Procedure-related factors often include an emergency procedure, the lack of antimicrobial prophylaxis, longer duration of the procedure, leakage of CSF after the procedure, and an early reoperation (Chiang, et al., 2014). A prospective cross-sectional study demonstrated that presence of SSIs were strongly associated with a longer total length of stay at a hospital, a higher body mass index, a longer surgical procedure, and the presence of a blood transfusion using bivariate analysis (Bellusse, Riberio, de Campos, de Brito Poveda, & Galvao, 2015). A larger retrospective study found that older patients, male sex, longer operation preparation time and operation duration, greater number of devices or insertions into and out of the body, and presence of multiple HAIs were all contributing factors to increased SSIs (Lee, et al., 2018). Another study focusing more specifically on SSIs related to craniotomies and craniectomies found the following bivariate associations: comorbidity of peripheral vascular diseases, prior operations or radiation on the brain, presence of a tumor, high glucose levels, an increased preoperative length of stay, an NHSN risk index score greater than or equal to 2, presence of any kind of CSF drain, and postoperative leakage of CSF (Chiang, et al., 2014). The study also found that increased duration of any operative procedure was significant in a multivariate model (Chiang, et al., 2014). Dasenbrock, et al. (2016) found that after an aneurysmal subarachnoid hemorrhage (SAH), the SAH severity scale and the number of non-infectious complications were both significant in predicting the presence of meningitis or

ventriculitis. A prospective study which looked at deep neurosurgical wound infections leading to meningitis and ventriculitis after craniotomies found that using univariate analysis a Glasgow Coma Score less than 10, an emergency surgery, total shaving of the head, the use of an external drainage device, subsequent operation, and CSF leakage all increased the associated relative risk of infection significantly (Korinek, et al., 1997). Our focus here is EVD-related infections and preventative efforts.

1.3 External Ventricular Drains

External ventricular drain (EVD) placements are procedures commonly performed by neurosurgeons to relieve increased intracranial pressure (ICP) by draining CSF. They can be placed emergently at the bedside or electively in the operating room. Ventriculoperitoneal (VP) shunts drain the excess CSF fluid into a patient's peritoneal cavity, whereas an EVD carries the excess CSF fluid out of the body and into a separate collection bag (Muralidharan, 2015). The amount of CSF drained from the EVD can be adjusted to maintain a constant and safe pressure on the brain. VP shunts are a long-term solution for increased ICP, whereas EVDs are typically used in the short-term. If there is continued need for shunting, the patient will undergo EVD removal and VP shunt placement. Estimates for incidence of meningitis and ventriculitis after placement of an EVD vary greatly and can be as little as 1 to 4% or can occur in up to 22% of cases (Parks & Nohra, 2010) (Tavakoli, Peitz, Ares, Hafeez, & Grandhi, 2017). Meningitis is defined as inflammation and infection of the meninges, while ventriculitis is defined as inflammation and infection of the ventricles. CSF can be drawn from the EVD directly or can be collected from the drainage bag to for testing and running cultures. Medications can also be introduced directly into

the subarachnoid space of the brain through the EVD. Once an EVD is in place, monitoring the patient and the drain for CSF leakage, fluctuating intracranial pressure, and obstruction in the tubing, device, or CSF fluid is vital to keeping the EVD safe and functional (Muralidharan, 2015).

Meningitis and ventriculitis are often caused specifically by SSIs that are introduced during placement of the EVD or because of substandard EVD monitoring and care. Typical symptoms of meningitis and ventriculitis caused by SSIs in EVDs can be a new headache, nausea, lethargy, a change in mental state, and/ or a fever (Tunkel, et al., 2017). Once an infection is suspected, the CSF is tested for any abnormalities. Changes in CSF cell count, glucose, and/or protein might suggest presence of healthcare-associated meningitis or ventriculitis, but it does not guarantee it (Tunkel, et al., 2017). On the other hand, a normal CSF cell count, normal glucose, normal protein, and/or a negative gram stain does not necessarily exclude presence of healthcare-associated meningitis or ventriculitis (Tunkel, et al., 2017). Instead, a CSF culture is the definitive method of knowing whether a patient has contracted an HAI. If the culture test initially comes back as negative, it should be held for at least 10 days to ensure nothing grows in it (Tunkel, et al., 2017). A positive CSF culture, either single or multiple is strongly indicative of meningitis or ventriculitis, especially with clinical symptoms and abnormal cell counts (Tunkel, et al., 2017). However, an EVD, once removed, should not be cultured to determine presence of an HAI (Tunkel, et al., 2017).

Associated risk factors that are specific to EVDs occurring are systemic infections introduced to the body externally, depressed skull fractures, lack of tunneling of EVD catheters, CSF leakage at the site of drain insertion, unsterile catheter irrigation, frequency of CSF sampling, and extensive duration of EVD placement (Muralidharan, 2015). Minimizing breaks in the EVD system by limiting the changing of collection bags and tubing will help to reduce pathogen colonization and possible CSF infection. In case of colonization, antibiotics can be introduced but

it is more likely that the entire EVD system will have to be replaced with another EVD (Muralidharan, 2015). EVDs can also suffer from mechanical malfunctions such as kinking in the tubes, a failure of any part of the drainage system, or migration of the EVD catheter (Muralidharan, 2015). Other obstructions that can occur resulting in blocked EVDs and a possible infection are too much drainage of CSF, tight ventricles, or CSF leaks (Muralidharan, 2015). A review article on EVDs summarized the following variables as significantly increasing the chances of contracting an EVD infection based on univariate analysis: duration of catheterization, a neurosurgical operation, an already present co-infection, the use of multiple catheters simultaneously, age, and an underlying disease or a more severe diagnosis (Sorinola, Buki, Sandor, & Czeiter, 2019).

1.4 Infection Prevention

Evidence-based guidelines were issued to decrease the incidence of EVD-related infections. With counsel from the Healthcare Infection Control Practices Advisory Committee (HICPAC), the CDC and U.S. Department of Health and Human Services (DHHS) have established guidelines and strategies to prevent the spread of HAIs and to assist in surveilling the spread of HAIs in healthcare institutions (Healthcare Infection Control Practices Advisory Committee, 2017). These include guidelines specific to healthcare settings (e.g., inpatient and outpatient settings, dialysis), healthcare worker, disease or organism, procedure or device, antibiotic resistant organisms, and basic infection preventions (e.g., hand hygiene, disinfection and sterilization) (Healthcare Infection Control Practices Advisory Committee, 2017). In addition to these specific guidelines, there are also core guidelines that the HICPAC considers most vital to infection prevention and are unlikely to change regardless of any additional research conducted.

Of the published situation-specific categorized guidelines, the core guidelines selected are based on which recommendations were included in more than one of the numerous guidelines (Appendix A). Core practice categories that the HICPAC has outlined are leadership support, which refers to the bodies in charge of healthcare facilities and organizations; education and training of healthcare personnel on infection prevention; patient, family, and caregiver education; performance monitoring and feedback; standard precautions (i.e., hand hygiene, environmental cleaning and disinfection, injection and medication safety, risk assessment with appropriate use of personal protective equipment, minimizing potential exposures, reprocessing of reusable medical equipment); transmission-based precautions, temporary invasive medical devices for clinical management; and occupational health (Healthcare Infection Control Practices Advisory Committee, 2017).

