



Audiology
Clinical Practice
Guideline
Meningitis

2013-June

Table of Contents

1. PURPOSE AND SCOPE:.....	3
2. BACKGROUND:.....	4
a. Current Standards of Practice:	4
3. GUIDELINE DEVELOPMENT:	5
a. Principles:	5
b. Target Population:	6
4. LITERATURE REVIEW:	7
a. Hearing Loss and Meningitis - General	7
b. Hearing Loss and Bacterial Meningitis.....	7
c. Hearing Loss and Viral/Aseptic Meningitis.....	8
d. Hearing Loss and Fungal Meningitis.....	9
e. Cochlear Implantation and Bacterial Meningitis.....	9
f. Key Statements from Literature	10
5. RECOMMENDATIONS:.....	12
6. MENINGITIS AUDIOLOGY CARE PATH.....	14
7. IMPACTS.....	15
APPENDIX A - References.....	16

PURPOSE AND SCOPE:

Purpose:

Hearing loss is a known risk factor associated with meningitis. A guideline is needed for clinicians regarding who should be tested and how often follow-up should occur based upon the evidence in the literature.

There is limited evidence for distinct Audiologic protocols for children with meningitis. The purpose of this guideline is to provide direction for the Audiologic care of patients with meningitis in B.C. The audience for this guideline is primarily Audiologists in Public Health Units and Hospitals in B.C., but other care providers of these children (including Otolaryngologists) may also find it helpful.

Scope:

This guideline was developed to support consistent evidence-based Audiologic care of infants/young children in B.C. who have had meningitis. It details the current standards of practice in this area, a description of the target population and the types of testing recommended. Six recommendations are made specifying who to test, how often audiometric testing should occur as well as time sensitive referrals. This is a minimum service level guideline.

1. BACKGROUND:

a. Current Standards of Practice:

There is ongoing discussion in the field of Audiology regarding the follow-up of post-meningitic children, specifically, which children should be followed and the frequency of that follow-up. Given the impact of serial testing on the stress/well-being of families and workload for Audiologists, it is important to consider which children are at risk to ensure best use of limited clinical resources within the framework of family-centered care.

In the absence of a universally accepted, evidence-based follow up schedule, British Columbia's Children's Hospital (BCCH) and the British Columbia Early Hearing Program (BCEHP) have historically taken a conservative approach to the follow up of these children, pending this guideline development. The current BCCH and BCEHP protocols indicate follow-up hearing assessment for children diagnosed with meningitis every three months for the first year post diagnosis and six months thereafter until they are three years post-meningitis. This is regardless of pathogen or the presence of hearing loss after the initial hearing test.

BCCH and BCEHP aim to diagnose a post-meningitic permanent hearing loss as soon as possible with appropriate habilitation and follow-up. Children diagnosed with hearing loss due to meningitis must be followed closely to ensure that, if the family chooses to consider a cochlear implant (CI), they do not lose the opportunity due to cochlear ossification. The onset of cochlear ossification changes post meningitis can be very rapid, occurring as early as 2-4 weeks after infection, and can put the possibility of CI at significant risk [e.g., 1, 2, 3].

2. GUIDELINE DEVELOPMENT:

This Guideline was developed by the BCCH Audiology Department and the BCEHP. It was reviewed by BCCH Paediatric Otolaryngologists, BC Regional Audiology Practice Leads or Senior Audiologists; BCCH Quality Improvement Project Lead, the BCEHP Regional Coordinators Council and Audiology Working Group. The guideline was shared with public health Audiologists through a series of teleconferences in the Winter of 2012. Consultation was also undertaken with Audiologists in other provinces who test infants and children (e.g., Ontario, Nova Scotia, Manitoba, Saskatchewan).

A literature search was conducted between January and April 2012 using Pub Med. Search terms always included meningitis and at least one of the following key words: hearing, hearing loss, deafness, viral meningitis, aseptic meningitis, bacterial meningitis, fungal meningitis, infants and/or children. English-language articles published between 1978-2012 were selected for screening. Additional articles were identified from the bibliographies of the articles retrieved. Articles that were not available through the University of British Columbia were excluded. Abstracts were screened and articles were included if (1) subjects were younger than 18 years old at the time of diagnoses of meningitis and (2) results included audiological follow-up data. Studies were either prospective or retrospective studies, case studies, or meta-analyses. Sequelae other than hearing loss were not the focus of this review and were not included. Only post-natal (i.e., acquired) causes of meningitis were considered. In utero infections such as cytomegalovirus, herpes, rubella, syphilis and toxoplasmosis are beyond the scope of this guideline

The views contained in this guideline have not been influenced by any funding bodies of public health Audiology services.

This Guideline will be reviewed for new literature updates in two years, in Winter 2015.

a. Principles:

This Guideline meets the following service principles:

- Audiologic care coordinated and provided by the child's local Audiology clinic whenever possible.
- Recommendations based on evidence.
- Takes advantage of services available through BCEHP and its' clinical information system, the British Columbia Early Surveillance Tool (BEST) when applicable.
- Accommodates unique and atypical clinical situations.
- Family-centered care.
- Encourages consistency in service access and provision across B.C.

- Facilitates informed decision making by supporting all communication opportunities.
- Aligns with the BCCH Audiology and Public Health Regional Audiology Programs.
- Assists the local Public Health Audiologist with service timelines and referrals dependant on the child's Audiology outcomes.

It does not include follow up schedules for children who have concomitant disease, disorders and pre-existing hearing loss.

b. Target Population:

The patient population for this practice guideline includes children from birth to age 18 years who have had a diagnosis of meningitis.

