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CLINICAL ARTICLE

A standardized infection prevention bundle for reduction of CSF shunt infections in adult ventriculoperitoneal shunt surgery performed without antibiotic-impregnated catheters

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OBJECTIVE Ventriculoperitoneal (VP) shunt insertion and revision surgeries are some of the most common procedures that are performed by neurosurgeons. Shunt infections within the adult population are associated with significant morbidity and mortality and rates remain high. The objective of the current study was to use quality improvement (QI) methodology to create a standardized infection prevention bundle aimed at reducing the rate of shunt infections.

METHODS A prospective, single-center, single-surgeon QI study was undertaken. Patients were included if they were 18 years of age or older and were undergoing a VP shunt insertion or revision. The primary outcome of the study was the development of a shunt-related surgical site infection, within 1 year of surgery, as defined according to the Canadian Nosocomial Infection Surveillance Program guidelines. There was no standardized protocol prior to July 2013. A bundle coined as the Calgary Adult Shunt Infection Prevention Protocol (CASIPP) was implemented on July 1, 2013, and updated on July 1, 2015, when 2% chlorhexidine gluconate in 70% isopropyl alcohol replaced povidone-iodine for preoperative skin antisepsis. Protocol compliance was regularly monitored using a standardized process. No antibiotic-impregnated catheters were used.

RESULTS A total of 621 consecutive VP shunt insertions and revisions were included in the study. The rate of shunt infection was 5.8% during the period in which there was no standardized shunt protocol. After the implementation of the CASIPP the infection rate decreased to 4.0%, and after introduction of the chlorhexidine/alcohol skin antisepsis, the infection rate was 0% in 379 consecutive procedures ($p < 0.0001$). Multivariable logistic regression analysis demonstrated that the use of chlorhexidine/alcohol with CASIPP was associated with a significant reduction in the odds of developing a shunt infection (OR 0.032, 95% CI 0–0.19, $p = 0.0005$).

CONCLUSIONS The implementation of a standardized shunt infection prevention bundle within the adult population, without the use of antibiotic-impregnated catheters, significantly reduced the rate of shunt infections which was sustained over many years. The use of 2% chlorhexidine gluconate in 70% isopropyl alcohol for preoperative antisepsis may have played a significant role. Multicenter studies should be completed to verify the effectiveness of the authors' protocol.

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KEYWORDS hydrocephalus; shunt; infection

ABBREVIATIONS AIC = antibiotic-impregnated catheter; CASIPP = Calgary Adult Shunt Infection Prevention Protocol; CNISP = Canadian Nosocomial Infection Surveillance Program; FMC = Foothills Medical Center; HCRN = Hydrocephalus Clinical Research Network; iNPH = idiopathic normal pressure hydrocephalus; IPC = infection prevention and control; QI = quality improvement; VP = ventriculoperitoneal.

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Hydrocephalus is a common debilitating neurological condition affecting approximately 175 per 100,000 adults.[1] Patients with hydrocephalus are unable to clear CSF from their brain, which leads to progressive accumulation of CSF and brain injury.[1,2] The only effective treatments for hydrocephalus involve diversion of CSF within the brain with an endoscopic third ventriculostomy or the permanent diversion of CSF away from the brain with a shunt implant. The most common shunt types are the ventriculoperitoneal (VP), ventriculoatrial, and lumboperitoneal.[3–5] VP shunt implantation is a predominant neurosurgical procedure worldwide in both children and adults.[6–8]

While treatment of hydrocephalus in adults with a CSF shunt is effective, the surgical procedure is frequently complicated by failure of the shunt system, which requires surgical revision.[3] The initial and any subsequent shunt surgeries in adult patients have also been associated with a high (5%–15%) risk of infection during the first postoperative year.[7–11] Shunt infections are associated with significant morbidity and mortality, which adversely affect both families and patients.[10,11] At a minimum, shunt infections usually result in additional surgical procedures, prolonged intravenous antibiotic treatment, and extended hospital stays, with the average direct hospital costs per infection ranging between $50,000 and $100,000 USD.[12]

