A Protocol for Diagnosis and Management of Cerebrospinal Shunt Infections and other Infectious Conditions in Neurosurgical Practice

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ABSTRACT

Infections of the cerebrospinal shunts and other neurosurgical structures are not uncommon in the clinical practice. These infections are mostly clinical emergencies carrying negative prognostic impacts on the patients as well as spending healthcare resources. The low pathogenicity nature of some implicated pathogens results in minimal physical signs that may complicate the diagnosis and mislead the practitioner. Furthermore, little good prospective data exist in the field of neurosurgical infections and most available evidence is derived from retrospective nonrandomized studies. This protocol is meant to utilize the available evidence-based best practice to guide for diagnosis and managing common neurosurgical infections including those associated with cerebrospinal shunts. The effective management of these neurosurgical infections requires a good collaboration between the clinical team, clinical pharmacist and clinical microbiologist.

Background

Neurosurgical infections represent a spectrum of diseases that range from simple, superficial skin infections with favorable outcome to fulminant, potentially fatal conditions such as post-operative bacterial meningitis. There is little evidence to support the optimal management of these syndromes in the neurosurgical literature with rarity of well-constructed prospective studies to generate a solid platform of recommendations (BSAC, 1995; BSAC, 2000; Arlotti, Grossi & Pea, 2010). Considering the minimal diagnostic findings of some neurosurgical infections, their prognostic outcome and the impact on the hospital resources, this protocol is aimed to outline the best practice currently accepted to diagnose and manage such infections. The objectives of this protocol are focused around utilizing the available evidence for:

• Speedy diagnosis and initiation of proper management of neurosurgical infections to prevent their complications.

• Reducing hospital stay, improving treatment outcome, and preventing relapse.

• Customizing the laboratory procedures as per the clinical needs “patient’s centered testing”.

• Maximizing the potential of success of surgical interventions when proper medical treatment is timely given.

• Reducing the potential of iatrogenic infections caused by unnecessary sampling, antimicrobial misuse, cost, development of antimicrobial resistance, and adverse events.

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Search Strategies and Selection Criteria

The English literature using the PubMed and EMBASE databases from inception through December 2011 were searched to identify randomized controlled trials and prospective as well as retrospective studies addressing management of shunt or neurosurgical infections without time restrictions. The bibliographies of retrieved papers were also searched for additional references. The MeSH terms used for PubMed search (text terms for EMBASE) included "Shunt infection" OR "neurosurgical infection" OR "Brain abscess" OR "Subdural empyema" OR "Epidural abscess" OR "Suppurative intracranial thrombo-phlebitis" OR "post-operative meningitis" OR "EVD infection" OR "ventriculitis" AND "guidelines" OR "Randomiz(s)ed clinical trial" OR "case-control studies" OR "follow-up studies" OR "prospective studies" OR "retrospective studies" OR ""cohort studies" OR "observation studies" OR "prognosis". The studies analysed were the available guidelines and peer-reviewed reports of cohort or case-control human studies, without age restriction, which focused on neurosurgical patients and either presented or allowed comparison between the different management modalities. A summary protocol is presented from those cited studies.

Microbiology of Neurosurgical Infections

Understanding the microbiology of neurosurgical infections is complex as there are variable reports of patients' population and microbiological investigations in the literature. Polymicrobial infections are not uncommon, reflecting the origins of the infection (Brook 1992, Brook 2009). The most significant organisms isolated are the Gram positive streptococcal and staphylococcal species; in particular Staphylococcus aureus and Streptococcus millerii and other anaerobic organisms originating from the upper respiratory tract or seeded following a transient bacteremic attack in susceptible patient population. Gram negative aerobic bacteria, including the coliforms, account for up to 30% of the isolates and are more commonly encountered in neurosurgical infections secondary to ear-focused pathology (De louvois, Gortavai & Hurley, 1977, Goodkin, Harper & Pomeroy, 2004). History of trauma usually suggests a complicated microbiological etiology with S. aureus and polymicrobial skin commensals often contributing. Although the Gram negative enteric bacteria are not very common causes of neurosurgical infections, specific species have been implicated in particular neurosurgical syndromes e.g. post-meningitis brain abscess due to Citrobacter in neonates (Goodkin, Harper & Pomeroy, 2004). These Gram negative enteric pathogens are a major concern due to the increasing problem of their antimicrobial resistance via various mechanisms such as the possession of extended spectrum β-lactamase or AmpC enzymes. Another challenge in treating neurosurgical pathogens is the multidrug resistant Gram positive organisms such as methicillin-resistant Staphylococcus aureus (MRSA) and Vancomycin resistant Enterococci (VRE) (Roche, Humphreys & Smyth, 2003).