The Infections Diseases Society of America's Standards and Practice Guidelines Committee in collaboration with the American Academy of Neurology, American Association of Neurological Surgeons, and Neurocritical Care Society have developed guidelines and recommendations for clinicians for the evaluation, diagnosis, and management of meningitis and healthcare-associated ventriculitis (Tunkel, et al., 2017). It provides the following guidelines for the best approach to prevent infection in patients with EVDs:

- Administration of a prophylactic antimicrobial prior to placement of the EVD (Tunkel, et al., 2017)
- Use of drains that are impregnated with antimicrobials (Tunkel, et al., 2017)
- Opposition against prolonged administration of prophylactic antimicrobials for the entire duration of the EVD (Tunkel, et al., 2017)
- Discouragement of fixed interval exchanges (Tunkel, et al., 2017)

- Implementation of a standardized protocol to insert CSF drains (Tunkel, et al., 2017)

Unfortunately, a six-year study conducted from 2006 to 2012 showed that the trends in mortality and length of stay related to bloodstream infections, pneumonia, SSIs, and UTIs has not changed substantially, indicating that Medicare's introduction of the HACs Initiative has not been as successful as originally expected (Glied, Cohen, Liu, Neidell, & Larson, 2016). In order to further decrease the incidence of HAIs and associated their burden on the health system and patients, the U.S. Department of Health and Human Services (HHS) has included HAIs in their Healthy People 2020 goals. (Office of Disease Prevention and Health Promotion, 2019). Healthy People 2020 is a 10-year agenda implemented by the HHS to improve health in the United States by focusing on high priority issues (Office of Disease Prevention and Health Promotion, 2019). By partnering with the CDC, National Institute of Health (NIH), Food and Drug Administration (FDA), and others, a four-step plan was designed (Office of Disease Prevention and Health Promotion, 2019). They cover goals focused on decreasing HAIs at healthcare locations, specifically acute-care hospitals, ambulatory surgical centers, and end-stage renal disease facilities; increasing influenza vaccination among healthcare personnel, such as doctors, nurses, etc.; and promoting antibiotic stewardship (Office of Disease Prevention and Health Promotion, 2019).

1.5 Policy Change

In July of 2017, our institution updated its policy regarding the care of ICP monitoring devices, which includes EVDs and their associated bedside care. The purpose of this policy change

was to reduce the incidence of HAIs for patients who had received EVDs because of the distinct compromising dangers that neurosurgical infections can have. The policy states the following: "All patients with an intracranial pressure device will be cared for by a registered professional nurse, who has been oriented to intracranial pressure monitoring and external ventricular drain management. A nurse to nurse consultation will be requested and provided by an experienced critical care unit nurse from medical intensive care unit, trauma burn center, or resource intensive care whenever necessary". The policy also goes on to cover external drainage and monitoring system set up for an EVD for registered nurses; procedure for insertion of EVDs for physicians, advanced practice providers, and registered nurses; procedure for an ordered, soiled, or dislodged dressing change for physicians and advanced practice providers; procedure for obtaining cerebral perfusion pressure readings for registered nurses; procedure for CSF sample from an EVD for registered nurses; procedure for instillation into a proximal port of external drainage and monitoring system for physicians and advanced practice providers; procedure for changing of CSF collection bags for registered nurses; and important general aspects about external drainage and monitoring systems that should be taken into account. In addition to the update, the institution also held an educational workshop for registered nurses on proper EVD procedures and to familiarize them with the policy update, specifically highlighting the changes, in September 2017. The entire policy is included in Appendix B.

1.5.1 Major Updates to Policy

There were four major changes to the original policy that were expected to directly decrease the incidence and associated complications related to HAIs. The first change was implementing dressing changes after being soiled or upon order by a physician or advanced practice practitioner,

instead of the prior policy which stipulated stapling the dressing to the wound after insertion or removal of an EVD. The second change was regarding CSF collection for testing. Under the previous policy, the CSF drainage bag was collected every day and sent to the lab for testing, which meant that it took approximately twenty-four hours for the fluid to be tested and cultured. After implementation of the new policy, CSF was collected from the buretrol instead of the drainage bag and sent to the lab vials, shortening the processing time. The third policy change was the required use of five barriers (i.e., mask, cap, gloves, sterile gown, and sterile drape on the patient) were added to the already required hand hygiene and sterile technique for whenever a physician or advanced practice provider performs interventions that break the EVD system, such as inserting a new EVD or for repairing the system. The fourth and final change was that the frequency of CSF testing was changed from daily to two times a week on Mondays and Thursdays. All four of these changes to the policy were implemented in order to decrease the amount of breaks in the system and to ensure sterile techniques are used by all personnel who interact with EVD patients.

2.0 Methods

2.1 Patient Sample Selection

There were several steps involved in choosing the correct patient population to sample. Working in conjunction with the insurance department, patients with International Classification of Diseases, Tenth Revision, Clinical Modification (ICD) codes corresponding to "drainage of cerebral ventricle with drainage device" were isolated. Because UPMC slowly transitioned from ICD-9 to ICD-10 between August 2015 and November 2015 through the collection process, both 0221 (from ICD-9) and 009630Z (from ICD-10) were used to choose patients who had undergone procedures for EVDs. Therefore, in September 2015 there was an overlap of ICD codes so that both ICD-9 and ICD-10 codes were used. From the pool of patients in the entire system who had at one point received an EVD, patients that had been admitted specifically for "neurosurgical" services were chosen. These selected patients' electronic medical records on Cerner, specifically the surgical notes, pre-op and post-op notes, intraoperative notes, and follow-up evaluation notes, were carefully read to determine whether the patient had in fact received an EVD. The timeline for data collection was between January 2014 and October 2018. The policy update regarding intracranial pressure monitoring devices happened in July 2017, so patient cases that were dated before and including July 31, 2017 were classified as following the previous protocol whereas patient cases dated after July 31, 2017 were classified as following the new protocol.

2.2 Data Collection on Patients

On the electronic medical record Cerner, the following were provided from the insurance department: medical record number, case number, procedure date, procedure time, procedure description, service used, and surgeon. Using the medical record number, each patient was confirmed to have had an EVD. Each patient's CSF results were also recorded, specifically the highest white blood cell count, lowest glucose, highest protein, and highest red blood cell count. Any microbiology lab results for each patient's CSF was recorded and the strain of a positive culture, if any, was noted. The site of the CSF sample collection was recorded as well. This referred to whether the CSF sample which was sent for testing was removed from the EVD collection bag or from the EVD's buretrol. The duration of the EVD and the EVD placement type were also recorded. The EVD placement type referred to whether the patients received an EVD during a surgical procedure in an operating room (i.e., surgical) or whether the patient had an EVD placed at the bedside in the patient's room (i.e., bedside). Patients were divided into three classes of HAIs: confirmed, possible, and no evidence. Patients with confirmed HAIs had microbiology lab results of CSF that indicated growth of an organism or organisms. Possible HAIs meant that the patient's CSF had either a glucose level < 40 and/or a white blood cell count > 100. Patients with no evidence of HAIs had no microbiological growth in their CSF fluid and also had a glucose count greater than 40 and a white blood cell count fewer than 100.

2.3 Statistical Analysis

The statistical analysis program STATA was used to analyze data. Simple linear regression modeling was used to determine how the duration of the EVD in days and procedure time in minutes affected the white blood cell count and glucose level with significance given at a p-value of < 0.05. Analysis of variance (ANOVA) modeling was used to determine whether the surgeon, location of CSF specimen sampling (i.e., bag or EVD), and EVD placement (i.e., bedside, surgical, or both) had an effect on white blood cell count and glucose levels. Each variable was analyzed separately using one-way ANOVA additive model and then analyzed again using an interaction model to determine whether they had any effect on each other. In order to model the continuous variables and discrete categorical variables together, analysis of covariance (ANCOVA) was used to determine interactions between EVD duration, procedure time, surgeon, specimen source, and EVD placement result together in a multivariable regression system. Multivariate analysis of variance (MANOVA) was used to determine how interactions between EVD duration, procedure time, surgeon, CSF specimen source, and EVD placement related to the white blood cell count and the glucose levels in the CSF. Logistic regression was used to determine the odds ratios of surgeon, CSF specimen source, and EVD placement on the presence of HAIs, as determined by CSF culture and white blood cell count and glucose level. The possible and confirmed HAIs were grouped together for the odds ratio analysis. Statistical significance for ANOVA, ANCOVA, MANOVA, and logistic regression was determined based on a p-value < 0.05. On significant variables determined by ANOVA, ANCOVA, and MANOVA regression analyses, postestimation pairwise tests were run using Scheffé's correction.