Numerous perioperative and intraoperative strategies have been proposed to reduce the rate of shunt infections.[13–18] While high-quality randomized clinical trials have not been undertaken, numerous quality improvement (QI) studies, although limited to the pediatric patient population, have convincingly demonstrated that standardized shunt infection prevention bundles that are protocolized are an effective way to reduce the rate of shunt infections. The Hydrocephalus Clinical Research Network (HCRN) instituted an 11-step protocol for shunt insertion procedures at multiple HCRN member sites, which resulted in an overall reduction in shunt infections from 8.8% to 5.7% in 1571 pediatric patients.[16] Yang et al. subsequently demonstrated that implementation of the HCRN protocol at a nonmember pediatric site also resulted in a reduction in the shunt infection rate.[17] While Okamura et al. recently published their results with a shunt infection reduction protocol in 52 adult patients, comprehensive studies focused on the implementation of infection reduction protocols are lacking in the adult hydrocephalus patient population.[18] Accordingly, we sought to develop and assess the efficacy of a standardized shunt infection reduction bundle, utilizing QI methodology, for adults undergoing a surgical insertion or revision of a VP shunt. We hypothesized that implementation of that protocol would lead to a reduction in the rate of shunt infections over time without the use of antibiotic-impregnated CSF shunts.

Methods

This QI initiative was a prospective cohort study that compared the rate of postoperative shunt infections before and after implementation of a standardized shunt protocol at the Foothills Medical Center (FMC), Calgary, Alberta, Canada. Surgeries were conducted by a single surgeon. The study was prepared according to the Standards for Quality Improvement Reporting Excellence (SQUIRE 2.0) guidelines.[19]

Shunt Protocol

Prior to this study there were no standardized protocols directed at the reduction of infection rates associated with CSF shunt procedures at our institution. Certain practices ubiquitous to most surgical procedures, such as preoperative intravenous antibiotic administration and skin preparation with povidone-iodine, were typically undertaken. To address the issue of standardization, multidisciplinary meetings were held with members of the neurosurgical and the Infection Prevention and Control (IPC) teams to create, refine, and implement the infection prevention bundle we termed the Calgary Adult Shunt Infection Prevention Protocol (CASIPP), which was designed to reduce the rate of shunt infections.

A literature review was undertaken to determine which elements were appropriate for inclusion as part of the CASIPP, including examination of elements from the successful HCRN shunt infection protocol.[16] Prophylactic antibiotics and normothermia were included in the protocol, as several studies had demonstrated that ongoing maintenance of normothermia and administration of antibiotics at least 30 minutes prior to incising the skin both lead to a reduction in surgical site infections.[20–22] Normothermia was defined as a core temperature between 36°C and 37.5°C and was monitored by the anesthesia team during the operative procedure.[23–25]

Surgical iodine–impregnated adhesive drapes (e.g., Ioban) were part of our protocol as they have been shown to reduce the risk of surgical site infections in other surgical procedures by reducing skin contact with shunt implants and holding surgical drapes in place.[26] Bejko et al. conducted a study in a group of 5100 cardiovascular surgery patients in whom an Ioban drape significantly reduced the rate of surgical site infections (6.5% vs 1.9%, $p = 0.001$).[26] Double gloving was a feature of our protocol, as previous studies have demonstrated that it can reduce the rate of infection during shunt procedures.[27,28] Tulipan and Cleves performed a study on 863 patients who had undergone a CSF diversion procedure and the rate of shunt infection was 15.2% in the single-glove group compared to 6.7% in the double-gloved group ($p = 0.0002$).[27] Similarly, another study by Kulkarni et al. found that handling of the shunt when surgical gloves were breached was a significant predictor for the development of a shunt infection.[28] The evidence to support a significant benefit versus the risk and costs of either injection of intrathecal antibiotics into the shunt reservoir at the time of surgery or the use of antibiotic-impregnated catheters (AICs) was not strong enough in adult patients to be included in the protocol.[14,18,29] Ultimately, we identified four pre- and perioperative elements: 1) preoperative optimization; 2) perioperative field sterile precautions; 3) perioperative staff sterile precautions; and 4) factors related to the shunt system (Fig. 1).