Empirical treatment is usually formulated on the basis of the susceptibility of local bacterial strains and the pharmacokinetic properties of various antibiotics. It needs to be adjusted later to the narrowest spectrum based on the microbiological culture, to obtain specific bactericidal action and prevent secondary resistant superinfections. The usual empirical regimen in neurosurgical infections consists of a third-generation cephalosporin and metronidazole, and whenever S. aureus is presumed then a specific antistaphylococcal penicillin is added to the regimen (Table 1). The empirical regimen may be modified depending on the clinical assessment of risk factors of the patient that suggests a particular presumed etiology of the infection. In the later case, it is extremely crucial to communicate the expected pathogen to the laboratory where enhanced organism's specific isolation techniques can be implemented. The hospital clinical pharmacist or the antimicrobial committee is expected to provide vancomycin dosage and monitoring advice. They are also consulted regarding the choice of a regimen in special populations e.g. pediatrics, pregnant, patients with renal or liver insufficiency. The use of antimicrobial therapy should be accompanied by appropriate supportive therapy and neurosurgical interventions as per the guidelines for different clinical scenarios.

Whenever possible, adequate microbiology specimens should be obtained before commencing treatment. This is critical for better recovery of the implicated pathogen but should never delay the initiation of antimicrobial treatment or surgical interventions. Specimens submitted to the laboratory should be representative of the type of infection, e.g. aspirate rather than swabs, and need to be precisely labeled with brief useful data, e.g. clinical and radiological diagnosis. This is essential for guided lab processing, reporting, proper timing of surgical procedures and follows up. It will also allow the laboratory to optimize its processing according to the patients' needs such as perusing an organism-based approach based on specific clinical scenarios. Minimal sample details to be entered in the comment section of order entry should indicate the presence of a particu-

lar device (shunt or EVD) and the source of specimen e.g. suspected shunt infection, cerebrospinal fluid (CSF) sampled by needle aspiration of the Spitz-Holter valve, or post-shunt removal for checking sterility of CSF – EVD sample. Sending critical neurosurgical specimens to the laboratory without communication or inclusion of sufficient data may result in mishandling the specimen. Needless to emphasize is the use of appropriate sterile containers for all central nervous system (CNS) specimens to avoid the confusion resulting from culturing valuable specimens received in non-sterile containers.

Table 1. Guidance on the suggested empirical treatment of common neurosurgical infections: Note the dose stated is for an average weight healthy adult. The codes: *italic: safe in penicillin allergy,* underline: contraindicated in penicillin allergy, **bold: caution in severe penicillin allergy due to possible cross-reactivity**