3. LITERATURE REVIEW:

a. Hearing Loss and Meningitis - General

Children with meningitis are at high risk to develop hearing loss (HL). The reported incidence of hearing loss varies from 2-31% [4], although meta-analyses by Baraff, et al. [5] and Chandran, et al. [6], as well as a study conducted within Canada [7], suggest the incidence of permanent hearing impairment is closer to 10%. The variability in reported incidence rates is likely due to differences in the interval between the acute illness and the testing, differences in hearing testing methods and interpretation, definitions of hearing impairment, and population characteristics (e.g., pathogenic organisms and whether or not the studies were pre- or post-vaccine for *H. influenzae*). Many studies regarding meningitis have been retrospective, uncontrolled, with substantial loss of subjects to follow-up. Methodology and interpretation of results has varied greatly between studies. Many studies have failed to exclude the confounding variable of coexisting conductive hearing loss. Studies using auditory brainstem response (ABR) as the method of diagnosing hearing loss used click-ABR stimuli and air-conduction ABR latency delays to determine the degree and type of hearing loss; however, the inadequacy of such methods is well known [e.g., 8, 9]. These issues make interpretation of the literature difficult.

There is no current universally accepted standard for the Audiologic follow up of children with meningitis. Many authors suggest following children with bacterial meningitis [10-23], other authors suggest following both viral and bacterial meningitis [24-27] and others recommend following all post-meningitic infants and children, or do not specify the type of meningitis to follow [28-32]. Although the timing and length of audiological follow up varies between studies, follow up prior to discharge or shortly after recovery is typical [10, 12-14, 17, 18, 20-22, 25, 30, 33].

b. Hearing Loss and Bacterial Meningitis

It is clear that children with bacterial meningitis are at risk of permanent hearing loss [for review, see: 5, 6, 26, 34]. Bacterial meningitis is associated most commonly with *Haemophilus influenzae* type b, *Streptococcus pneumoniae*, and *Neisseria meningitides* [5, 22]. With the introduction of vaccines for *H. influenzae* type b in the 1990's, the number of cases of meningitis and resultant hearing loss due to *H. influenzae* has been greatly reduced leaving *S. pneumoniae* and *N. meningitides* to become the leading causes of bacterial meningitis in the US [5, 22]. The most common pathogens causing meningitis related hearing loss are also those most likely to cause cochlear ossification (*Streptococcus pneumoniae* > *Neisseria meningitides* > *Haemophilus influenzae*) [35, 36].

Husain, et al. [7] conducted a retrospective review of 104 children with confirmed bacterial meningitis identified at 8 tertiary Canadian hospitals. Their review revealed *S. pneumoniae* (56%), *Group B streptococcus* (13%), *N. meningitides* (11%), *H. influenzae* type B (8%), and *E. coli* (5%) to be the most common organisms causing

bacterial meningitis. *Group B streptococcus* was the main organism associated with bacterial meningitis during the neonatal period (58% of cases) whereas *S. pneumoniae* was more common beyond the neonatal period. Hearing loss was identified in 12/104 (11.5%) of cases [7]. According to Merkus, et al. [15] bacterial meningitis occurs more often in children under two years of age due to their immature immune system.

Hearing loss due to bacterial meningitis may range from mild unilateral to profound bilateral [e.g., 22, 37] and there is no consistent audiometric pattern [33]. Approximately 5% of children will develop severe/profound hearing loss [e.g., 5].

The incidence of bacterial meningitis is between 1.1 and 1.2 per 100,000 [e.g., 38, 39].

c. Hearing Loss and Viral/Aseptic Meningitis

Although viral meningitis is more common than bacterial meningitis, hearing loss is most commonly associated with bacterial meningitis [40]. Viral meningitis is caused by viral infection; however, the term “viral meningitis” is often used when the more accurate term is “aseptic meningitis”. Although the most commonly identified cause of aseptic meningitis is a virus, aseptic meningitis is defined as an inflammation of the meninges where no bacterial pathogen is identified, or there is no apparent cause [41]. In a recent retrospective study of Canadian children between 0-18 years, most cases (71%) of aseptic meningitis had undetermined aetiology [42]. However, when aetiology can be determined, enteroviruses account for 80-90% of cases [41-43]. There are other viral causes of aseptic meningitis or encephalitis, some of which include the mumps virus, the herpes viruses (herpes simplex viruses types 1 and 2, varicella zoster virus), the Epstein-Barr virus, and the human immunodeficiency virus (HIV) [44]. Additionally, other organisms (e.g., fungi, parasites) may cause symptoms consistent with aseptic meningitis [41].

While hearing loss as sequelae to bacterial meningitis is well documented, the audiological outcome of viral/aseptic meningitis is more controversial. There is a lack of agreement in the literature as several studies looking at hearing loss subsequent to viral meningitis have had conflicting results. These contradictory results may reflect, in part, how aseptic or viral meningitis is defined in each study. Many studies suggest that viral/aseptic meningitis does not cause hearing loss [10, 34, 45-55]. Nadol Jr [55] indicates that:

“Although studies have demonstrated viral infection during pregnancy (e.g., rubella infection in utero) may result in hearing loss, the evidence for acquired post-natal hearing loss due to viral aetiology is much weaker. Somehow we must reconcile the convictions that viruses even sub-clinical infections may cause profound deafness with the fact that in over 2200 cases of viral meningitis with symptoms severe enough to require hospitalization, not one case of hearing loss was reported” [55].

Consistent with Nadol Jr, most studies looking at meningitis related to enteroviruses suggest essentially no causal relationship between viral meningitis caused by enteroviruses and permanent hearing loss [13, 25, 45, 46, 49-53, 56]. Nonetheless, there are studies that suggest viral/aseptic meningitis may cause hearing loss, albeit not to the extent and degree as that seen for bacterial meningitis [13, 24, 25, 29, 57].