The CASIPP was implemented on July 1, 2013. After the implementation of the protocol the neurosurgical and IPC teams continued to hold regular meetings to review the infection rates and to discuss possible changes

1.	**Preoperative optimization**	Avoidance of hypothermia or hyperglycemia	Administer prophylactic antibiotics at least 30 minutes prior to first skin incision*	Limit operating room traffic#
2.	**Operating field sterile precautions**	Use alcohol-based chlorhexidine solution for prepping surgical field	Wait 3 minutes for prep to dry before applying drapes	Ioban applied to surgical field
3.	**Operating staff sterile precautions**	Full standard hand scrub required by all participants	All participants double glove for procedure	Outer gloves of all participants changed after draping completed
4.	**Shunt system**	Each shunt implant packaging only opened when needed	Avoid contacting the shunt device with the drapes	Ensure minimal shunt device handling

** Cefazolin 2g IV is recommended as first line agent. Clindamycin 500 mg IV may be used if patient has cefazolin allergy*
 # Only essential staff in operating room. Ideally no more than 7 persons and avoid unnecessary traffic in/out of operating theater

FIG. 1. Calgary Adult Shunt Infection Prevention Protocol (final version). IV = intravenous.

that could be made to the protocol. On July 1, 2015, 2% chlorhexidine gluconate in 70% isopropyl alcohol was substituted for the previously used povidone-iodine solution for preoperative skin antisepsis (Fig. 1). This adjustment was based on several studies that had demonstrated that 2% chlorhexidine gluconate in 70% isopropyl alcohol was superior to povidone-iodine for preoperative skin antisepsis.[30–33] In 2018, a preoperative chlorhexidine bath regimen was implemented given that it was low risk and had been shown to reduce the rates of postoperative infection in certain patient populations.[34]

Patient Population

The Calgary Adult Hydrocephalus Clinic Database was evaluated in conjunction with the IPC to establish an 18-month (January 2012 until June 2013) baseline shunt infection rate when no standardized shunt protocol was being used. All documented VP shunt surgeries were reviewed by the IPC to identify all patients with positive CSF cultures, and each of these identified patients was adjudicated by medical record review to determine if they met the Canadian Nosocomial Infection Surveillance Program (CNISP) guidelines for the determination of a shunt surgery–associated infection (Table 1).[35]

Consecutive patients undergoing shunt insertion or revision surgery at the FMC by a single experienced neurosurgeon (M.G.H.) between January 2012 and January 2021 were assessed for enrollment in the study. The inclusion criteria were age ≥ 18 years and patients undergoing placement or revision of a VP shunt. Occasional shunt insertions by other neurosurgeons were excluded to allow a uniform patient population. Patients had a minimum postoperative follow-up interval of 1 year. Patients who underwent a CSF diversion surgery other than a VP shunt were excluded.

Data Collection and Variables

Data were collected prospectively for patients before and after implementation of the CASIPP. From January 1, 2012, to July 1, 2013, data were collected on the infection rates of patients who underwent a shunt surgery without following a standardized protocol. On July 1, 2013, the CASIPP was implemented and the data on all patients undergoing a shunt surgery were collected prospectively until January 2021. A detailed analysis of medical charts and operative notes was completed to determine important clinical characteristics of the patients and to further define the nature of the infected shunts. Data regarding age, sex, etiology of hydrocephalus, and type of procedure were collected. The etiology of hydrocephalus was classified as acquired, unrecognized congenital, transitional, or idiopathic normal pressure hydrocephalus (iNPH).[36] The type of procedure was categorized as a shunt insertion if all of the hardware elements were newly inserted at the time of the procedure and as a shunt revision if at least one part of the preexisting shunt remained within the patient after the procedure was completed. The period in which there was no protocol was defined as "no protocol," the period after the implementation of the initial CASIPP was defined as "initial CASIPP," and the period after which 2% chlorhexidine gluconate in 70% isopropyl alcohol was defined as the "CASIPP with chlorhexidine/alcohol." The senior author used a checklist to record whether compliance with the protocol was achieved after each procedure was completed by using a checklist (see Supplementary Fig. 1).

Outcome Measure

The primary outcome measure of this study was a shunt-related surgical site infection, which was defined according to the CNISP guidelines (Table 1).[35] Patients were evaluated for possible shunt infections during clinic visits, emergency room visits, and hospital admissions for a minimum of 12 months from the procedure date. A secondary outcome measure was compliance with the CASIPP checklist (see Supplementary Fig. 1).