Clinical/ Radiological Diagnosis	Clinical Details	Empirical Antimicrobial Therapy	Duration	Note
Brain Abscess	Community-acquired: secondary to contagious source e.g. sinuses, otogenic, dental infections	**Ceftriaxone** 2g IV BID + *Metronidazole* 500mg IV q8h (liaise with the AB Team to switch MTZ after 48 h to oral route 400mg q 8 h if advisable)	6 weeks	Shift to organism's specific regimen after microbiology culture results with liaison with the microbiologist Specific treatment is usually more effective in eradicating the infection provided that good CNS concentration is obtained or an intrathecal route is used when indicated Prolonged use of broad spectrum agents is discouraged to prevent secondary resistant bacterial and fungal infections
	Secondary to open trauma			
	Postoperative or post-neurosurgical procedures	*Vancomycin* IV (AB Team recommended dose + **Meropenem** IV 2g q 8 h		
Subdural Empyema	Secondary to contagious source complicating bacteremia Secondary to trauma	**Ceftriaxone** 2g IV BID + *Metronidazole* 500mg IV q8h (liaise with the AB Team to switch MTZ after 48 h to oral route 400mg q 8 h if advisable)	6 weeks	
	Postoperative or post-neurosurgical procedures	*Vancomycin* IV (AB Team recommended dose) + **Meropenem** IV 2g q 8 h	6 weeks	
Cranial Epidural Abscess		**Ceftriaxone** 2g IV BID + *Metronidazole* 500mg IV q8h (liaise with the AB Team to switch MTZ after 48 h to oral route 400mg q 8 h if advisable)	6 weeks	
Suppurative Intracranial Thrombophlebitis		**Ceftriaxone** 2g IV BID + *Metronidazole* 500mg IV q8h (liaise with the p AB Team to switch MTZ after 48 h to oral route 400mg q 8 h if advisable)	6 weeks	
Post-Operative Or Neurosurgical Procedure Meningitis	To be distinguished from (chemical) aseptic meningitis following surgery (esp. around the posterior fossa) As a result of local non-infective inflammation. CSF remains sterile.	*Vancomycin* IV (AB Team recommended dose) + **Meropenem** IV 2g q 8 h Antibiotic therapy can be stopped after 7 days if CSF samples are sterile and the diagnosis of aseptic meningitis is confirmed based on clinical assessment of the patient and review of microbiology results	Gram + 2 weeks Gram - 3 weeks	Shift to organism's specific regimen after microbiology culture results with liaison with the microbiologist
Post Neurosurgical Wound Infection	Without skull/bone flap involvement	IV / oral antistaphylococcal penicillin e.g. Flucloxacillin 1g q 6 hours unless patient has positive MRSA culture at any site then *Vancomycin* IV until sensitivity available If penicillin allergic, MRSA negative: *Clindamycin* IV 900mg q 8 h OR 450mg orally q 6 h (based on clinical assessment of severity and liaison with the AB Team)	1-2 week	Screen for MRSA and determine MIC to Vancomycin if applicable Shift to organism's specific regimen after microbiology culture results with liaison with the microbiologist
	Involving the skull/ bone flap suspected infected cranioplasty or skull bone osteomyelitis	*Vancomycin* IV (AB Team recommended dose) + **Meropenem** IV 2 q 8 h	6 weeks	

Clinical/ Radiological Diagnosis	Clinical Details	Empirical Antimicrobial Therapy	Duration	Note
CSF Shunt Infections Diagnosis Confirmed by Positive Microscopy or Two Positive Consecutive CSF Cultures	Gram + organisms suspected	1st line: Shunt removal and EVD insertion *vancomycin* IV (AB Team recommended dose) OR Intrathecal (IT) 20mg/d (via IVD or a separate reservoir) Or both routes +/- *Rifampicin* 600mg BID IV or Oral: liaise with the AB Team about IV-oral switch) if advisable	1-2 week	IT vancomycin dose is not determined by age or weight (only in small slit ventricles use 10 mg/d). Adjust rifampicin dose if weight is less than 50 kg Seek advice of pharmacy/ microbiology when an isolate is resistant to Rifampicin, Duration depends on clinical-microbiological response before re-shunting
	Gram – organisms suspected	1st line: Shunt removal and EVD insertion IV **Ceftriaxone** 2g twice daily + / - intrathecal (IT) *gentamicin* 5mg daily	2-3 weeks	
EVD - Ventriculitis Diagnosis Confirmed by Positive Culture and Microscopy or two Consecutive CSF Cultures	Gram + organisms suspected	Intrathecal (IT) *Vancomycin* 20mg OD immediately after obtaining the 2nd CSF and Clamp drain ≥15 min. +/- IV *Vancomycin* therapy may be added based on the isolate MIC or clinical severity	1-2 week	Liaise with the microbiologist regarding the MIC of the isolate Remove and replace infected EVDs whenever possible or if CSF cultures remain positive despite appropriate therapy in case where is EVD was not removed
	Gram – organisms suspected	Intrathecal (IT) *gentamicin* 5mg OD immediately after obtaining the 2nd CSF and Clamp drain ≥15 min. +/- IV **Meropenem** 2g q 8 h may be added based on the isolate MIC or clinical severity	2-3 weeks	