The incidence of viral and aseptic meningitis is between 4.6 and 4.8 per 100,000 [e.g., 38, 41].

d. Hearing Loss and Fungal Meningitis

The literature regarding fungal meningitis and hearing loss is scarce. Only two studies were found that addressed fungal meningitis and hearing loss specifically [55, 58]. Both suggest hearing loss is possible. Nadol Jr [55] reported hearing loss in 3/7 cases, with retrocochlear involvement suspected in at least two of the cases based on low speech discrimination scores. Yuanjie, et al. [58] reported hearing loss in 1/11 cases, but details about the hearing loss and diagnosis were not provided.

e. Cochlear Implantation and Bacterial Meningitis

The audiological considerations for cochlear implantation remain essentially the same in post-meningitic hearing loss as for other hearing loss patients (e.g., bilateral severe to profound SNHL). The critical difference is the potential for ossification of the inner ear which results in a time pressure on the decision whether or not to implant. Cochlear ossification can be rapid and may compromise the success of cochlear implantation [2, 3].

Cochlea ossification is a progressive inflammatory process where the inner ear structures (cochlea and semicircular canals) become fibrosed and subsequently ossify. Cochlear microstructures (membranous inner ear, organ of corti, hair cells, etc) become partially or completely replaced by new bone. There is evidence that cochlear ossification starts at the round window, scala tympani of the basal turn and then proceeds apically; this is often preceded by changes in the semi-circular canals [3, 59, 60]. Early fibrosis can impede the placement of an implant array inside the cochlea and if new bone is laid down, cochlear implantation may not be possible. At the time of implantation, studies have shown the presence of ossification to be high (62%-90%) [36, 60]. While there are drill out procedures and specialized "double array" cochlear implants available, the success of such procedures is considerably less than standard implantation [36, 59, 61]. It is therefore desirable, when parents have decided on an option of a cochlear implant, to implant prior to the advanced stages of the ossification process.

Diagnosis of cochlea ossification is made through imaging of the temporal bone using computed tomography (CT) and magnetic resonance imaging (MRI). Approximately 1 in 3 patients who have profound hearing loss following meningitis will demonstrate signs of ossification on imaging [2, 35]. Overall sensitivity of MRI with CT is estimated to be in the region of 94.1% [62] whereas CT alone may be only 50%.

The timing of the imaging is important. Most patients with meningitis will have brain imaging at the time of diagnosis but this may be too early to show any ossification changes. If hearing loss is found, repeat imaging at serial intervals is one way of tracking whether ossification is occurring. It has been suggested that imaging should occur within 2 weeks of the audiological assessment showing hearing loss [63]. If initial imaging shows no sign of ossification, there is a low chance (approximately 10%) of ossification being present on future scans. If there are early signs of fibrosis or ossification on the initial scan then progression on future scans is much more likely (approximately 80%) [35].

Bilateral severe to profound SNHL patients would be ideal implant candidates if their imaging does not show far advanced ossification. In cases where ossification has commenced, implantation may still be possible with specialized surgical techniques and specialized implant arrays.

The picture is less clear when post-meningitic patients do not meet the hearing loss criteria for implantation (e.g. severe SNHL; asymmetrical hearing loss) but have imaging consistent with ossification. Delay in implant consideration in these cases may make future implantation difficult if not impossible due to complete ossification of the cochlea.

Any child with post-meningitic hearing loss may be at risk for ossification. Children with bilateral severe to profound hearing loss regardless of imaging results AND children whose imaging suggests ossification regardless of the degree of hearing loss should be promptly counselled regarding communication options. If the family is in agreement, an urgent referral to Cochlear Implant Services for (a) medical evaluation and (b) consultation with the team to gather further information about this option is warranted. The Otolaryngologist on the CI team will facilitate prompt imaging, of both CT and MRI, to look for ossification or progression of ossification. This should occur within 2 weeks of the assessment showing hearing loss. If such initial imaging does not show ossification, further imaging is only necessary if there is a subsequent change in the hearing thresholds as per the Audiology follow up plan outlined in this document.

f. Key Statements from Literature

- There is a clear association between bacterial meningitis and hearing loss. The association between viral meningitis and hearing loss is unclear. It is possible but highly unlikely that aseptic/viral meningitis will result in permanent hearing loss. There are only a few studies looking at fungal meningitis and hearing loss; the two included in this literature review suggest hearing loss possible. Overall, hearing loss as sequelae to viral/aseptic and fungal meningitis cannot be ruled out.
- The onset of HL associated with bacterial meningitis most likely occurs early in the course of the illness [12, 15, 20-22, 25, 32, 64-69]. All patients with meningitis require audiological assessment when the acute illness has stabilized.

- Most of the literature indicates that otitis media (OM) is common in children with meningitis, especially early after the infection [20, 22, 28, 65, 70-72]; however, Richardson, et al. [73] would refute this.
- Any permanent hearing loss is sensorineural [e.g., 5] and cochlear in origin [64].
- If normal hearing is demonstrated after the first few days of hospitalization it is highly unlikely to change (i.e., develop into permanent sensorineural hearing loss) [11, 13, 25, 65, 74]. In all the studies reviewed, there were very few reported cases of children with normal hearing developing hearing losses [i.e., Kulahli, et al. [75] suggested mild hearing loss in three patients; however, no details were provided; Kutz, et al. [37] indicated a case where a child with normal hearing developed unilateral moderate hearing loss 16 months after hospitalization and Woolley, et al. [22] reported a 7 month-old with normal hearing at discharge who developed a bilateral moderate to moderate-severe sensorineural hearing loss within 6 months].
- Although hearing loss may improve, fluctuate, or deteriorate, the majority of hearing losses are likely to be stable. If hearing fluctuates, it can take a year or more to stabilize. If improvement in hearing levels are seen it is most likely to occur in children with mild to moderate sensorineural hearing loss rather than severe to profound sensorineural hearing loss. If hearing loss is severe-profound, improvement is possible, but unlikely [11, 12, 14-16, 22, 25, 29, 30, 32, 37, 50, 54, 55, 65-68, 75-77].
- Cochlear implant candidacy is determined on audiological and imaging results combined with the potential for rapid progression of cochlear ossification, which may impede implant success.
- Any child with hearing loss attributable to the meningitis requires temporal bone imaging with CT and MRI within two weeks of the audiogram demonstrating hearing loss. Medical professionals are responsible for this imaging.
- Referral to the cochlear implant team for consultation is indicated if (1) there is bilateral severe-to-profound hearing loss irrespective of imaging results, (2) imaging is indicative of ossification irrespective of the degree of hearing loss, or (3) unilateral hearing loss is present and imaging is indicative of ossification.