TABLE 1. Diagnostic criteria for a shunt infection according to the CNISP

CNISP Criteria in Pts w/ In Situ Shunt
Microbe isolated from CSF & ≥1 of the following:
Fever (≥38.0°C)
Neurological signs or symptoms
Abdominal signs or symptoms
Shunt malfunction/obstruction signs or symptoms

Pt = patient.

TABLE 2. Baseline characteristics of the 621 shunting procedures included in the study

Variable	Value
Pt age, yrs	
<60	146 (23.5%)
60 to <75	203 (32.7%)
75 to <80	112 (18.0%)
≥80	160 (25.8%)
Sex	
Male	369 (59.4%)
Female	252 (40.6%)
Etiology	
Acquired	97 (15.6%)
Congenital	72 (11.6%)
Transitional	47 (7.6%)
iNPH	405 (65.2%)
Procedure type	
New insertion	330 (53.1%)
Revision	291 (46.9%)
Protocol	
No protocol	69 (11.1%)
Initial CASIPP	173 (27.9%)
CASIPP w/ chlorhexidine/alcohol	379 (61.0%)
Follow-up duration, mos	46.1 ± 28.6

Values are presented as number (%) of patients or mean ± SD.

Statistical Analysis

The primary analytical aim was the comparison of shunt infection rates between three periods: 1) no protocol, 2) after initial implementation of the CASIPP, and 3) after implementation of chlorhexidine/alcohol for preoperative skin antisepsis. Continuous variables are reported as means ± standard deviations. Categorical variables are reported as frequencies (n) and percentages. Univariable association of categorized factors with infection was assessed using a Fisher's exact test or chi-square test with Yates' correction, as appropriate. Variables with $p < 0.10$ on the univariate analysis were included in the multivariable logistic regression analysis. Due to the limited number of outcome events, odds ratios, confidence intervals, and p values in the multivariable logistic regression models were computed using exact conditional analysis. Two-sided p values < 0.05 were considered significant. Statistical analyses were performed using SAS version 9.4.

Ethics

The study was assessed by the University of Calgary Conjoint Health Research Ethics Board and was considered exempt from review in accordance with the QI methodology that was planned. At the completion of the QI study, ethics approval was obtained to undertake detailed analysis with a waiver of consent. There were no investigator or patient conflicts of interest.

Results

There were 621 procedures performed in 400 patients from January 2012 to January 2021. Sixty-nine (11.1%) procedures occurred before the introduction of any shunt protocol, and 173 (27.9%) procedures took place after implementation of the initial CASIPP, and 379 (61.0%) procedures occurred after chlorhexidine/alcohol use was implemented as a preoperative skin preparation for all patients (Table 2). The etiology of hydrocephalus for most of the patients was iNPH (65.2%), with the remaining patients having a combination of acquired (15.6%), unrecognized congenital (11.6%), and transitional (7.6%) hydrocephalus.[36] New shunt insertions constituted 53.1% of the procedures, and the remainder were shunt revisions (Table 2). There was no significant change in the etiology of hydrocephalus during the study period. The numbers of shunt revisions during each phase of the study were also very similar. The percentage of cases that were revisions were 44% before the bundle was implemented, 47% after the initial implementation of the bundle, and 47% after it was mandated that chlorhexidine/alcohol be used for antisepsis.

There were 11 shunt infections that occurred during the study period. Four of these infections were during the period in which there was no protocol and 7 occurred after the implementation of the initial CASIPP, and there were no infections after chlorhexidine/alcohol was substituted for preoperative skin antisepsis (Table 3; Fig. 2). These results translated to a shunt infection rate of 5.8%, 4.0%, and 0% for the respective periods ($p < 0.0001$). Ten of the infections occurred during a new shunt insertion and only 1 infection developed after a shunt revision; the association of procedure type with infection was found to be significant ($p = 0.01$). There was no significant association between age ($p = 0.13$), sex ($p > 0.99$), or hydrocephalus etiology ($p = 0.38$) and the development of a shunt infection.