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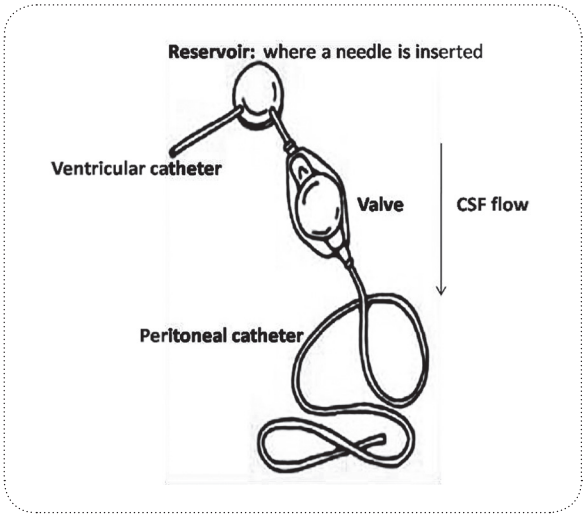

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Figure 1. A schematic presentation of the conventional ventriculoperitoneal shunt

Spotlights on Cerebrospinal Shunt Infections

Cerebrospinal shunts are inserted for treating hydrocephalus resulting from a variety of reasons and they are liable to malfunction or infection. The CSF shunts vary in their appearance but essentially consist of a ventricular tube, a second tube to drain the CSF to another cavity, and a one-way Spitz-Holter valve to control the direction and rate of flow (Figure 1). Some may have a reservoir (e.g. Ommaya) to allow easy access, sampling of the ventricular CSF and administration of drugs; while others have an inbuilt pressure-sensing device. Ventriculoperitoneal (VP) shunts are more commonly used than the ventriculoatrial (VA) type with no significant difference in their rates of infection (Choux, Genitori & Lang, 1992). Sometimes an externalized system, the external ventricular drainage device (EVD), is temporarily used to control the intracranial pressure or as a route of drug administration. Infections of the CNS shunts occur at a variable rate in different practices depending on several variables of which the age is considered the most significant host factor. The operative infection rate is a more useful indicator than the case infection rate. The former is often cited around 10% and increases after shunt revision (Choux, Genitori & Lang, 1992; O'Kane, Richards & Winfield, 1997; Walters, Hoffman & Hendrick, 1984; George, Leibrock & Epstein, 1979; Odio, McCracken & Nelson, 1984). Patients undergoing shunt revision are at risk of recurrence of infection and in more than half of these cases the same organism is isolated (George, Leibrock & Epstein, 1979; Odio, McCracken & Nelson, 1984).

The majority of shunt infections are true internal shunt infection following colonization of the inner surfaces of the shunt tubing and valve. External shunt infections constitute only less than 5% of shunt infections in the reported literature worldwide (BSAC, 1995; BSAC, 2000). Physicians should not be misled by the low pathogenicity nature of the shunt pathogens and attribute that to response to the antimicrobial therapy alone. Despite the minimal physical signs and laboratory findings, shunt infections carry negative prognostic impacts on the patients as well as high hospital costs –estimated to be about eight times as much as the original insertion procedure (Chocrane, Kestle & Steinbok, 1995; McLone, 1982). Most CNS shunt infections are caused by skin commensal flora, the Coagulase Negative Staphylococci (CoNS), while the etiology of a smaller proportion is due to S. aureus, and other organisms such as Gram Negative bacteria and fungi which typically favor an immunosuppressed host (George, Leibrock & Epstein, 1979; Langley, Gravel & Moore, 2009; Sarguna & Lakshmi, 2006; Clemmensen, Rasmussen & Mosdal, 2010). Abdominal pathology needs to be considered as a potential source of infections caused by these enteric organisms.