3.0 Results

There were 313 entries isolated from using both ICD-9 and ICD-10 codes 0221 and 009630Z, respectively. There were 162 cases which used were specifically admitted for neurosurgical services and the focus of the analysis. After removing repeat cases (56) for patients who had multiple procedures on the same day, there were 106 unique patient cases. There were 36 entries which had no CSF data and were assumed to have had no evidence of an HAI to require a CSF test. One of those entries with no CSF data had to be removed because the patient died before receiving an EVD. 28 of the entries with no CSF data were pre-policy, and 7 of the entries were post-policy. 70 entries had their CSF fluid tested, of which 7 entries had confirmed HAIs based on the microbiology culture and 63 entries had no growth in their CSF. 5 of the entries with confirmed HAIs were pre-policy, and 2 of them were post-policy. Of the 63 entries which had no growth in the CSF culture, 37 of them had possible HAIs based on their glucose or white blood cell count; 31 entries were pre-policy, and 6 entries were post-policy. The remaining 26 entries without growth in the CSF culture had no evidence of HAIs because of their normal glucose and white blood cell count; 21 were pre-policy, and 5 were post-policy. These results are summarized in Table 1.

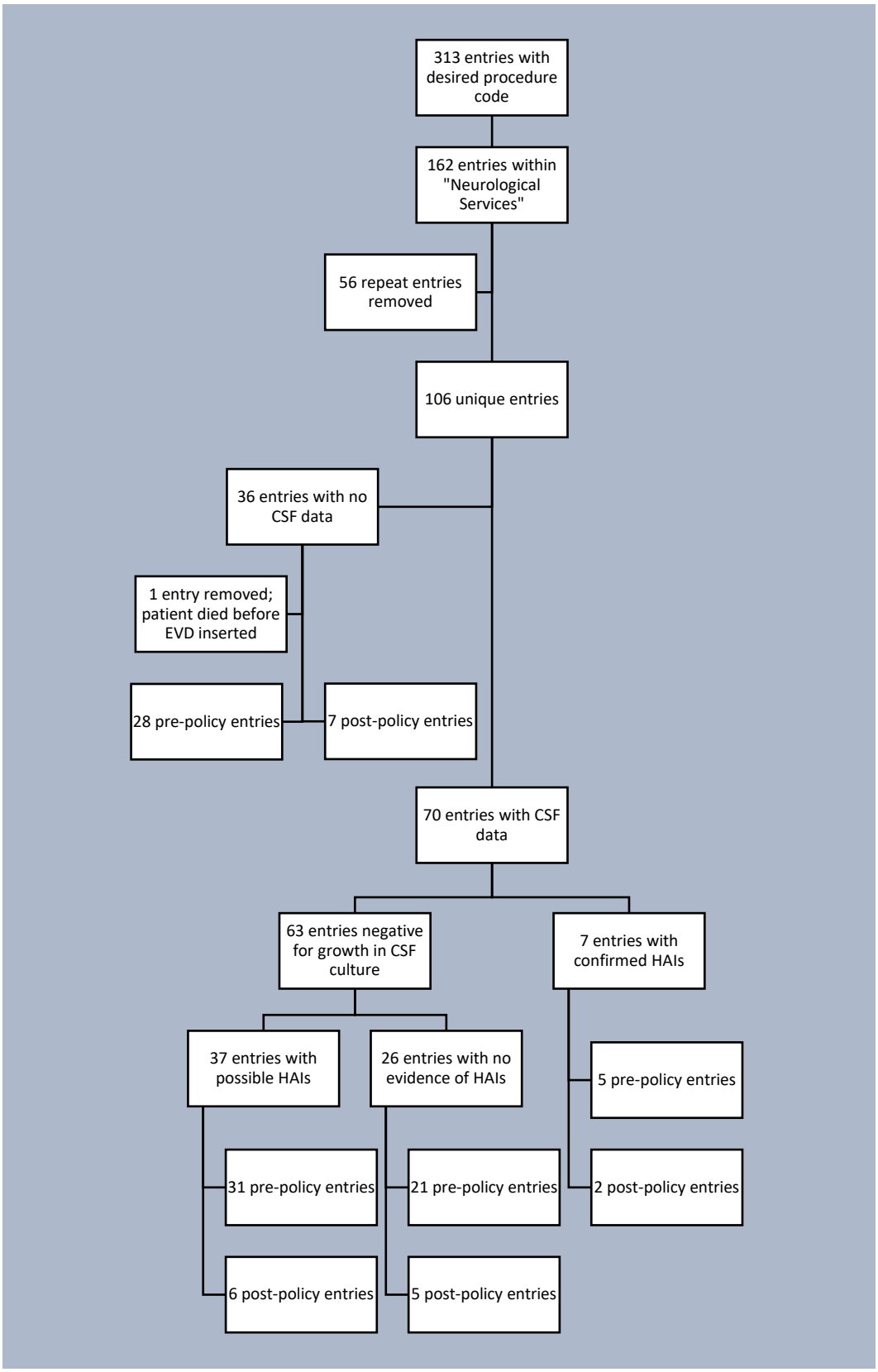

Figure 1 Flowchart of Patient Data

Table 1 Summary of Patient and EVD Procedures

	Pre-Policy Cases	Post-Policy Cases
Confirmed HAIs	5	2
Possible HAIs	31	6
No Evidence of HAIs (CSF Tested)	21	5
No Evidence of HAIs (No CSF Tested)	28	7

Table 2 categorizes and summarizes characteristics for the 106 unique entries. 67 entries (69.07%) had an EVD placed during surgery, 27 entries (27.84%) had a bedside EVD, 3 entries (2.83%) had both, and 9 entries (8.49%) did not explicitly mention whether the EVD was placed surgically or by the bedside. 36 entries (33.96%) did not have CSF taken for analysis. 58 entries (54.72%) had CSF taken from the EVD drainage bag while 12 entries (11.32%) had CSF taken from the buretrol. Surgeon 1 performed 5 procedures (4.72%), surgeon 2 performed 55 procedures (51.89%), surgeon 3 performed 11 procedures (10.38%), surgeon 4 performed 21 procedures (19.81%), surgeon 5 performed 10 procedures (9.43%), and surgeons 6, 7, 8, and 9 performed 1 procedure each (0.94%). 14 entries (13.21%) did not have EVD monitoring, so the duration of the EVD could not be determined. The average duration of the EVD in days was 7.98 ± 5.35. The average procedure time in minutes was 144.83 ± 124.23.

Table 2 Patient Characteristics

Variable	Entries
EVD Placement	
Surgery	67 (63.21%)
Bedside	27 (25.47%)
Both	3 (2.83%)
Unknown	9 (8.49%)
Specimen From	
No CSF	36 (33.96%)
EVD Bag	58 (54.72%)
EVD Buretrol	12 (11.32%)
Surgeon	
1	5 (4.72%)
2	55 (51.89%)
3	11 (10.38%)
4	21 (19.81%)
5	10 (9.43%)
6	1 (0.94%)
7	1 (0.94%)
8	1 (0.94%)
9	1 (0.94%)
EVD Duration	
No Data Monitoring	14
Mean (days)	7.98 ± 5.35
Procedure Time	
Mean (minutes)	144.83 ± 124.23

Table 3 focused specifically on the patients' white blood cell count and possible variables that could have affected it. Simple linear regression analysis on procedure time (p-value 0.363), EVD duration (0.622), and procedure time when controlling for EVD duration (p-value 0.362), and EVD duration controlling for procedure time (p-value 0.621) showed that there was no significant effect on the outcome. ANOVA regression analysis was conducted on the categorical variables. The following variables did not significantly affect the white blood cell count separately: HAI presence (p-value 0.292), surgeon (p-value 0.415), CSF specimen source (p-value 0.599), and EVD placement (p-value 0.737). An additive model of the surgeon, CSF specimen source, and EVD placement showed no significant effect on the white blood cell count. On the other hand, an

interactive model of the surgeon, CSF specimen source, and EVD placement did have a significant effect on the white blood cell count (p-value 0.020). When this model was broken down, the surgeon and CSF specimen source while controlling for EVD placement was significantly related to the white blood cell count (p-value 0.020); additionally, the surgeon and EVD placement when controlling for the CSF specimen source was also significantly related to the white blood cell count (p-value 0.003). Regression models taken both the categorical variables (surgeon, CSF specimen source, and EVD placement) and continuous variables (procedure time and EVD duration) into account showed no significance in the additive model (p-value 0.585) but was significant in the interactive model (p-value < 0.001). Breaking the interactive model down further showed that significant relationships exited between the following and the white blood cell count: surgeon controlling for everything else (p-value < 0.001), surgeon and CSF specimen source controlling for everything else (p-value < 0.001), EVD placement controlling for everything else (p-value 0.021), surgeon and EVD placement controlling for everything else (p-value < 0.001), surgeon and procedure time controlling for everything else (p-value < 0.001), surgeon and EVD duration controlling for everything else (p-value 0.031), and EVD duration controlling for everything else (p-value < 0.001). Only the significant models were further analyzed and documented.