Thirteen organisms were identified as being responsible for the development of a shunt infection (Table 4). The most common organism was coagulase-negative *Staphylococcus* (46.1%), followed by *Staphylococcus aureus* (23.1%). In 2 patients, multiple organisms were identified.

Compared to the period in which there was no protocol, and with adjustment for the effect of new shunt insertion versus revision, the use of the CASIPP with chlorhexidine/alcohol was independently associated with a reduced risk of shunt infection when adjusting for type of procedure (CASIPP with chlorhexidine/alcohol vs no protocol used, exact OR 0.032, 95% CI 0–0.19, $p = 0.0005$) (Table 5).

TABLE 3. Univariable analysis of patient and procedure characteristics

Variable	Shunt Infection		p Value
	Yes (n = 11)	No (n = 610)	
Age, yrs			0.13
<60	3 (27.3%)	143 (23.4%)	
60 to <75	6 (54.5%)	197 (32.3%)	
75 to <80	2 (18.2%)	110 (18.0%)	
≥80	0 (0%)	160 (26.3%)	
Sex			>0.99
Male	7 (63.6%)	362 (59.3%)	
Female	4 (36.4%)	248 (40.7%)	
Etiology			0.38
Acquired	1 (9.1%)	96 (15.7%)	
Congenital	3 (27.3%)	69 (11.3%)	
Transitional	0 (0%)	47 (7.7%)	
iNPH	7 (63.6%)	398 (65.3%)	
Procedure type			0.01
New insertion	10 (90.9%)	320 (52.5%)	
Revision	1 (9.1%)	290 (47.5%)	
Protocol			<0.0001
No protocol	4 (36.4%)	65 (10.7%)	
Initial CASIPP	7 (63.6%)	166 (27.2%)	
CASIPP w/ chlorhexidine/alcohol	0 (0%)	379 (62.1%)	

Values are presented as number (%) of patients unless indicated otherwise.

Correspondingly, compared to the initial CASIPP period, the CASIPP with chlorhexidine/alcohol was also associated with a reduced risk of developing a shunt infection (exact OR 0.042, 95% CI 0–0.22, p = 0.0002). In this multivariable model, the initial CASIPP was not associated with a significant reduction in shunt infection rates compared to reductions when there was no protocol in place (exact OR 0.73, 95% CI 0.17–3.57, p = 0.85). Given the limited number of shunt infections during the study period, additional variables could not be reliably included in the multivariable model. However, the other factors examined were not significantly associated with infection, and in an overadjusted multivariable model that included categorized age and etiology, the use of the CASIPP with chlorhexidine/alcohol remained an independent predictor of reducing shunt infections, and its effect was not appreciably diminished compared to the effect of the reported model.

Compliance was > 98% for all elements, and there were no significant associations noted between protocol violations and infections.

Discussion

Our study demonstrated that the implementation of a standardized shunt infection prevention protocol significantly reduced the rate of shunt infections within the adult population from 5.8% to 4.0% after the initiation of the CASIPP, and to 0% in 379 consecutive shunt operations after chlorhexidine/alcohol replaced povidone-iodine for preoperative skin antisepsis within that bundle. The multivariable analysis demonstrated that use of the CASIPP with chlorhexidine/alcohol was an independent predictor of reduced rate of shunt infections. Importantly, neither intrathecal antibiotics injected into the shunt reservoir at