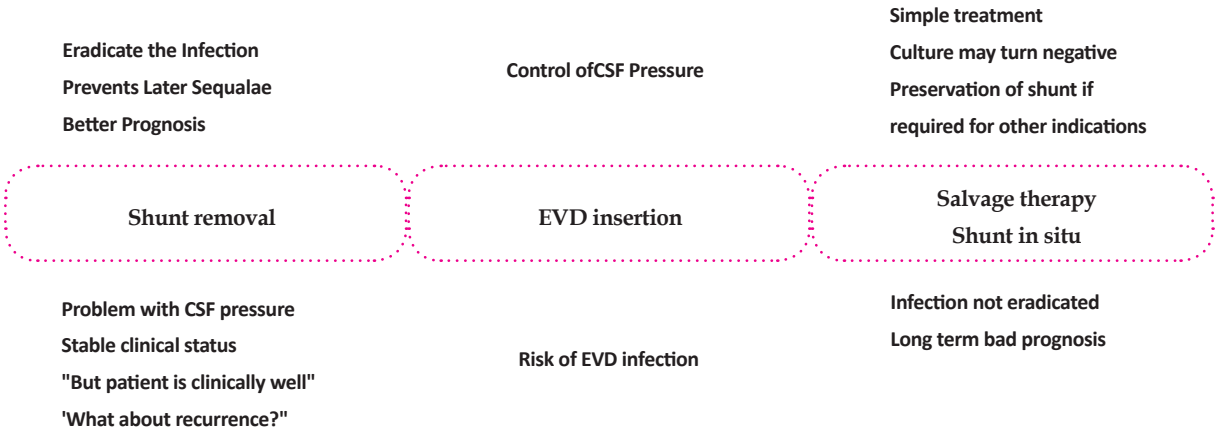

Figure 2. The clinical dilemma of an infected shunt

Management of Internal Shunt Infections

Earlier attempts of preserving part or the whole shunt resulted in poor long term outcome (Callaghan, Cohen & Stewart 1961). The currently accepted best clinical practice emphasizes on early removal of the infected shunt and insertion of a temporary external drainage device (EVD). This raises the success rate of managing such infections from 30% to 95% as shown in data gathered in the USA and Europe (Frame & McLaurine, 1984; Bisno & Sternau, 1994). Bisno and Sternau reviewed the results of 20 different studies comparing the success rate of shunt removal with either two or one-step revision versus salvage therapy and have found the compiled results indicates that removal of the shunt is essential (Bisno & Sternau, 1994). Since then salvage therapy is not followed to manage shunt infections (cure rate 20%) except in few selected cases caused by S. epidermidis if surgery is not possible for clinical reasons e.g. where an access is used to deliver chemotherapy. The Infectious Diseases Society of America (IDSA) however still recommends removal of the device in Coagulase Negative Staphylococcal shunt infections (Liu, Bayer & Cosgrove, 2009). For other organisms, there is consensus on early shunt removal as a main factor to control the infection. Sterility of CSF is required prior to insertion of the new shunt to prevent the recurrence of infection but not to remove the entire infected shunt. It is very unlikely to eradicate the infection in the shunt without device removal since the organisms exist in a bacteriological status of a biofilm raising their minimal inhibitory concentration (MIC) 500 times more than the in vitro laboratory sensitivity result (Bayston & Penny, 1972; Gilber, Collier & Brown, 1990; Evans & Holmes 1987; Braxton, Ehrlich & Hall-Stoodley, 2005; Fux, Quigley & Worel 2006). Based on the numerous observational, cohort studies a consensus on the key point in the management of shunt infections exists (BSAC 1995; BSAC 2000; Schreffler, Schreffler & Wittler, 2002; James, Walsh &Wilson, 1980; Tunkel, Hartman & Kaplan 2004), and the following protocol is recommended (Figure 3):