Table 3 White Blood Cell Count's Relation to Variables using Regression Analyses

Variables	p-value
Simple Linear Regression Analysis	
Procedure Time	0.363
EVD Duration	0.622
Procedure Time controlling for EVD Duration	0.362
EVD Duration controlling for Procedure Time	0.621
ANOVA Regression Analysis	
HAI Presence	0.292
Surgeon	0.415
CSF Specimen Source	0.599
EVD Placement	0.737
Surgeon, CSF Specimen Source, EVD Placement (Additive)	0.474
Surgeon, CSF Specimen Source, EVD Placement (Interactive)	0.020
Surgeon and CSF Specimen Source controlling for EVD Placement	0.002
Surgeon and EVD Placement controlling for CSF Specimen Source	0.003
ANCOVA Regression Analysis	
Surgeon, CSF Specimen Source, EVD Placement, Procedure Time, EVD Duration (Additive)	0.585
Surgeon, CSF Specimen Source, EVD Placement, Procedure Time, EVD Duration (Interactive)	< 0.001
Surgeon controlling for everything else	< 0.001
Surgeon and CSF Specimen Source controlling for everything else	< 0.001
EVD Placement controlling for everything else	0.021
Surgeon and EVD Placement controlling for everything else	< 0.001
Surgeon and Procedure Time controlling for everything else	< 0.001
Surgeon and EVD Duration controlling for everything else	< 0.001
Procedure Time and EVD Duration controlling for everything else	0.031
EVD Duration controlling for everything else	< 0.001

Table 4 focused on specially on the patients' glucose levels and the possible variables that could have affected it. Neither the procedure time (p-value 0.238) nor the EVD duration (0.852) affected the glucose levels. Moreover, procedure time controlling for EVD duration (p-value 0.238) and EVD duration controlling for procedure time (p-value 0.853) did not have any significant effect on glucose levels either. The presence of HAIs was very significantly correlated to the glucose level (p-value 0.001). ANOVA analysis of the other variables, including surgeon (0.714), CSF specimen source (0.373), and EVD placement (0.459), did not yield significant

results. Both the additive model and the interactive model looking at the surgeon, CSF specimen source, and EVD placement were not significantly related to glucose levels (P-value 0.682 and 0.576, respectively). The additive model and interactive model using the ANCOVA regression analysis on all five variables (surgeon, CSF specimen source, EVD placement, procedure time, and EVD duration) also did not show any significant relation to the glucose levels (p-value 0.799 and 0.769, respectively).

Table 4 Glucose Level's Relation to Variables using Regression Analyses

Variable	p-value
Simple Regression Analysis	
Procedure Time	0.238
EVD Duration	0.852
Procedure Time controlling for EVD Duration	0.238
EVD Duration controlling for Procedure Time	0.853
ANOVA Regression Analysis	
HAI Presence	0.001
Surgeon	0.714
CSF Specimen Source	0.373
EVD Placement	0.459
Surgeon, CSF Specimen Source, EVD Placement (Additive)	0.682
Surgeon, CSF Specimen Source, EVD Placement (Interactive)	0.576
ANCOVA Regression Analysis	
Surgeon, CSF Specimen Source, EVD Placement, Procedure Time, EVD Duration (Additive)	0.799
Surgeon, CSF Specimen Source, EVD Placement, Procedure Time, EVD Duration (Interactive)	0.769

MANOVA regression analysis determined that there was so significant relation of the surgeon, CSF specimen source, EVD placement, procedure time, and EVD duration variables to both the white blood cell count and the glucose levels. Wilk's lambda test statistic had a p-value of 0.798, Lawley-Hotelling trace test statistic had a p-value of 0.812, Pillai's trace test statistic had a p-value of 0.783, and Roy's largest root test statistic had a p-value of 0.577.

Table 5 MANOVA Analysis of White Blood Cell Count and Glucose Level to All Variables

Variables	Wilks's Lambda	Lawley-Hotelling Trace	Pillai's Trace	Roy's Largest Root
Surgeon, CSF Specimen Source, EVD Placement, Procedure Time, EVD Duration	0.798	0.812	0.783	0.577

Testing means from ANOVA using pairwise comparison yielded the results from Table 6. The white blood cell ANOVA test for the surgeon and CSF specimen source interaction while controlling for EVD placement resulted in surgeon 5 and an EVD bag for the CSF specimen source compared to surgeon 2 and an EVD bag for the CSF specimen source was significant (p-value 0.44) with a contrast of 16787.13 ± 7340.216. The white blood cell ANOVA test for the surgeon and EVD placement interaction while controlling for CSF specimen source resulted in surgeon 5 and a surgical placement compared to surgeon 2 and a surgical placement was significant (p-value 0.11) with a contrast of 24684.16 ± 5991.203. The glucose ANOVA test for HAI presence showed a significant relationship when comparing the possible HAI entries to the entries which had no evidence of HAIs (p-value 0.001) with a contrast of -19.04 ± 5.631. The remaining comparisons displayed as "Not Estimable" in STATA.

Table 6 Pairwise Comparisons of Significant Variables for White Blood Cell Count and Glucose Levels

Variables	Contrast	p-value
White Blood Cell ANOVA		
Surgeon and CSF Specimen Source interaction controlling for EVD Placement	Surgeon 5 and EVD Bag vs. Surgeon 2 and EVD Bag (16787.13 ± 7340.216)	0.044
Surgeon and EVD Placement interaction controlling for CSF Specimen Source	Surgeon 5 and Surgical Placement vs. Surgeon 2 and Surgical Placement (24684.16 ± 5991.203)	0.011
Glucose Count ANOVA		
HAI Presence	HAI Possible vs. No Evidence of HAI (-19.04 ± 5.631)	0.001

The odds ratio of each variable on the presence of HAIs was also determined as showed in Table 7. For this logistic regression analysis, the possible and confirmed HAI entries were grouped together and were compared to the entries that had to evidence of HAIs. The odds ratio of the procedure time on HAIs was 1.001 (95% CI 0.999, 1.005) with a p-value of 0.290. EVD duration was found to be significant in determining the presence of HAIs with a p-value of < 0.001 and an odds ratio of 1.202 (95% CI 1.080, 1.338). The odds ratio of the surgeon on HAI presence was 1.047 (95% CI 0.803, 1.338) with a p-value of 0.735 and was not significant. CSF specimen source and EVD placement were both significantly related to HAI presence (p-value < 0.001 and 0.013, respectively) with odds ratios of 7.000 (CI 95% 2.888, 16.966) and 2.381 (95% CI 1.118, 5.074), respectively. When analyzing procedure time, EVD duration, surgeon, CSF specimen source, and EVD placement together in a joint odds ratio, the following outcomes were obtained when controlling for the other variables: procedure time had an odds ratio of 1.001 (95% CI 0.998, 1.005) and a p-value of 0.541, EVD duration had an odds ratio of 1.149 (95% CI 1.018, 1.300) and a p-value of 0.025, surgeon had an odds ratio of 1.032 (95% CI 0.751, 1.418) and a p-value of 0.847,

CSF specimen source had an odds ratio of 4.233 (95% CI 1.685, 10.635) and a p-value of 0.002, and EVD placement had an odds ratio of 1.623 (95% CI 0.642, 4.101) and a p-value of 0.306.