4. RECOMMENDATIONS:

Existing BCCH and BCEHP protocols for meningitis children recommends far more appointments than are necessary for the large majority of the children. The following are recommended:

Recommendation #1: Audiologists should test all children who have had meningitis, regardless of pathogen. There is a clear connection between bacterial meningitis and hearing loss. The association between viral and fungal meningitis is less clear. To be conservative, this guideline recommends that all children who have had meningitis be tested, until further evidence is available.

Recommendation #2: Children with meningitis should be tested as soon as possible after diagnosis. To facilitate appropriate timely referrals to Audiology, a Meningitis Information Sheet will be developed by BCCH and the BCEHP Medical Advisory Group for distribution to physicians.

Recommendation #3: Children with normal hearing on the first test should have a second test three months later, a third test six months after the first test and then discharged if normal. For the purpose of this guideline, normal hearing is defined at 25dBHL or less at .5, 2, and 4KHz bilaterally. The overwhelming majority of articles indicate if hearing is normal during the acute phase or shortly after, the child's hearing will likely remain within the normal range. Woolley, et al. [22] state "reassurance (to families) can be provided if initial hearing studies suggest normal hearing because children who do not have early hearing impairment are unlikely to have hearing loss later" due to the meningitis. Prompt retesting is advised if parents/caregivers develop concerns for a change in hearing following the initial normal hearing test.

Recommendation #4: Children who have sensorineural hearing loss should be referred for urgent medical investigation by their Audiologist to their medical professional and re-tested within two weeks. Those who have stable results between those two tests should have reassessment every three months for the first year; every six months after that, until they are three years post-meningitis and annually thereafter. Stable hearing loss is defined as less than or equal to 10dB changes at .5, or 2 or 4KHz. More frequent assessment is left to the discretion of the child's care team.

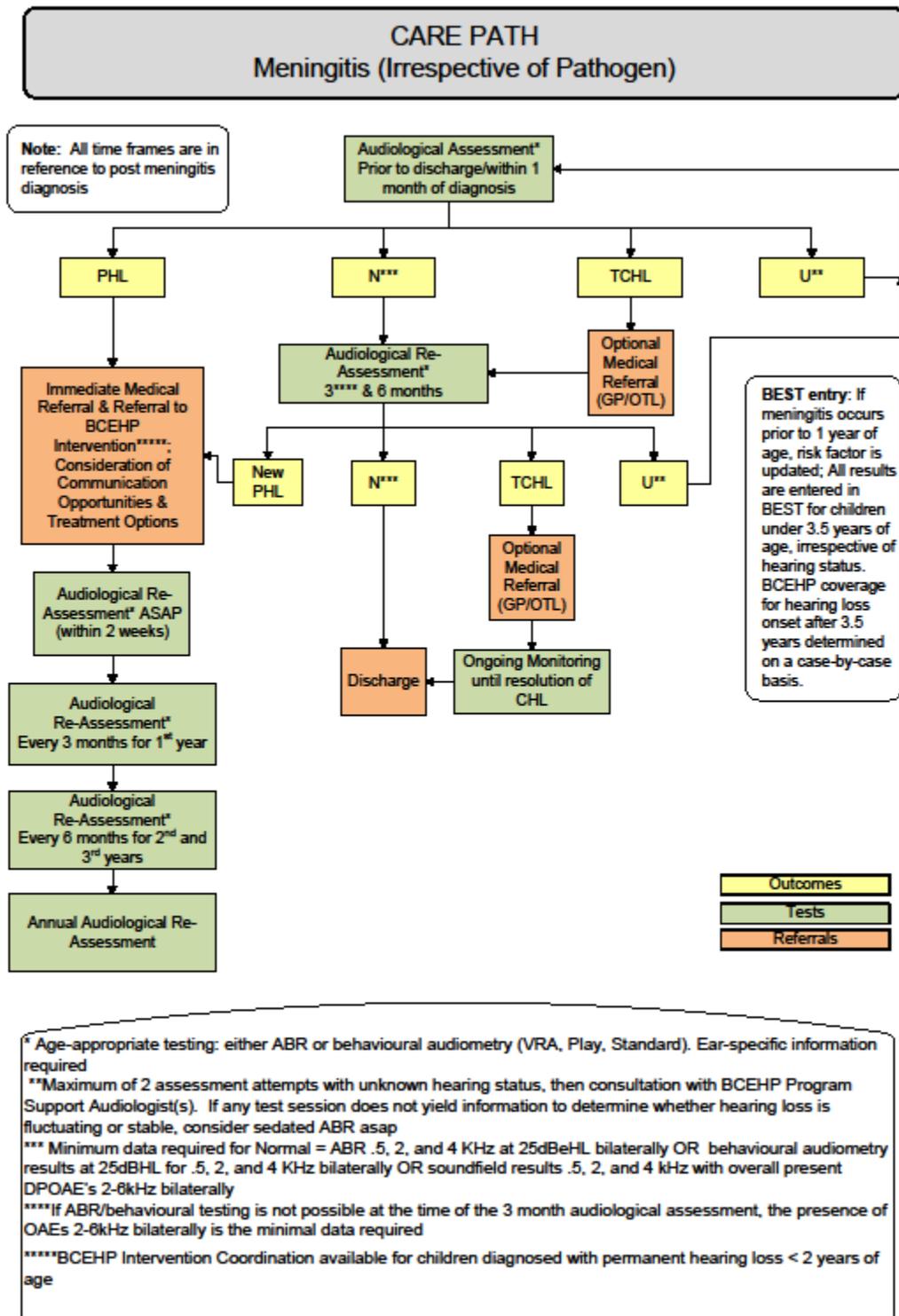
Recommendation #5: Children who have fluctuating or worsening sensorineural hearing loss should be referred for urgent medical investigation by their Audiologist to the child's medical professional. Evidence suggests that if the loss is to progress, that it would most likely do so early in the course of the disease. A change in hearing is defined as a change of greater than 10dB at two or more frequencies OR 20dB or greater change at one frequency with good test reliability. The schedule for reassessment of these children will be determined on a case-by-case basis with the care team.