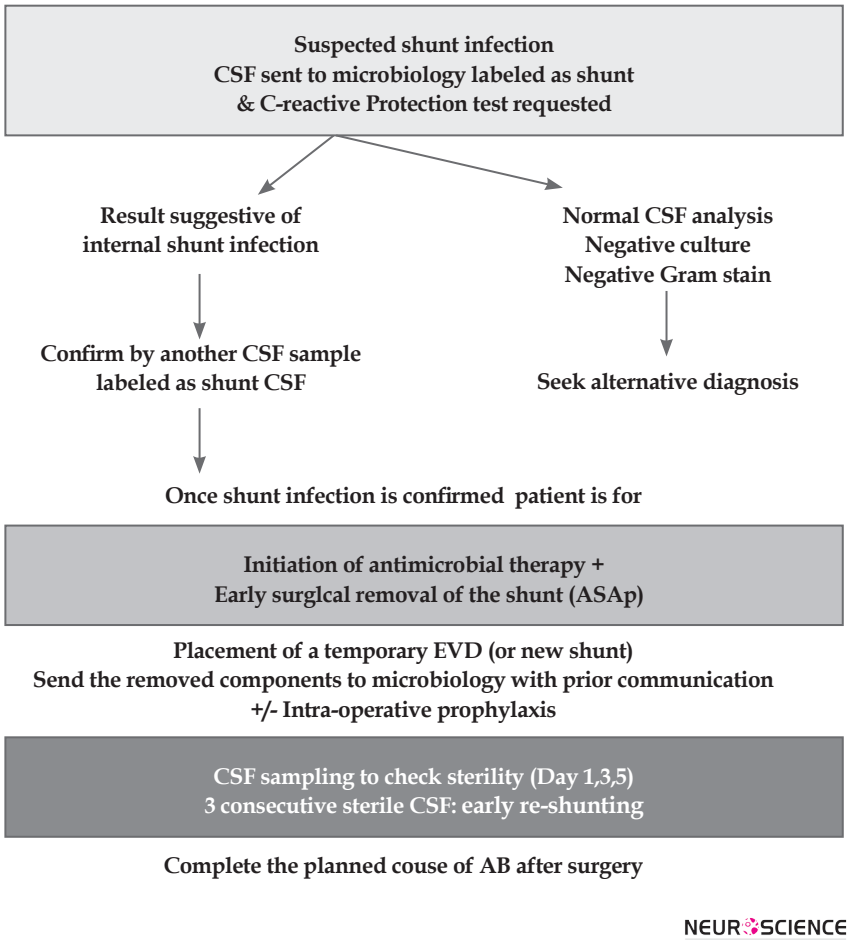

Figure 3. Algorithm for management of a suspected cerebrospinal shunt infection

• As soon as diagnosis is confirmed by two positive cultures of the same organism or one culture along with positive Gram stain, the entire infected shunt is removed to control infection and a temporary EVD inserted until sterility of CSF is obtained. This, in combination with antimicrobial therapy, is the most successful treatment.

• The target is to shorten the time for using the temporary EVD as it is very liable to infection especially after 10 days of insertion. For this, sterility is checked by CSF analysis on a designated unit algorithm to schedule patients for re-shunting. CSF should be examined on three specimens, using samples from the ventricular catheter rather than the collection bag.

• The expected interval between first and second surgery is 7-10 days. Clinical and microbiological monitoring should show resolution of the infection by days 5 (Note: the final culture results being available by day 7). If this is the case, re-shunting on the other side should be carried out at the earliest possible time.

• An alternative approach is early surgical removal of the infected shunt and insertion of the new shunt (one stage procedure) which carries 70% success rate for eradicating the infection compared with 95% in the two-stage strategy (Bisno & Sternau, 1994).

• Less common external shunt infections are ideally managed by drainage of pus, removal of infected device whenever clinically possible as well as the bone flap if present, soft tissue closure if possible, insertion of a temporary device at a new site and interval antibiotics for 7-14 days followed by replacement of a permanent device.

Critical Points in Managing Shunt Infections

A. The Shunt Multidisciplinary Team

The optimum management of shunt infections usually requires an input from a multidisciplinary team composed of neurosurgical, infectious diseases, microbiol-

ogy and pharmacy units. The team needs to discuss the individual cases based on the clinical and microbiological assessment for effective management plans. The development of Shunt Multidisciplinary Team is highly recommended in institutions where shunt insertion is a frequently performed procedure for optimal diagnostic and management interventions, tailoring the hospital protocol on particular case basis, and keeping shunt infection register.

B. Route of Antimicrobial Therapy: Parenteral versus Local Therapy

There are various preferences towards the route of administering antibiotics to treat shunt infections. While some experts recommend the parenteral route, reserving the local therapy to specific situations (Tunkel, Hartman & Kaplan 2004), intraventricular or intrathecal therapy is preferred in other practices (BSAC 1995). The local instillation of antibiotics in the CNS is not well defined and should always be assessed in parallel with the isolate MIC and risk of neurotoxicity. Vancomycin and gentamicin are the two commonly used intraventricular drugs with data generated from scattered institutes' experience. Few case reports described the use of amphotericin B intraventricularly (Chiou, Wong & Lin, 1994; Shapiro, Javad & Mealey, 1989). It should be noted that there is no detailed pharmacokinetics or efficacy studies available to date regarding the use of drugs intraventricularly and dosing is based solely on expert opinions. The nature of the micro-organism and its MIC together with the institute experience indicate whether the antimicrobial therapy needs to be administered by intravenous, intrathecal or both routes.