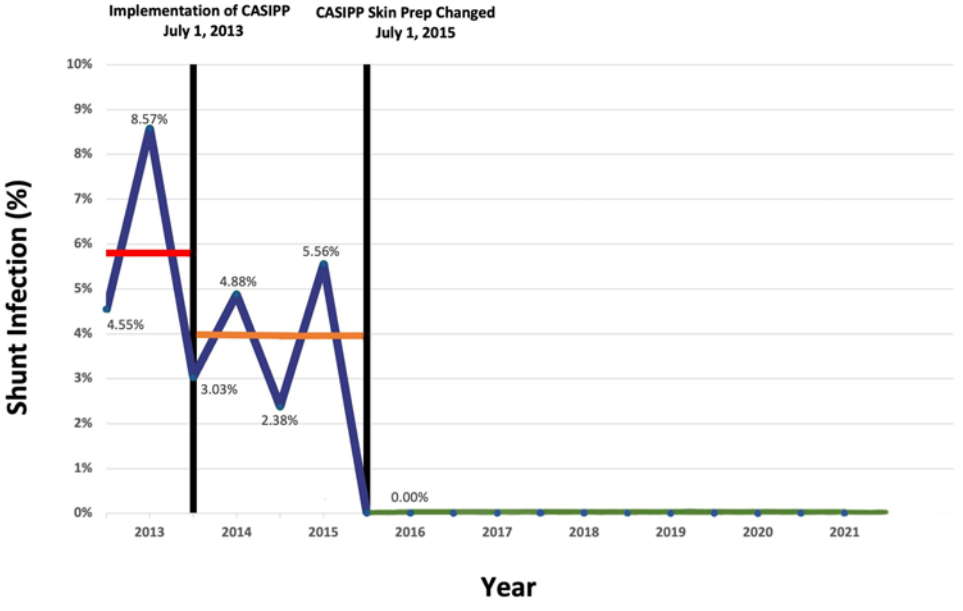

FIG. 2. Line graph comparing shunt infection rates before, after initial CASIPP implementation, and after changing the skin preparation from povidone-iodine solution to 2% chlorhexidine gluconate in 70% isopropyl alcohol. Respectively, the infection rates were 5.8% (*red line*), 4.0% (*orange line*), and 0.0% (*green line*) (p < 0.0001). There was not only a decrease in the rate of shunt infections, but also a decrease in the variation in the number of shunt infections over time.

TABLE 4. Organisms responsible for shunt infections

Organism	No. Identified (n = 13)
Coagulase-negative *Staphylococcus*	6 (46.1%)
Staphylococcus aureus	3 (23.1%)
Cutibacterium (Propionibacterium) acnes	2 (15.4%)
Corynebacterium species	1 (7.7%)
Histoplasma capsulatum	1 (7.7%)

TABLE 5. Multivariable analysis of risk of shunt infection with no protocol as the baseline

Variable	OR (95% CI)	p Value
Initial CASIPP (vs no protocol)	0.726 (0.17–3.57)	0.85
CASIPP w/ chlorhexidine/alcohol (vs no protocol)	0.032 (0–0.19)	0.0005
Procedure type: revision (vs new insertion)	0.098 (0.002–0.71)	0.01

the time of surgery nor antibiotic-impregnated shunt catheters was used as a part of the protocol to obtain this result.

Shunt Infection Prevention Protocols

The HCRN developed an 11-step protocol, which was implemented in four different pediatric centers, and found that it resulted in a reduction in the rate of shunt infections from 8.8% to 5.7%.[16] CASIPP shared some features with the HCRN protocol, such as the use of 2% chlorhexidine gluconate in 70% isopropyl alcohol, double gloving, and Ioban drapes. Okamura et al. reported a shunt infection prevention protocol for adult patients undergoing a first-time shunting procedure before and after implementing a shunt protocol.[18] These authors used povidone-iodine for skin preparation, and prior to shunt insertion the shunt device was immersed in a vancomycin solution and then vancomycin and gentamycin were injected into the shunt reservoir after insertion. Okamura et al. reported no infections in 52 procedures after the implementation of their protocol. Although these results are impressive, in the present study we were able to achieve the same result when our protocol with chlorhexidine/alcohol was used in 379 consecutive adult patients without the use of intrathecal antibiotics.

Antibiotic-Impregnated Catheters

There has been much debate in the literature surrounding the utility of AICs, as there is still no unifying consensus on whether their use should be mandatory during shunting procedures given that their ability to reduce the rate of shunt infections is inconsistent.[12,14,29,37,38] In 2016, the HCRN reported a modified version of their original protocol, for which AICs did not demonstrate a significant effect on the rate of shunt infections in pediatric patients.[37] Under this protocol the reported overall rate of shunt infections was 6% (95% CI 5.1%–7.2%) at eight participating centers.[37] This rate did not significantly differ from the rates of infection after the implementation of the original protocol (5.7%; 95% CI 4.6%–7.0%), and the authors suggested that the effectiveness of AICs in shunt procedures was unclear. It has also been suggested that antibiotic catheters may also cause treatment-related complications. A recent systematic review by Konstantelias et al. found that the use of these catheters resulted in an increased rate of shunt infections caused by methicillin-resistant *S. aureus* and gram-negative bacilli.[39] Given that the literature surrounding the use of AICs was inconclusive we chose not to include it in our protocol.