Recommendation #6: A diagnosis of bilateral severe to profound hearing loss regardless of imaging results, and those with imaging suggestive of ossification irrespective of the degree and laterality of the hearing loss, should include prompt counselling regarding communication opportunities.

If the family is in agreement, an urgent referral to Cochlear Implant Services for (a) medical evaluation and (b) consultation with the team to gather further information about the possibility of cochlear implantation is warranted. This is recommended to ensure that if the child is a candidate, they do not lose their opportunity for a CI due to cochlear ossification. The CI Coordinator may be reached at (604) 875 2345, ext: 7723. The CI Referral Form may be found at:

<http://www.bcchildrens.ca/NR/rdonlyres/4BAF0690-30E7-499B-A1E0-90C04217BFCA/56661/cochlearreferralform.doc>

5. MENINGITIS AUDIOLOGY CARE PATH



6. IMPACTS

The impacts of this guideline are expected to be:

- Less anxiety for families about when the hearing loss might appear with these children. The evidence clearly shows the hearing loss is present during the acute phase of the illness and not months later as previously thought.
- Less visits to Audiology for families.
- Less Audiology resources needed to appropriately follow children with meningitis; this will relieve a taxed public health audiology service to more efficiently serve paediatric cases in the Province.

There are no known or perceived barriers to implementing this guideline. It is expected that this guideline will be well received in the community of Audiology and with families.

APPENDIX A - References

- [1] P. R. Axon, R. H. Temple, S. R. Saeed, and R. T. Ramsden, "Cochlear ossification after meningitis," *The American Journal of Otology*, vol. 19, pp. 724-729, 1998.
- [2] M. Durisin, S. Bartling, C. Arnoldner, M. Ende, J. Prokein, A. Lesinski-Schiedat, H. Lanfermann, T. Lenarz, and T. Stover, "Cochlear osteoneogenesis after meningitis in cochlear implant patients: a retrospective analysis," *Otology & Neurotology*, vol. 31, pp. 1072-8, Sep 2010.
- [3] H. X. Xu, S. S. Joglekar, and M. M. Paparella, "Labyrinthitis ossificans," *Otology & Neurotology*, vol. 30, pp. 579-580, 2009.
- [4] A. Davis and K. Davis, "Descriptive epidemiology of childhood hearing impairment," in *Comprehensive Handbook of Pediatric Audiology*, R. Seewald and A. M. Tharpe, Eds., ed San Diego: Plural Publishing, 2011, pp. 85-111.
- [5] L. J. Baraff, S. I. Lee, and D. L. Schriger, "Outcomes of bacterial meningitis in children: a meta-analysis," *Pediatric Infectious Disease Journal*, vol. 12, pp. 389-394, 1993.
- [6] A. Chandran, H. Herbert, D. Misurski, and M. Santosham, "Long-term sequelae of childhood bacterial meningitis an underappreciated problem," *The Pediatric Infectious Disease Journal*, vol. 30, pp. 3-6, 2011.
- [7] E. Husain, R. Chawla, S. Dobson, and H. D. Davies, "Epidemiology and outcome of bacterial meningitis in Canadian children: 1998-1999," *Clinical and Investigative Medicine*, vol. 29, pp. 131-135, 2006.
- [8] J. J. Eggermont, "The inadequacy of click-evoked auditory brainstem responses in audiological applications," *Annals New York Academy of Science*, vol. 388, pp. 707-709, 1982.
- [9] C. L. Mackersie and D. R. Stapells, "Auditory brainstem response wave I prediction of conductive component in infants and young children," *American Journal of Audiology*, vol. 3, pp. 52-58, 1994.
- [10] R. L. Baldwin, R. S. Sweitzer, and D. B. Freind, "Meningitis and sensorineural hearing loss," *Laryngoscope*, vol. 95, pp. 802-5, Jul 1985.
- [11] P. E. Brookhouser, M. C. Auslander, and M. E. Meskan, "The pattern and stability of postmeningitic hearing loss in children," *Laryngoscope*, vol. 98, pp. 940-8, Sep 1988.
- [12] P. R. Dodge, H. Davis, R. D. Feigin, S. J. Holmes, S. L. Kaplan, D. P. Jubelirer, B. W. Stechenberg, and S. K. Hirsh, "Prospective evaluation of hearing impairment as a sequela of acute bacterial meningitis," *New England Journal of Medicine*, vol. 311, pp. 869-74, Oct 4 1984.
- [13] H. Guiscafre, L. Benitez-Diaz, M. C. Martinez, and O. Munoz, "Reversible hearing loss after meningitis prospective assessment using auditory evoked responses," *Annals of Otology, Rhinology & Laryngology*, vol. 93, pp. 229-232, 1984.