C. Duration of Treatment

Duration of antimicrobial treatment (10 to 21 days) varies depending on clinical and microbiological response, but should be as short as possible to avoid secondary infections from external drainage (BSAC, 2000). For most Gram positive bacteria 10-14 days of antibiotics is adequate provided that the whole shunt has been removed. The common practice is to give 7-10 days of antibiotics while the temporary EVD is in situ then for 24-48h hours only following re-shunting. Gram negative organisms & fungi require 14-21 days of therapy (after shunt removal). Longer duration of antibiotic treatment may be required in cases of slow response to treatment shown on serial examination of the CSF. The prolonged antimicrobial courses are however to be avoided to prevent secondary nosocomial infections with resistant organisms such as Serratia, Enterobacter, Citrobacter which are otherwise rare etiology of shunt infections (Langley, Gravel & Moore, 2009)

D. Laboratory Considerations

The microbiology plays a central role in supporting the clinical team for optimum management of shunt infections. Determining the MIC of the isolate to standard antimicrobial agents is useful in optimizing treatment and assessing the need for intraventricular therapy. Susceptibility patterns of the local strains have to be considered. For example, it is not advisable to use empirical antipseudomonal agents like ceftazidime where Pseudomonas resistance to the agents is common. The hospital antibiogram, local antibiotic policy, and the microbiologist should provide guidance on this aspect. Also, cephalosporins, e.g. ceftriaxone, are not to be used when the infecting organism is possibly an ESBL producer and the use of such agents is better deferred in high prevalence settings until ruling out the ESBLs possibility by the laboratory. The antimicrobial treatment needs to be modified and de-escalated following the results of the culture and sensitivity report as per individual case. This is done to obtain a more specific action and also to prevent secondary infections following use of broad spectrum agents. It is recommended to review the antimicrobial therapy for each case on regular basis and correlate it with the whole microbiology profile of the patient. For instance when an antimicrobial agent with adequate anaerobic coverage is used (augmentin, tazocin), metronidazole is no longer required in the regimen. The laboratory can also support the management by using enhanced laboratory methods to check sterility in post-removal phase of shunt infections which can be useful in accelerating the recovery of the patients. In addition, communication with the laboratory is essential for a customized organism-based approach, e.g. extended anaerobic incubation is not routinely done in CSF specimens but in case of a shunt specimen may aid in isolating a significant pathogen, e.g. Propinobacterium acnes. Table 2 outlines the specimens to be submitted to microbiology upon suspicion of shunt infection.

E. Pharmacological Aspects – Design of Antimicrobial Regimen for Neurosurgical Patients

Drugs to be given must achieve therapeutic concentration in the CNS for effective management of neurosurgical infections. This is best guaranteed by giving the maximum dose when using intravenous route for the correct duration or using local CNS antimicrobial treatment as indicated. The oral drugs can be used only when high bioavailability and effective penetration of blood

brain barrier (BBB) are guaranteed e.g. metronidazole and rifampicin. Rifampicin, given occasionally for synergism with vancomycin, should never be given as monotherapy. Cautions are applied to the use of rifampicin in tuberculosis endemic areas for the possibility of inducing resistance in asymptomatic tuberculosis patients. The drug is known to be a potent inducer of drug-metabolizing enzymes so adjusting the dose of drugs like anticonvulsants needs to be considered. Recently, linezolid has been used with success in managing shunt infections (Ntziora & Falagas 2007; Castro, Soriano & Escrich 2005; Maranich & Rajnik, 2008). The successful use of linezolid in treating shunt infections would have an optimistic therapeutic impact when VRE species are encountered. The detailed pharmacological aspect of antibiotics in neurosurgical infections is beyond the scope of this protocol and the reader is referred to a recently published, comprehensive review of the role of different antimicrobials in managing neurological infections (Sinner & Tunkel, 2004).

It is recommended to determine and document the stop date for all antibiotics prescribed and review the clinical diagnosis based on laboratory results and patient's response. If an alternative diagnosis is considered then completing the antibiotic treatment needs to be evaluated on case by case basis. An important emphasis is placed on the avoidance of the use of penicillin-containing antibiotics, e.g. tazocin, in a patient with penicillin allergy. Drugs with intermediate cross-reactivity (ceftriaxone and meropenem) should not be also used when the penicillin allergy is severe or life-threatening. For instance: immediate rash after penicillin administration could be a sign of potential anaphylaxis. Figure 4 summarizes the safety profile of various antimicrobial groups in penicillin allergy (BNF, 2011).