The BASICS (British Antibiotic and Silver Impregnated Catheters for ventriculoperitoneal Shunts) trial, published in 2019, was a three-armed randomized controlled trial that enrolled 1605 patients undergoing insertion of their first VP shunt.[29] Patients were randomized to receive a standard shunt catheter, an AIC, or a silver catheter. Patients who received an AIC had a significantly lower rate of infections than patients who received a standard shunt (HR 0.38, 97.5% CI 0.18–0.80). Although the overall rate of shunt infection in the study decreased from 6% to 2% in the group with AICs, this result included both pediatric and adult patients. The rates of overall infections, irrespective of study randomization group, were 7.9% of 592 pediatric patients, 4.6% of 499 adult patients < 65 years of age, and only 1% of 503 adult patients ≥ 65 years of age. The overall infection rate in adult and elderly patients was low at baseline, and at the time the BASICS trial was published, the infection rate in our patient population had already dropped to zero, negating a need to reconsider adding AICs to the CASIPP.

Chlorhexidine

Several studies have shown that 2% chlorhexidine gluconate in 70% isopropyl alcohol is superior to povidone-iodine for preoperative skin antisepsis.[30–32] For instance, Darouiche et al. conducted a randomized controlled trial in which patients at six different centers were randomized to receive preoperative antisepsis with povidone-iodine or chlorhexidine-alcohol, with, respectively, infection rates of 16.1% versus 9.5% (p = 0.004).[30] Similarly, studies in which patients have undergone surgical hardware implantation have shown that chlorhexidine reduces the rate of postoperative infection.[33] Sarmey et al. conducted a systematic review of studies that had implemented comprehensive protocols or single interventions to reduce the rate of CSF shunt infections in children and found that the use of chlorhexidine was associated with a significant reduction in the rate of postoperative shunt infections.[40] For our study we cannot comment on the exact impact of the addition of chlorhexidine/alcohol preoperative use as an antiseptic preparation as the outcome may be attributable to the combination of the entire bundle along with the addition of the chlorhexidine/alcohol and high protocol adherence, but the data suggest that the preoperative chlorhexidine/alcohol played a major role.

The use of a preoperative chlorhexidine bath has also been shown to reduce the rates of postoperative infection. Kapadia et al. performed a randomized controlled trial assessing this intervention in patients undergoing hip and knee arthroplasties.[34] In one group patients performed a chlorhexidine bath the night before and the morning of

the procedure, and in the other group patients bathed with antibacterial soap prior to the operation, the standard of care procedure. The authors found that the odds of infection were significantly higher in the standard of care cohort than the chlorhexidine cohort (OR 8.15, 95% CI 1.01–65.6, p = 0.049).[34] This intervention was considered low risk with a potential significant benefit and was added to the CASIPP in early 2018 at a time when infection rates were approaching zero. Given that the procedure-associated infection rate was already low, it is not possible to comment on the specific role in the reduction of shunt infection, although it should be noted that the shunt procedure infection rate has remained zero for the 3 years following the implementation of the preoperative chlorhexidine bath.