- [14] S. Kotagal, C. Rosenberg, D. Rudd, L. M. Dunkle, and S. Horenstein, "Auditory evoked potentials in bacterial meningitis," *Archives of Neurology*, vol. 38, pp. 693-5, Nov 1981.
- [15] P. Merkus, R. H. Free, A. M. Mylanus, R. Stokroos, M. Metselaar, E. van Spronsen, W. Grolman, and J. H. M. Frijns, "Dutch cochlear implant group (CI-ON) consensus protocol on postmeningitis hearing evaluation and treatment," *Otology & Neurotology*, vol. 31, pp. 1281-1286, 2010.
- [16] O. Ozdamar, N. Kraus, and L. Stein, "Auditory brainstem responses in infants recovering from bacterial meningitis. Audiologic evaluation," *Archives of Otolaryngology*, vol. 109, pp. 13-8, Jan 1983.
- [17] A. Riordan, A. Thomson, J. Hodgson, and A. Hart, "Children who are seen but not referred: Hearing assessment after bacterial meningitis," *British Journal of Audiology*, vol. 27, pp. 375-377, 1993.
- [18] U. Rosenhall, O. Nylen, J. Lindberg, and A. Kankkunen, "Auditory function after Haemophilus influenzae meningitis," *Acta Oto-Laryngologica*, vol. 85, pp. 243-7, Mar-Apr 1978.
- [19] E. D. Silkes and J. Chabot, "Progressive hearing loss following Haemophilus influenzae meningitis," *International Journal of Pediatric Otorhinolaryngology*, vol. 9, pp. 249-256, 1985.
- [20] V. Smyth, B. O'Connell, R. Pitt, M. O'Callaghan, and J. Scott, "Audiological management in the recovery phase of bacterial meningitis," *International Journal of Pediatric Otorhinolaryngology*, vol. 15, pp. 79-86, Feb 1988.
- [21] M. B. Wellman, D. D. Sommer, and J. McKenna, "Sensorineural hearing loss in postmeningitic children," *Otology & Neurotology*, vol. 24, pp. 907-12, Nov 2003.
- [22] A. L. Woolley, K. A. Kirk, A. M. Neumann Jr, S. M. McWilliams, J. Murray, D. Freind, and B. J. Wiatrak, "Risk factors for hearing loss from meningitis in children," *Archives of Otolaryngology --Head & Neck Surgery*, vol. 125, pp. 509-514, 1999.
- [23] C. C. Morton and W. Nance, "Newborn hearing screening -- a silent revolution," *The New England Journal of Medicine*, vol. 354, pp. 2151-2164, 2006.
- [24] A. A. Asadi-Pooyaa, A. Asadi-Pooyaa, and D. Rosen, "Hearing impairment after bacterial and aseptic meningitis in children," *Journal of Pediatric Neurology*, vol. 6, pp. 31-34, 2008.
- [25] X. Bao and V. Wong, "Brainstem auditory-evoked potential evaluation in children with meningitis," *Pediatric Neurology*, vol. 19, pp. 109-112, August 1998.
- [26] H. M. Fortnum, "Hearing impairment after bacterial meningitis: a review," *Archives of Disease in Childhood*, vol. 67, pp. 1128-1133, 1992.
- [27] Joint Committee on Infant Hearing (JCIH), "Year 2007 position statement: principles and guidelines for early hearing detection and intervention programs," *Pediatrics* vol. 120, pp. 898-921, 2007.

- [28] H. Bedford, J. de Louvois, S. Halket, C. Peckham, R. Hurley, and D. Harvey, "Meningitis in infancy in England and Wales: follow up at age 5 years," *British Medical Journal*, vol. 323, pp. 1-5, 2001.
- [29] T. Finitzo-Hieber, R. Simhadri, and J. P. Hieber, "Abnormalities of the auditory brainstem response in post-meningitic infants and children," *International Journal of Pediatric Otorhinolaryngology*, vol. 3, pp. 275-86, Dec 1981.
- [30] W. M. Keane, W. P. Potsic, L. D. Rowe, and D. F. Konkle, "Meningitis and hearing loss in children," *Archives of Otolaryngology*, vol. 105, pp. 39-44, Jan 1979.
- [31] D. W. Kimberlin, "Meningitis in the neonate," *Current Treatment Options in Neurology*, vol. 4, pp. 239-248, 2002.
- [32] I. Koomen, D. E. Grobbee, J. J. Roord, R. Donders, A. Jennekens-Schinkel, and A. M. Van Furth, "Hearing loss at school age in survivors of bacterial meningitis: assessment, incidence, and prediction," *Pediatrics*, vol. 112, pp. 1049-1053, 2003.
- [33] S. J. Berlow, D. D. Caldarelli, G. J. Matz, D. H. Meyer, and G. G. Harsch, "Bacterial meningitis and sensorineural hearing loss: a prospective investigation," *Laryngoscope*, vol. 90, pp. 1445-52, Sep 1980.
- [34] P. B. McIntyre, C. S. Berkey, S. M. King, U. B. Schaad, T. Kilpi, G. Y. Kanra, and C. M. Odio Perez, "Dexamethasone as adjunctive therapy in bacterial meningitis a meta-analysis of randomized clinical trials since 1988," *Journal of the American Medical Association*, vol. 278, pp. 925-931, 1997.
- [35] P. Caye-Thomasen, M. S. Dam, S. H. Omland, and M. Manton, "Cochlear ossification in patients with profound hearing loss following bacterial meningitis," *Acta Oto-Laryngologica*, vol. 132, pp. 720-725, 2012.
- [36] D. Philippon, F. Bergeron, P. Ferron, and R. Bussieres, "Cochlear implantation in postmeningitic deafness," *Otology & Neurotology*, vol. 31, pp. 83-87, 2009.
- [37] J. W. Kutz, L. M. Simon, S. K. Chennupati, C. M. Giannoni, and S. Manolidis, "Clinical predictors for hearing loss in children with bacterial meningitis," *Archives of Otolaryngology --Head & Neck Surgery*, vol. 132, pp. 941-945, 2006.
- [38] S. Kamei and T. Takasu, "Nationwide survey of the annual prevalence of viral and other neurological infections in Japanese inpatients," *Internal Medicine*, vol. 39, pp. 894-900, 2000.
- [39] D. R. Strutton and P. E. Stang, "Prophylaxis against respiratory syncytial virus (RSV), varicella, and pneumococcal infections: economic-based decision-making," *The Journal of Pediatrics*, vol. 143, pp. S157-S162, 2003.
- [40] H. Porter and F. H. Bess, "Children with unilateral hearing loss," in *Comprehensive Handbook of Pediatric Audiology*, R. C. Seewald and A. M. Tharpe, Eds., ed San Diego: Plural Publishing, 2011, pp. 175-191.
- [41] K. J. Connolly and S. M. Hammer, "The acute aseptic meningitis syndrome," *Infectious Disease Clinics of North America*, vol. 4, pp. 599-622, 1990.
- [42] B. E. Lee, R. Chawla, J. M. Langley, S. E. Forgie, M. Al-Hosni, K. Baerg, E. Husain, J. Strong, J. L. Robinson, U. Allen, B. J. Law, S. Dobson, and H. D.