Table 7 Odds Ratios of Variables as Related to HAI Presence

Variables	Odds Ratios (95% CI)	p-value
Separate Analyses		
Procedure Time	1.001 (0.999, 1.005)	0.290
EVD Duration	1.202 (1.080, 1.338)	< 0.001
Surgeon	1.047 (0.803, 1.366)	0.735
CSF Specimen Source	7.000 (2.888, 16.966)	< 0.001
EVD Placement	2.381 (1.118, 5.074)	0.013
Joint Analyses		
Procedure Time	1.001 (0.998, 1.005)	0.541
EVD Duration	1.149 (1.018, 1.300)	0.025
Surgeon	1.032 (0.751, 1.418)	0.847
CSF Specimen Source	4.233 (1.685, 10.635)	0.002
EVD Placement	1.623 (0.642, 4.101)	0.306

4.0 Discussion

The factors chosen to determine possible risk association were based on recommendations from the CDC, guidelines from the Infectious Diseases Society of America (IDSA), and previously published research papers. Simple linear regression showed no significant impact of procedure time and EVD duration, both separately and together, on the white blood cell count or glucose levels. Since the white blood cell count and the glucose levels were used as a controlling factor for possible HAIs, the presence of increased white blood cells and a lower glucose was assumed to correlate with a possible infection. This was used in the many cases that a clear confirmed HAI was not verified by CSF culture. The results of these regression analyses disagreed with results that Lee, et al. (2018) and Korinek, et al. (1997) found, possibly because of the small sample size that was analyzed. It was unexpected because the longer the interior is exposed to the environment, the more likely it is to be exposed to infection-causing organisms.

ANOVA regression analysis demonstrated a significant link between the surgeon, CSF specimen source, and EVD placement on the white blood cell count when using the interactive model (p-value 0.020). When this was broken down, the two significant categories were surgeon and CSF specimen source interactions controlling for EVD placement (p-value 0.002) and surgeon and EVD placement interactions when controlling for CSF specimen source (p-value 0.003). Using postestimation methods of pairwise comparison with Scheffé correction, the significant connections within the interactive ANOVA model were tested. The surgeon and CSF specimen source interaction while controlling for EVD placement showed that surgeon five and a CSF sample from the EVD bag compared pairwise to surgeon two and a CSF sample from the EVD bag was significant (p-value 0.044) with a contrast in white blood cell count of 16787.13 ±

7340.216. The surgeon and EVD placement interaction while controlling for the CSF specimen source showed that surgeon five and a surgically placed EVD compared pairwise to surgeon two and a surgically placed EVD was significant (p-value 0.011) with a contrast in white blood cell count of 24684.16 ± 5991.203. Both of these outcomes could be the result of an outlier that had a particularly high white blood cell count than is typically found in the case of an infection. Furthermore, it was unusual to see that the presence of HAIs did not affect the white blood cell count because high counts of white blood cells were one of the characteristics used to classify presence of a possible HAI. This unusual result could be explained by a left-skewed distribution instead of a normal distribution of white blood cells. For the glucose levels, the only ANOVA regression analysis with significant results was the presence of HAIs (p-value 0.001). Pairwise comparison with Scheffé correction showed that the contrast between glucose levels in patients with possible HAIs and patients with no evidence of HAIs was -19.04 ± 5.631, which was significant with a p-value of 0.001. This was logical since low glucose levels were used to establish which patients had possible HAIs. No comparable data was found in the literature for CSF source and EVD placement and requires further analysis to determine whether a significant difference exists between the two and their connection to incidence of HAIs.

ANCOVA regression analysis established a significant link between the white blood cell count and an interactive model between the surgeon, CSF specimen source, EVD placement, procedure time, and EVD duration (p-value < 0.001). After breaking this regression model down, the following had significant interactions with the white blood cell count: surgeon controlling for everything else (p-value < 0.001), surgeon and CSF specimen source controlling for everything else (p-value < 0.001), EVD placement controlling for everything else (p-value 0.021), surgeon and EVD placement controlling for everything else (p-value < 0.001), surgeon and procedure time

controlling for everything else (p-value < 0.001), surgeon and EVD duration controlling for everything else (p-value < 0.001), procedure time and EVD duration controlling for everything else (p-value 0.031), and EVD duration controlling for everything else (p-value < 0.001). Postestimation analysis with this ANCOVA regression yielded results that were "Not Estimable". Having taken every variable into account resulted in a model that was significantly affecting the white blood cell count; however, there is no way of indicating by how much and which specific variables were significant because of the lack of postestimation calculations. There was no significant relationship between the additive and interactive ANCOVA models for any of the variables and the glucose levels. MANOVA showed no significant interactions between surgeon, CSF specimen source, EVD placement, procedure time, and EVD duration with the white blood cell count and the glucose levels.

The only significant variables when compared separately as they related to the presence of HAIs were EVD duration, which had an odds ratio of 1.001 (95% CI, 1.080, 1.338) and a p-value < 0.001, the CSF specimen source, which had an odds ratio of 7.000 (95% CI, 2.888, 16.966) and a p-value < 0.001, and the EVD placement, which had an odds ratio of 2.381 (95% CI, 1.118, 5.074) and a p-value 0.013. When the variables were analyzed together, the significant odds ratios were EVD duration with a p-value of 0.025 (OR 1.149; 95% CI 1.018, 1.300) and CSF specimen source with a p-value of 0.002 (OR 4.233, 95% CI 1.685, 10.635). While the EVD placement and CSF specimen source were not variables that were studied in research, the increase in HAIs as a result of EVD duration is a well-documented occurrence. Though it follows that a sample which has been collecting in a bag for a longer period of time is more likely to have growth in CSF culture compared to the CSF specimen, it is also possible that the greater number of entries prior to the

switch which required CSF collection from the buretrol is a confounding variable, implying that the reduction in HAIs may not necessarily be a result of the CSF specimen source.

The study is not without its limitations, the biggest one being that the study was a retrospective observational study. While a randomized control trial would be the most effective way to conduct the study, it cannot be conducted because of ethical reasons. Another limitation was that the number of patients was too small and attributed to the statistically inconclusive results. Because of how recent the policy change is, the number of patients after implementation of the policy is significantly fewer than the patients before policy implementation. Matching the cases to the controls and using pair-wise comparisons based on factors such as age, procedure description (e.g., craniotomy, hematoma evacuation), sex, or others could help to emphasize important factors. Even after trying to eliminate biases, there will still remain factors which have not been taken into account in determining causes or risk factors or the effect of the policy on HAI incidence.

This study can be improved upon and expanded by including other factors in the analysis to determine whether they have any effect on the presence of HAIs, such as age, sex, and/ or other comorbidities. Since the policy is recent and the patient sample size too small, redoing the study after some time has passed to increase sample size will help to determine whether any factors are significantly affecting HAIs. This study can eventually be used to continue updating policies regarding HAIs related to EVDs. Patients who are likely to be at risk based on these results can be monitored more closely for potential incidents of HAIs or can be given more aggressive prophylactic measures.