Use of Bundles in Other Operative Settings

It is also important to emphasize the associated value of employing protocols or bundles that can be followed within the surgical setting to reduce complications.[41] Surgical checklists have been shown to result in reduced rates of complications, including surgical site infections, in a variety of clinical settings.[28] Checklists lead to changes on both a personal and system level as healthcare personnel involved in the surgery become more aware of the potential risk of infection development in the patient and typically change their behaviors accordingly to attempt to reduce this risk. For instance, Pronovost et al. demonstrated that the use of a standardized checklist decreased the infection rate for insertion of central venous catheters in the intensive care unit, with an infection rate per 1000 catheter days decreasing from 2.7 to zero at 3 months (p = 0.002) after implementation of their protocol.[42] Haynes et al. were the first to show that the use of a surgical preoperative checklist led to lower complications and mortality.[43] The authors designed a checklist based on the WHO guidelines for safe surgical practice. There was diverse representation from eight hospitals around the world that prospectively assessed 3733 patients before implementation of the checklist and 3955 after implementation.[43] The rate of death decreased from 1.5% to 0.8% (p = 0.003) and inpatient complications decreased from 11% to 7% (p < 0.001) after the checklist was introduced.[43] Loftus et al. recently conducted a randomized clinical trial in which 236 adult patients undergoing surgery were randomized to receive the usual standard of care or treatment with a perioperative infection prevention bundle.[44] Patients who were treated with the bundle had a significantly reduced risk of developing a surgical site infection (HR 0.12, 95% CI 0.02–0.92, p = 0.04).[44] The process of introduction of a standardized perioperative protocol is often difficult to separate from the elements of the protocol. However, what can be referred to as the ritual of following a checklist can be essential for both the successful introduction as well as the sustainability of any shunt infection prevention strategy.

Study Strengths and Limitations

There were several strengths to our study. First, this study was prospective in nature, which allowed us to assess the temporal relationship between changes in the shunt infection prevention protocol and the rate of shunt infection. Second, the number of shunt surgery procedures was large (n = 621) and represents the largest adult patient series reported to date regarding shunt infection prevention. Third, the CASIPP was undertaken jointly with the IPC, which independently monitored all procedures for evidence of infection and met routinely with the neurosurgery team to assess infection-associated issues and protocol compliance. Fourth, there was minimal risk for selection bias as most of the adult patients who underwent an insertion or revision of a VP shunt at the study center were included in the study. Because the FMC is the only center in southern Alberta that performs shunt surgeries, the study patient population was quite diverse and also representative of the regional adult hydrocephalus patient population. Fifth, the CASIPP uses strategies that are easy to achieve, unambiguous, and simple to follow. Sixth, the protocol does not require either intrathecal antibiotic administration or the use of AICs. Therefore, our protocol should be easily and economically generalizable to other centers.

The limitations of this study include that it was performed at a single center and included only cases with operations performed by a single surgeon who has special expertise in shunt insertions. This study was not randomized, and therefore we could not control for unknown confounders that could have biased our results. Also, other procedural changes not specific to CASIPP were not accounted for during the study interval, which could have influenced our results. These other changes included the use of neuronavigation for insertion of the proximal shunt catheter and using a laparoscopic technique for placement of the distal catheter.[3] However, while both interventions are considered significant for reducing the overall shunt failure rate, these interventions are considered unlikely to afford benefit regarding surgical infection risk reduction. For the group of patients who were treated prior to the implementation of the standardized protocol, we are unsure of what specific steps were taken to reduce the risk of developing a shunt infection, such as how often double gloving and chlorhexidine were used, but we had baseline data regarding the shunt infection rate prior to the initiation of the protocol. Finally, the small number of infection events precluded more accurate quantification of protocol effects, and the use of complex analytical approaches additionally controlled for possible within-patient correlations in this cohort; however, each of the 11 infections occurred in an individual patient.

Conclusions

Our study has demonstrated that implementing a standardized shunt infection prevention protocol within the adult population can significantly reduce the rate of shunt infections and that the use of 2% chlorhexidine gluconate in 70% isopropyl alcohol for preoperative antisepsis, when added to the protocol, appears to have played a significant role in achievement of the goal of shunt infection reduction. While we believe that the continuous monitoring and adjustments to our shunt protocol were key to achieving this success, we believe the CASIPP can be easily generalized to other centers. Larger, multicenter studies should be completed to verify the effectiveness of our protocol.

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Conception and design: Hamilton, Conly. Acquisition of data: Hamilton, Fong, Conly. Analysis and interpretation of data: Hamilton, Muram, Isaacs, Sader, Fong. Drafting the article: Hamilton, Muram, Isaacs, Sader. Critically revising the article: Hamilton, Muram, Isaacs, Sader, Holubkov, Conly. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Hamilton. Statistical analysis: Muram, Holubkov. Administrative/technical/material support: Hamilton, Conly. Study supervision: Hamilton.

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

Supplementary Figure 1. https://thejns.org/doi/suppl/10.3171/2022.5.JNS22430.

Previous Presentations

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