- Davies, "Paediatric investigators collaborative network on infections in Canada (PICNIC) study of aseptic meningitis," *BMC Infectious Diseases*, vol. 6, 2006.
- [43] C. M. Wilfert, S. N. Lehrman, and S. L. Katz, "Enteroviruses and meningitis," *Pediatric Infectious Disease*, vol. 2, pp. 333-341, 1983.
- [44] M. Blank and A. R. Tunkel, "Infections of the central nervous system," in *Principles and Practice of Geriatric Medicine*. vol. 1, M. S. John Pathy, A. J. Sinclair, and J. E. Morley, Eds., ed Chichester: Wiley, 2006, pp. 1763-1778.
- [45] R. C. Baker, A. W. Kummer, J. R. Schultz, M. Ho, and J. Gonzalez del Ray, "Neurodevelopmental outcome in infants with viral meningitis in the first three months of life," *Clinical Pediatrics*, vol. 35, pp. 295-301, 1996.
- [46] I. Bergman, M. J. Painter, E. R. Wald, D. Chiponis, A. L. Holland, and H. G. Taylor, "Outcome in children with enteroviral meningitis during the first year of life," *The Journal of Pediatrics*, vol. 110, pp. 705-709, 1987.
- [47] M. L. Lepow, N. Coyne, L. B. Thompson, D. H. Carver, and F. C. Robbins, "A clinical, epidemiologic and laboratory investigation of aseptic meningitis during the four-year period, 1955-1958. II. The clinical disease and its sequelae," *The New England Journal of Medicine*, vol. 266, pp. 1188-1193, 1962.
- [48] A. G. Michos, V. P. Syriopoulou, C. Hadjichristodoulou, G. L. Daikos, E. Lagona, P. Douridas, G. Mostrou, and M. Theodoridou. (2007, Aseptic meningitis in children: analysis of 506 cases. *PLoS ONE* 2(8), e674. Available: www.plosone.org
- [49] M. L. Rorabaugh, L. E. Berlin, F. Heldrich, K. Roberts, L. A. Rosenberg, T. Doran, and J. F. Modlin, "Aseptic meningitis in infants younger than 2 years of age: acute illness and neurologic complications," *Pediatrics*, vol. 92, pp. 206-211, 1993.
- [50] U. Rosenhall and A. Kankkunen, "Hearing alterations following meningitis. 1. Hearing improvement," *Ear & Hearing*, vol. 1, pp. 185-90, Jul-Aug 1980.
- [51] C. J. Sells, R. L. Carpenter, and C. G. Ray, "Sequelae of central-nervous-system enterovirus infections," *The New England Journal of Medicine*, vol. 293, pp. 1-4, 1975.
- [52] C. M. Wilfert, R. J. Thompson, T. R. Sunder, A. O'Quinn, J. Zeller, and J. Blacharsh, "Longitudinal assessment of children with enteroviral meningitis during the first three months of life," *Pediatrics*, vol. 67, pp. 811-815, 1981.
- [53] T. Yang, L. Huang, C. Lu, C. Kao, W. Lee, P. Lee, C. Chen, F. Huang, C. Lee, and L. Chang, "Clinical features and factors of unfavorable outcomes for non-polio enterovirus infection of the central nervous system in northern Taiwan, 1994-2003," *Journal of Microbiology Immunology and Infection*, vol. 38, pp. 417-424, 2005.
- [54] S. W. Yeat, S. Z. M. Mukari, H. Said, and R. Motilal, "Post meningitic sensori-neural hearing loss in children - alterations in hearing level," *Medical Journal of Malaysia*, vol. 52, pp. 285-290, 1997.
- [55] J. B. Nadol Jr, "Hearing loss a sequela of meningitis," *The Laryngoscope*, vol. 88, pp. 739-755, 1978.