Appendix A Core Infection Prevention and Control Practices for Safe Healthcare Delivery in All Settings Recommendations by the HICPAC

Core Practices Table

Core Practice Category	Core Practices	Comments
1. Leadership Support References and resources: 1-12	1. Ensure that the governing body of the healthcare facility or organization is accountable for the success of infection prevention activities. 2. Allocate sufficient human and material resources to infection prevention to ensure consistent and prompt action to remove or mitigate infection risks and stop transmission of infections. Ensure that staffing and resources do not prevent nurses, environmental staff, et. al., from consistently adhering to infection prevention and control practices. 3. Assign one or more qualified individuals with training in infection prevention and control to manage the facility's infection prevention program. 4. Empower and support the authority of those managing the infection prevention program to ensure effectiveness of the program.	To be successful, infection prevention programs require visible and tangible support from all levels of the healthcare facility's leadership.
2. Education and Training of Healthcare Personnel on Infection Prevention References and resources: 1-4, 6-8, 10-13	1. Provide job-specific, infection prevention education and training to all healthcare personnel for all tasks. 2. Develop processes to ensure that all healthcare personnel understand and are competent to adhere to infection prevention requirements as they perform their roles and responsibilities. 3. Provide written infection prevention policies and procedures that are available, current, and based on evidence-based guidelines (e.g., CDC/ HICPAC, etc.) 4. Require training before individuals are allowed to perform their duties and at least annually as a refresher. 5. Provide additional training in response to recognized lapses in adherence and to address newly recognized infection transmission threats (e.g., introduction of new equipment or procedures).	Training should be adapted to reflect the diversity of the workforce and the type of facility, and tailored to meet the needs of each category of healthcare personnel being trained.
3. Patient, Family and Caregiver Education References and resources: 2-5, 7-8, 10-11	1. Provide appropriate infection prevention education to patients, family members, visitors, and others included in the caregiving network.	Include information about how infections are spread, how they can be prevented, and what signs or symptoms should prompt reevaluation and notification of the patient's healthcare provider. Instructional materials and delivery should address varied levels of education, language comprehension, and cultural diversity.

Core Practice Category	Core Practices	Comments
4. Performance Monitoring and Feedback References and resources: 1-14	1. Monitor adherence to infection prevention practices and infection control requirements. 2. Provide prompt, regular feedback on adherence and related outcomes to healthcare personnel and facility leadership. 3. Train performance monitoring personnel and use standardized tools and definitions. 4. Monitor the incidence of infections that may be related to care provided at the facility and act on the data and use information collected through surveillance to detect transmission of infectious agents in the facility.	Performance measures should be tailored to the care activities and the population served.
5. Standard Precautions	Use Standard Precautions to care for all patients in all settings. Standard Precautions include: 5a. Hand hygiene 5b. Environmental cleaning and disinfection 5c. Injection and medication safety 5d. Risk assessment with use of appropriate personal protective equipment (e.g., gloves, gowns, face masks) based on activities being performed 5e. Minimizing Potential Exposures (e.g. respiratory hygiene and cough etiquette) 5f. Reprocessing of reusable medical equipment between each patient and when soiled	Standard Precautions are the basic practices that apply to all patient care, regardless of the patient's suspected or confirmed infectious state, and apply to all settings where care is delivered. These practices protect healthcare personnel and prevent healthcare personnel or the environment from transmitting infections to other patients.
5a. Hand Hygiene References and resources: 3, 7, 11	1. Require healthcare personnel to perform hand hygiene in accordance with Centers for Disease Control and Prevention (CDC) recommendations. 2. Use an alcohol-based hand rub or wash with soap and water for the following clinical indications: a. Immediately before touching a patient b. Before performing an aseptic task (e.g., placing an indwelling device) or handling invasive medical devices c. Before moving from work on a soiled body site to a clean body site on the same patient d. After touching a patient or the patient's immediate environment e. After contact with blood, body fluids or contaminated surfaces f. Immediately after glove removal 3. Ensure that healthcare personnel perform hand hygiene with soap and water when hands are visibly soiled. 4. Ensure that supplies necessary for adherence to hand hygiene are readily accessible in all areas where patient care is being delivered.	Unless hands are visibly soiled, an alcohol-based hand rub is preferred over soap and water in most clinical situations due to evidence of better compliance compared to soap and water. Hand rubs are generally less irritating to hands and are effective in the absence of a sink. Refer to "CDC Guideline for Hand Hygiene in Health-Care Settings" or "Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, 2007" for additional details.

Core Practice Category	Core Practices	Comments
5b. Environmental Cleaning and Disinfection References and resources: 4, 7, 10, 11, 13, 21	1. Require routine and targeted cleaning of environmental surfaces as indicated by the level of patient contact and degree of soiling. a. Clean and disinfect surfaces in close proximity to the patient and frequently touched surfaces in the patient care environment on a more frequent schedule compared to other surfaces. b. Promptly clean and decontaminate spills of blood or other potentially infectious materials. 2. Select EPA-registered disinfectants that have microbiocidal activity against the pathogens most likely to contaminate the patient-care environment. 3. Follow manufacturers' instructions for proper use of cleaning and disinfecting products (e.g., dilution, contact time, material compatibility, storage, shelf-life, safe use and disposal).	When information from manufacturers is limited regarding selection and use of agents for specific microorganisms, environmental surfaces or equipment, facility policies regarding cleaning and disinfecting should be guided by the best available evidence and careful consideration of the risks and benefits of the available options. Refer to "CDC Guidelines for Environmental Infection Control in Health-Care Facilities" and "CDC Guideline for Disinfection and Sterilization in Healthcare Facilities" for details.
5c. Injection and Medication Safety References and resources: 11, 17-20	1. Use aseptic technique when preparing and administering medications 2. Disinfect the access diaphragms of medication vials before inserting a device into the vial 3. Use needles and syringes for one patient only (this includes manufactured prefilled syringes and cartridge devices such as insulin pens). 4. Enter medication containers with a new needle and a new syringe, even when obtaining additional doses for the same patient. 5. Ensure single-dose or single-use vials, ampules, and bags or bottles of parenteral solution are used for one patient only. 6. Use fluid infusion or administration sets (e.g., intravenous tubing) for one patient only 7. Dedicate multidose vials to a single patient whenever possible. If multidose vials are used for more than one patient, restrict the medication vials to a centralized medication area and do not bring them into the immediate patient treatment area (e.g., operating room, patient room/cubicle) 8. Wear a facemask when placing a catheter or injecting material into the epidural or subdural space (e.g., during myelogram, epidural or spinal anesthesia)	Refer to "Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, 2007" for details.

Core Practice Category	Core Practices	Comments
5d. Risk Assessment with Appropriate Use of Personal Protective Equipment References and resources: 7, 11, 20	1. Ensure proper selection and use of personal protective equipment (PPE) based on the nature of the patient interaction and potential for exposure to blood, body fluids and/or infectious material: a. Wear gloves when it can be reasonably anticipated that contact with blood or other potentially infectious materials, mucous membranes, non-intact skin, potentially contaminated skin or contaminated equipment could occur. b. Wear a gown that is appropriate to the task to protect skin and prevent soiling of clothing during procedures and activities that could cause contact with blood, body fluids, secretions, or excretions. c. Use protective eyewear and a mask, or a face shield, to protect the mucous membranes of the eyes, nose and mouth during procedures and activities that could generate splashes or sprays of blood, body fluids, secretions and excretions. Select masks, goggles, face shields, and combinations of each according to the need anticipated by the task performed. d. Remove and discard PPE, other than respirators, upon completing a task before leaving the patient's room or care area. If a respirator is used, it should be removed and discarded (or reprocessed if reusable) after leaving the patient room or care area and closing the door. e. Do not use the same gown or pair of gloves for care of more than one patient. Remove and discard disposable gloves upon completion of a task or when soiled during the process of care. f. Do not wash gloves for the purpose of reuse. 2. Ensure that healthcare personnel have immediate access to and are trained and able to select, put on, remove, and dispose of PPE in a manner that protects themselves, the patient, and others	PPE, e.g., gloves, gowns, face masks, respirators, goggles and face shields, can be effective barriers to transmission of infections but are secondary to the more effective measures such as administrative and engineering controls. Refer to "Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, 2007" as well as Occupational Safety and Health Administration (OSHA) requirements for details.
5e. Minimizing Potential Exposures References and resources: 1, 7, 11, 16	1. Use respiratory hygiene and cough etiquette to reduce the transmission of respiratory infections within the facility. 2. Prompt patients and visitors with symptoms of respiratory infection to contain their respiratory secretions and perform hand hygiene after contact with respiratory secretions by providing tissues, masks, hand hygiene supplies and instructional signage or handouts at points of entry and throughout the facility 3. When space permits, separate patients with respiratory symptoms from others as soon as possible (e.g., during triage or upon entry into the facility).	Refer to "Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, 2007" for details.