Table 2. Guidance on the microbiological specimens to be submitted to the laboratory when shunt infections are suspected

Time	Specimens to be Submitted to Microbiology	Processing	Comment
When Community Acquired Meningitis Suspected in a Shunted Patient	CSF by LP not through the shunt	CSF: Gram stain Analysis Culture	Diagnosis/management similar to non-shunted patients unless there is an evidence of ventriculitis.
Suspected Shunt Infection – Ventriculitis at Time of Presentation	CSF from: -Needle aspiration of the valve -The implantable reservoir if present But NOT the bag If there is an obstacle to obtain the appropriate specimen and a less useful specimen is collected then the specimen needs to be clearly labeled stating the collection method with liaison with the laboratory	CSF: Gram stain Analysis Culture	C-reactive protein along with microbiology tests. Two sets of positive CSF cultures with same organism (or one positive culture and positive Gram stain) are required for diagnosis before shunt removal.
At Procedure of Surgical Removal	Ventricular catheter Various sites of Shunt tubing "proximal, distal" The Spitz-Holter valve Reservoir "if present" Intraventricular portion of EVD if applicable	As sterile tissue: Microscopy from site of pathology and culture of various sites for bacteria, fungi and mycobacteria	Samples should not be fixed in formalin
Following Shunt Removal	CSF from the temporary EVD apparatus every other day to check for sterility and schedule for a new shunting	CSF labeled as D1, D3, D5 etc: Gram stain Analysis (Giemsa for sterility) Culture	Wait for sterility before re-shunting. This usually takes few days in CoNS, longer with other organisms
During re-shunting surgery	CSF and external wound Avoid unnecessary sampling and introduction of organisms in the new apparatus		Clearly labeled as reshunting wound otherwise skin flora are not usually reported by the lab
After surgery	As clinically indicated. Minimize invasive procedures to avoid iatrogenic infection.		Label as post-reshunt and liaise with the microbiologist about what is suspected

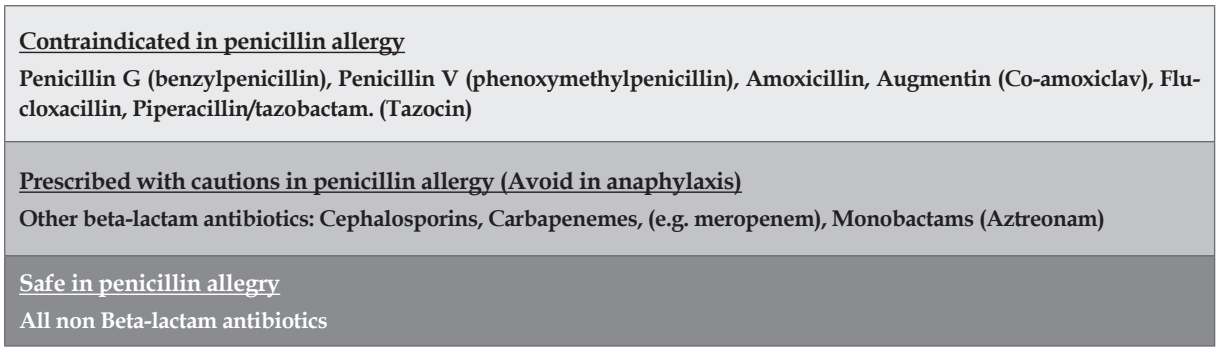

Figure 4. The safety profile of various antimicrobial groups in penicillin allergy

Discussion

It is sometimes challenging to efficiently diagnose and manage neurosurgical infections. The absence of well-designed randomized controlled trials has left this branch of infectious diseases not well defined. The described diagnostic and treatment protocol provides a starting point in neurosurgical units. Cases of shunt infections tend to be chronic so it is particularly advisable to liaise with the clinical microbiologist regarding the plan of management to optimize laboratory output and customize the plan based on the individualized strain whenever MIC data of the organism is obtained. Pharmacological properties of the drugs need special consideration in neurosurgical cases while the clinician's expertise is needed to develop such protocols and review them based on local and international updates.

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