- [56] C. Wilson, A. Roberts, and D. Stephens, "Improving hearing assessment of children post-meningitis," *Archives of Disease in Childhood*, vol. 88, pp. 976-7, Nov 2003.
- [57] G. Kanra, A. Kara, A. B. Cengiz, P. Isik, M. Ceyhan, and A. Atas, "Mumps meningoencephalitis effect on hearing," *Pediatric Infectious Disease Journal*, vol. 21, pp. 1167-9, Dec 2002.
- [58] Z. Yuanjie, C. Jianghan, X. Nan, W. Xiaojun, W. Hai, L. Wanqing, and G. Julin, "Cryptococcal meningitis in immunocompetent children," *Mycoses*, vol. 55, pp. 168-171, 2011.
- [59] J. Nichani, K. Green, P. Hans, I. Bruce, L. Henderson, and R. Ramsden, "Cochlear implantation after bacterial meningitis in children: outcomes in ossified and nonossified cochleas," *Otology & Neurotology*, vol. 32, pp. 784-789, 2011.
- [60] N. M. Young and T. Q. Tan, "Current techniques in management of postmeningitic deafness in children," *Archives of Otolaryngology -- Head & Neck Surgery*, vol. 136, pp. 993-8, Oct 2010.
- [61] J. T. Roland Jr, D. H. Coelho, H. Pantelides, and S. B. Waltzman, "Partial and double-array implantation of the ossified cochlea," *Otology & Neurotology*, vol. 29, pp. 1068-1075, 2008.
- [62] B. Isaacson, T. Booth, J. W. Kutz Jr, K. H. Lee, and P. S. Roland, "Labyrinthitis ossificans: how accurate is MRI in predicting cochlear obstruction?," *Otolaryngology Head and Neck Surgery*, vol. 140, pp. 692-696, 2009.
- [63] B. Y. Roukema, M. C. Van Loon, C. Smits, C. F. Smit, S. T. Goverts, P. Merkus, and E. F. Hensen. (2011, October 15, 2012). Cochlear implantation after bacterial meningitis in infants younger than 9 months. *International Journal of Otolaryngology 2011*, 9.
- [64] S. M. Bhatt, A. Lauretano, C. Cabellos, C. Halpin, R. A. Levine, W. Z. Xu, J. B. Nadol Jr, and E. Tuomanen, "Progression of hearing loss in experimental pneumococcal meningitis: correlation with cerebrospinal fluid cytochemistry," *The Journal of Infectious Diseases*, vol. 167, pp. 675-683, 1993.
- [65] S. L. Kaplan, F. I. Catlin, T. Weaver, and R. D. Feigin, "Onset of hearing loss in children with bacterial meningitis," *Pediatrics*, vol. 73, pp. 575-8, May 1984.
- [66] M. P. Richardson, A. Reid, M. J. Tarlow, and P. T. Rudd, "Hearing loss during bacterial meningitis.[Erratum appears in Arch Dis Child 1997 Apr;76(4):386]," *Archives of Disease in Childhood*, vol. 76, pp. 134-8, Feb 1997.
- [67] U. Rosenhall and A. Kankkuken, "Hearing alterations following meningitis. 2. Variable hearing," *Ear and Hearing*, vol. 2, pp. 170-176, 1981.
- [68] H. Vienny, P. A. Despland, J. Lutschg, T. Deonna, M. L. Dutoit-Marco, and C. Gander, "Early diagnosis and evolution of deafness in childhood bacterial meningitis: a study using brainstem auditory evoked potentials," *Pediatrics*, vol. 73, pp. 579-86, May 1984.
- [69] E. R. Wald, S. L. Kaplan, E. O. Mason, D. Sabo, L. Ross, M. Arditi, B. L. Wiedermann, W. Barson, K. S. Kim, R. Yogev, and D. Hofkosh,

- "Dexamethasone therapy for children with bacterial meningitis," *Pediatrics*, vol. 95, pp. 21-28, 1995.
- [70] R. Drake, J. Dravitski, and L. Voss, "Hearing in children after meningococcal meningitis," *Journal of Paediatrics & Child Health*, vol. 36, pp. 240-3, Jun 2000.
- [71] H. Fortnum and A. Davis, "Hearing impairment in children after bacterial meningitis: incidence and resource implications," *British Journal of Audiology*, vol. 27, pp. 43-52, Feb 1993.
- [72] T. A. Lieu, G. T. Ray, S. B. Black, J. C. Butler, J. O. Klein, R. F. Breiman, M. A. Miller, and H. R. Shinefield, "Projected cost-effectiveness of pneumococcal conjugate vaccination of healthy infants and young children," *The Journal of the American Medical Association*, vol. 283, pp. 1460-1468, 2000.
- [73] M. P. Richardson, A. Reid, T. J. Williamson, M. B. Chir, M. J. Tarlow, and P. T. Rudd, "Acute otitis media and otitis media with effusion in children with bacterial meningitis," *The Journal of Laryngology and Otology*, vol. 111, pp. 913-916, 1997.
- [74] M. Richardson, T. Williamson, A. Reid, M. Tarlow, and P. Rudd, "Testing for hearing loss after meningitis," *Journal of Pediatrics*, vol. 132, pp. 749-50, Apr 1998.
- [75] I. Kulahli, M. Ozturk, C. Bilen, S. Cureoglu, A. Merhametsiz, and N. Cagil, "Evaluation of hearing loss with auditory brainstem responses in the early and late period of bacterial meningitis in children," *Journal of Laryngology & Otology*, vol. 111, pp. 223-7, Mar 1997.
- [76] K. Grimwood, P. Anderson, V. Anderson, L. Tan, and T. Nolan, "Twelve year outcomes following bacterial meningitis: further evidence for persisting effects," *Archives of Disease in Childhood*, vol. 83, pp. 111-116, 2000.
- [77] J. T. MacDonald and S. Feinstein, "Hearing loss following Hemophilus influenzae meningitis in infancy. Diagnosis by evoked response audiometry," *Archives of Neurology*, vol. 41, pp. 1058-9, Oct 1984.