Core Practice Category	Core Practices	Comments
5f. Reprocessing of Reusable Medical Equipment References and resources: 2-4, 7-8, 11-13	1. Clean and reprocess (disinfect or sterilize) reusable medical equipment (e.g., blood glucose meters and other point-of-care devices, blood pressure cuffs, oximeter probes, surgical instruments, endoscopes) prior to use on another patient and when soiled. a. Consult and adhere to manufacturers' instructions for reprocessing. 2. Maintain separation between clean and soiled equipment to prevent cross contamination.	Manufacturer's instructions for reprocessing reusable medical equipment should be readily available and used to establish clear operating procedures and training content for the facility. Instructions should be posted at the site where equipment reprocessing is performed. Reprocessing personnel should have training in the reprocessing steps and the correct use of PPE necessary for the task. Competencies of those personnel should be documented initially upon assignment of their duties, whenever new equipment is introduced, and periodically (e.g., annually). Additional details about reprocessing essentials for facilities can be found in HICPAC's recommendations Essential Elements of a Reprocessing Program for Flexible Endoscopes (https://www.cdc.gov/hicpac/recommendations/flexible-endoscope-reprocessing.html). Refer to "CDC Guideline for Disinfection and Sterilization in Healthcare Facilities" for details.
6. Transmission-Based Precautions References and resources: 7, 11	1. Implement additional precautions (i.e., Contact, Droplet, and/or Airborne Precautions) for patients with documented or suspected diagnoses where contact with the patient, their body fluids, or their environment presents a substantial transmission risk despite adherence to Standard Precautions 2. Adapt transmission-based precautions to the specific healthcare setting, the facility design characteristics, and the type of patient interaction. 3. Implement transmission-based precautions based on the patient's clinical presentation and likely infection diagnoses (e.g., syndromes suggestive of transmissible infections such as diarrhea, meningitis, fever and rash, respiratory infection) as soon as possible after the patient enters the healthcare facility (including reception or triage areas in emergency departments, ambulatory clinics or physicians' offices) then adjust or discontinue precautions when more clinical information becomes available (e.g., confirmatory laboratory results). 4. To the extent possible, place patients who may need transmission-based precautions into a single-patient room while awaiting clinical assessment. 5. Notify accepting facilities and the transporting agency about suspected infections and the need for transmission-based precautions when patients are transferred.	Implementation of Transmission-Based Precautions may differ depending on the patient care settings (e.g., inpatient, outpatient, long-term care), the facility design characteristics, and the type of patient interaction, and should be adapted to the specific healthcare setting. Refer to "Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, 2007" for details.

Core Practice Category	Core Practices	Comments
7. Temporary invasive Medical Devices for Clinical Management References and resources: 8, 1	1. During each healthcare encounter, assess the medical necessity of any invasive medical device (e.g., vascular catheter, indwelling urinary catheter, feeding tubes, ventilator, surgical drain) in order to identify the earliest opportunity for safe removal. 2. Ensure that healthcare personnel adhere to recommended insertion and maintenance practices	Early and prompt removal of invasive devices should be part of the plan of care and included in regular assessment. Healthcare personnel should be knowledgeable regarding risks of the device and infection prevention interventions associated with the individual device, and should advocate for the patient by working toward removal of the device as soon as possible. Refer to "CDC Guidelines for Environmental Infection Control in Health-Care Facilities" and "CDC Guideline for Disinfection and Sterilization in Healthcare Facilities" for details.
8. Occupational Health References and resources: 1, 7, 16, 20	1. Ensure that healthcare personnel either receive immunizations or have documented evidence of immunity against vaccine-preventable diseases as recommended by the CDC, CDC's Advisory Committee on Immunization Practices (ACIP) and required by federal, state or local authorities. 2. Implement processes and sick leave policies to encourage healthcare personnel to stay home when they develop signs or symptoms of acute infectious illness (e.g. fever, cough, diarrhea, vomiting, or draining skin lesions) to prevent spreading their infections to patients and other healthcare personnel. 3. Implement a system for healthcare personnel to report signs, symptoms, and diagnosed illnesses that may represent a risk to their patients and coworkers to their supervisor or healthcare facility staff who are responsible for occupational health 4. Adhere to federal and state standards and directives applicable to protecting healthcare workers against transmission of infectious agents including OSHA's Bloodborne Pathogens Standard, Personal Protective Equipment Standard, Respiratory Protection standard and TB compliance directive.	It is the professional responsibility of all healthcare organizations and individual personnel to ensure adherence to federal, state and local requirements concerning immunizations; work policies that support safety of healthcare personnel; timely reporting of illness by employees to employers when that illness may represent a risk to patients and other healthcare personnel; and notification to public health authorities when the illness has public health implications or is required to be reported. Refer to OSHA's website for specific details on healthcare standards: Occupational Safety and Health Administration - Infectious Diseases (https://www.osha.gov/SLTC/healthcarefacilities/infectious_diseases.html).

Appendix B Institution's EVD Policy

Patient Care Policies and Procedures

TITLE: **INTRACRANIAL PRESSURE (ICP) MONITORING DEVICES -CARE OF**

POLICY: All patients with an intracranial pressure device will be cared for by a Registered Professional Nurse (RN), who has been oriented to ICP monitoring and external ventricular drain (EVD) management.

A nurse to nurse consultation will be requested and provided by an experienced Critical Care Unit nurse from MICU, TBC or RIC whenever necessary.

POINTS TO REMEMBER:

1. Normal ICP is 0-15mmHg.
2. Refer to ICP maintenance protocol when severe TBI orders utilized.
3. **EVDs can only be flushed by a physician or advanced practice provider (APP).**
4. A cerebrospinal fluid (CSF) sample is sent for C&S/gram stain, cell count, protein and glucose on Monday and Thursday weekly.
5. Level of drip chamber is measured in cms of water. Always reference the black column labeled ventricular cm H2O on the Duet External Ventricular Drainage and Monitoring System.
6. The transducer is leveled and zeroed at the external auditory canal. The transducer is leveled and zeroed every four hours and after every position change.
    a. To level: The laser is balanced with bubble in designated lines and laser beam in alignment with external auditory canal.

b. To zero transducer: Place drip chamber at zero level, turn stopcock off to patient and press zero button on monitor. The dead-end cap does not need to be removed because the air filter in the drip chamber is outlet to atmospheric pressure.

7. The dressing is placed by the physician or APP and will remain on unless it becomes soiled, comes off, or per physician order. The drainage tubing should not be routinely changed; it should remain for the duration of the EVD per AANN Clinical Practice Guidelines.

8. Assess the amount of drainage every hour. Record each time the drip chamber is emptied in the I&O section of the medical record every eight hours. Empty when full and at the end of each eight-hour shift.

9. A PT 48 (pressure tubing extension) may be added for radiology procedures under sterile conditions.

10. Whenever a neurosurgery physician or advanced practice provider performs interventions that break the EVD system, hand hygiene, 5 barriers (mask, cap, sterile gloves, sterile gown, and sterile drape) and sterile technique are required.

11. All EVD systems are to be clamped when transporting or changing level of head of bed, unless a physician's order states otherwise, by turning the stopcock closest to the insertion site off.

12. The laser is NOT part of the External Drainage and Monitoring system. Remove the laser when the drain is discontinued, and return it to designated storage area in unit.

13. A sign should be placed above the patient's bed warning not to move patient's bed.

A. <u>EXTERNAL DRAINAGE AND MONITORING SYSTEM (EDMS) SET UP FOR AN EXTERNAL VENTRICULAR DRAIN</u>
(RN)

EQUIPMENT: Sterile pack
3 sets sterile gloves, masks, hats
1 ICP monitoring kit (Duet External Drainage and Monitoring system)
3 non vented caps (included in drainage kit)

1 20mL syringe with interlink device
20mL sterile saline (preservative free)
1 Blunt Fill Needle
Transducer
2 packs sterile towels
EVD tubing label
Pressure cable
Laser

PROCEDURE:

1. Explain procedure to patient.
2. Perform hand hygiene.
3. Don cap and mask.
4. Open sterile towels.
5. Place sterile towels on bedside stand creating a sterile field.
6. Open EDMS, transducer, non-vented caps, one 20 ml syringe, one fill needle, and place on towels.
7. Perform hand hygiene and don sterile gloves.
8. Replace port caps with non-vented caps.
9. Attach tubing bracket to area on side marked "ventricular."
10. Connect transducer tubing to stopcock proximal to drip chamber.
11. With another nurse's assistance, draw up 20mL bacteriostatic saline.
12. Connect normal saline filled syringe to transducer end. Slowly flush out proximal port and flush to drip chamber.
    a. Close stopcock to drip chamber and flush remainder of pressure tubing to stopcock.
    a. Flush out port then flush to end.
13. Inspect entire length of tubing to make sure there are no air bubbles.

14. Remove the syringe and replace with non-vented cap.

15. Cover the tubing with sterile towels and prepare for insertion or tubing change.

B. INSERTION OF EXTRAVENTRICULAR DRAIN

EQUIPMENT:

Pre-procedure antibiotic (Cefazolin and/or Vancomycin)
Sterile pack
EVD catheter
EVD insertion tray
Xylocaine 1% with epinephrine
2 chlorhexidine prep sponges (Chloraprep)
#11 blade
Three packs of 3-0 nylon suture
Sterile gloves, masks, caps
Standard pack
Line dressing kit
Clippers with disposable head attachment
Telfa Dressing (optional: Benzoin or Mastisol to enhance adhesion)
Staple gun

External Ventricular Drain Placement Protocol (Physician/APP)

1. Gather equipment and perform hand hygiene.
2. Explain procedure to patient.
3. Position patient supine, with head of bed elevated 30-45 degrees.
4. Formal timeout.
5. Document consent on all patients in separate procedure note.
6. Administer single dose pre-op intravenous antibiotic:
   a. 1g Cefazolin or, if severe PCN allergy, 1 g Vancomycin administered within one hour of incision.

b. Both Cefazolin and Vancomycin should be administered if patient has history of MRSA colonization or infection.

c. In emergent cases antibiotic can be given post-procedurally.

7. Clip frontal region hair with clippers.

8. Perform 3-minute chlorhexidine sponge pre-scrub then dry with sterile towels. This pre-scrub can be abbreviated in emergent cases.

9. Sterile gown, sterile gloves, cap, and mask worn by physician operator; cap and mask worn by all in attendance with curtain closed to room.

10. Prep with 2 chlorhexidine prep sponges and allow to dry 3 minutes.

11. Anesthetize insertion site with Xylocaine 1% with epinephrine.

12. Perform standard catheter placement.

13. Monofilament 3-0 nylon suture only for skin closure and securing EVD catheter to skin.

14. Continue sterile technique through initial connection to drainage system.

15. Apply Telfa dressing (optional: benzoin or mastisol to enhance adhesion).

16. Enter formal procedure note in medical record.

External Ventricular Drain Placement Protocol
(RN)

1. Secure External Drainage and Monitoring system to bedside pole. Maintain the sterile field of patient end. Connect monitor cable to bedside monitor and to transducer. Rotate pressure column to the black "ventricular cm H2O" scale. Balance and zero, use 0-30mm/hg range scale on monitor.

2. Don cap and mask. **All personnel in attendance must wear a cap and mask. Room curtain must remain closed.**

3. Assist the physician/APP with draping the insertion site with sterile towels.

4. Maintaining sterile technique, open the EVD insertion tray and EVD catheter onto the sterile field. Place sterile end of EDMS on sterile field. The physician will take the end of the EDMS and secure on sterile field.

5. Make certain before the EVD is inserted that the transducer has been leveled and zeroed. The physician inserts the catheter into the desired location and sutures it in place. He attaches the end to the EDMS.

6. The nurse obtains an ICP reading. (Stopcock off to drip chamber.)

7. Document on the "Invasive Procedure Universal Protocol" form, date and time catheter inserted, tolerance of procedure, initial ICP reading, appearance of waveform, appearance of CSF, date and time of dressing and characteristics of insertion site in medical record.

C. **DRESSING CHANGE: IF ORDERED, SOILED, OR DISLODGED (Physician/APP)**

EQUIPMENT:
Sterile towels
Line dressing kit
Cap, mask and sterile gloves
Chlorhexidine prep sponge (Chloraprep)
Benzoin or Mastisol (optional)

PROCEDURE:

1. Explain procedure to patient.

2. Perform hand hygiene.

3. Don cap and mask.

4. Don sterile gloves.

5. Drape sterile towels around head and insertion site.

6. Remove existing dressing.
7. Discard gloves and perform hand hygiene.
8. Open dressing kit and don sterile gloves.
9. Cleanse with chlorhexidine prep sponge. Allow to dry.
10. Apply benzoin or mastisol and let dry.
11. Apply sterile Telfa dressing.
12. Document dressing change in medical record.

D. **OBTAINING CEREBRAL PERFUSION PRESSURE (CPP) READINGS (RN)**

PROCEDURE:

1. Obtain Mean arterial pressure by calculating [systolic + (2 x diastolic)]÷ 3, or by using mean button on monitor.
2. Subtract Mean ICP from Mean arterial pressure to equal CPP (MAP - ICP = CPP).
3. Record CPP in medical record a minimum of every hour and every time an ICP reading is done.
4. Notify physician for CPP less than 60 mm Hg.

E. **CSF SAMPLING FROM EVD (RN)**

EQUIPMENT:
Sterile gloves
Chlorhexidine prep sponge (Chloraprep)
Sterile towel
Sterile syringe
Collection tubes

PROCEDURE:

1. CSF samples will be drawn routinely every Monday and Thursday. CSF samples can be ordered outside of this schedule if there is clinical suspicion for infection.
2. Perform hand hygiene.
3. Turn proximal stopcock off to patient and distal stopcock off to drainage bag.
4. Open sterile towel.
5. Apply mask and sterile gloves.
6. Cleanse port on stopcock distal to the drip chamber with Chloraprep for 30 seconds.
7. Withdraw CSF from stopcock distal to drip chamber into sterile syringe.
8. Use sterile technique to transfer CSF sample from syringe to collection tubes.
9. Label and send tubes to Lab with irretrievable sticker.
10. Make sure to return stopcocks to ordered positions.
11. Document sampling procedure in medical record.

F. INSTILLATION INTO PROXIMAL PORT OF EDMS
(Physician/ APP)

1. To be performed by neurosurgery physician/APP.
2. Hand hygiene and sterile technique (cap, mask, sterile gown and gloves) maintained.
3. Perform chlorhexidine sponge prep of hub for 3 minutes and let dry.
4. Saline must be preservative free.

5. Document procedure in medical record.

G. CHANGING OF CSF COLLECTION BAG (RN)

EQUIPMENT:

New drainage bag
Sterile gloves
Sterile towel
Chlorhexidine prep sponge (Chloraprep)
Non-vented cap

PROCEDURE:

1. CSF drainage bag will be changed when the bag is full.
2. Perform hand hygiene.
3. Turn proximal stopcock off to patient and distal stopcock off to drainage bag.
4. Open sterile towel to use as sterile field.
5. Apply mask and sterile gloves.
6. Cleanse area of the leur lock connection between the stopcock and drainage bag with chlorhexidine prep sponge for 30 seconds.
7. Remove bag. Attach nonvented cap, and discard in biohazard waste container.
8. Attach new bag.
9. Make sure to return stopcocks to ordered positions.
10. Document procedure in medical record.

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