Exploring the audiological management of young children (0-6 years) diagnosed with bacterial meningitis

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Abstract

Background. Internationally, infectious diseases remain the greatest cause of morbidity among young children. Infectious disease burden is particularly high in low-to-mid income countries (LMIC). South Africa has a high prevalence of bacterial meningitis (BM), especially in children under the age of five. BM is also one of the commonest causes of acquired hearing loss in children. Given the fluctuating and transient nature of BM-related hearing loss, there is a need for an effective audiological protocol to facilitate timeous and appropriate audiological management. There is currently no universally accepted protocol for the audiological referral and management of children diagnosed with BM. Consequently, there is a need for an evidence-based protocol that will ensure timely referral and audiological testing of all children diagnosed with BM. Early identification of BM-related hearing loss in children will allow for timeous, appropriate audiological management and associated benefits, such as an option for placement in mainstream schooling.

Objectives. This study aimed to explore the audiological management of children diagnosed with BM at a tertiary hospital in the Western Cape, South Africa, with reference to: patterns of referral for audiological assessment following a diagnosis of BM; current audiological protocols for the management of children diagnosed with BM. It was anticipated that this study would generate evidence that could potentially be used to develop appropriate protocols for the audiological management of children diagnosed with BM in LMICs, specifically South Africa.

Methods. A retrospective record review was conducted using patient folders of children between 0 and 6 years who were treated for BM between May 2016 and May 2018. Data collection took place at Red Cross War Memorial Children's Hospital, which has a paediatric infectious diseases unit and an audiology department. Demographic and audiological data were recorded on a self-developed data abstraction form and data were analysed descriptively.

Results. A total of 291 patient folders were accessed for review in this study. Of those, 40 (13.7%) met the inclusion criteria for the study and were selected for review. The majority of excluded folders were for patients not referred for audiological testing post-BM diagnosis. For those children referred to audiology, average referral time was 15 days (SD = 24 days) and each patient attended an average of only 2 audiology appointments. Otoacoustic emissions testing and tympanometry were the most commonly performed audiological tests in all children. BM-related hearing loss developed in 2/19 of these patients. All patients who were diagnosed with BM-related hearing loss were subsequently fitted with hearing aids – one of whom was fitted unilaterally with a hearing aid and the other, a cochlear implant candidate, was lost to follow-up.

Conclusions. The key challenge experienced in this study was low referral rates to audiology (16%), which was followed by poor adherence to follow-up appointments – both of which were found to impede effective audiological management. Effective management and prevention of BM-related hearing loss pose challenges in LMICs. This study highlights the need for a well-defined referral pathway and an evidence-based protocol for the audiological management of children with BM within the South African health care setting. If this could be achieved, the early identification of hearing loss in these children has the potential to provide them with developmental, scholastic, and working opportunities in line with those of children with normal hearing.

Keywords

Meningitis, bacterial meningitis, paediatric bacterial meningitis, hearing loss, referral

Key Abbreviations

ABR – Auditory Brainstem Response

AABR – Automated Auditory Brainstem Response

BCCH – British Columbia Children's Hospital

BM – Bacterial Meningitis

BM-related hearing loss – Bacterial Meningitis Related Hearing Loss

CI – Cochlear Implant

CPA – Conditioned Play Audiometry

dBeHL – Decibels Estimated Hearing Level

dBHL – Decibels Hearing Level

dBnHL – Decibels Normal Hearing Level

EHDI – Early Hearing Detection and Intervention

HIV/AIDS - Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome

HPCSA – Health Professionals Counsel of South Africa

ICF – The International Classification of Functioning, Disability and Health

LMICs – Low-to-Mid Income Countries

NICD – National Institute for Communicable Diseases

OAE – Otoacoustic Emissions

PTA – Pure Tone Audiometry

RCWMCH – Red Cross War Memorial Children's Hospital

SDT – Speech Detection Threshold

SNHL – Sensorineural Hearing Loss

VRA – Visual Reinforcement Audiometry

WCDoH – Western Cape Department of Health

WHO – World Health Organization

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Chapter 1: Introduction

Introduction: This chapter provides the study background by presenting a review of information on the global and local burden of infectious diseases, with emphasis on meningitis in Africa and South Africa. Links between bacterial meningitis and hearing loss, as well as the impact of hearing loss, will be discussed to prepare the ground for formulating the study rationale.

Burden of Infectious Diseases

Infectious diseases remain the greatest contributor towards morbidity among children worldwide (Abhulimhen-Iyoha & Okolo, 2012). The burden of infectious diseases is especially high in low-to-mid income countries (LMICs) (Bhutta, Sommerfeld, Lassi, Salam, & Das, 2014). For example, infamous infectious diseases like human immunodeficiency virus, acquired immunodeficiency syndrome (HIV/AIDS), tuberculosis (TB), malaria, cholera, and meningitis, which are more prevalent in most LMICs, are known to be significant causes of disability and mortality (Kindhauser, 2003). In 2013, almost half (49.6%) of global deaths in children under 5 were from sub-Saharan Africa and 61.5% (1 914 000) of those deaths were due to infectious diseases such as meningitis and neonatal pneumonia (Liu et al., 2015).

Meningitis, which will be the focus topic for this study, remains in particular a significant health problem in the African continent. For instance, in 2017 the World Health Organisation (WHO) reported 31 103 cases of meningitis in Africa, including 2 278 deaths. Furthermore, LMICs account for 98% of the estimated 5.6 million disability-adjusted life years attributed to the disease (McIntyre, O'Brien, Greenwood, & van de Beek, 2012).

In South Africa, reports indicate that the incidence of bacterial meningitis (BM) has decreased from 2000 cases reported in 1972 to less than 500 in 2005 (Department of Health,

2011). This decrease is largely attributed to the introduction of the *Haemophilus influenzae* type b (Hib) conjugate vaccine into the routine infant immunization schedule in South Africa in 1999 (von Gottberg et al., 2006). Latest statistics estimate the annual incidence of BM in South Africa to be 4/100 000, with the highest incidences reported in Gauteng and the Western Cape (Department of Health, 2011). The greatest incidence of infection is reported in children under the age of 5. In this age group, the highest incidence is in children under the age of 1 (40/100 000), followed by children between the ages of 1 and 4 (7/100 000) (Department of Health, 2011; Meiring, Govender, Keddy, & al., 2009).

Meningitis is the infection of the cerebrospinal fluid and subsequent inflammation of the meninges. There are five main types of meningitis: bacterial, viral, fungal, parasitic, and non-infectious (Shih & Koeller, 2015). Bacterial and viral are the commonest types. The main bacteria responsible for childhood BM are *Streptococcus pneumoniae (S. pneumoniae)*, *Neisseria meningitides* (*N. meningitides)* and *Haemophilus influenzae (H. influenzae)* (Theodoridou et al., 2007). In a retrospective review, which investigated the organisms that are most likely to cause BM, it was found that Group B *Streptococcus* was the commonest microorganism that caused meningitis during the neonatal period, while *S. pneumoniae* was usually common after the neonatal period (Husain, Chawla, Dobson, Dele Davies, & Paediatric Investigators Collaborative Network on Infections in Canada, 2006). Furthermore, *S. pneumoniae* was found to have the greatest risk of sequelae, such as brain abscess, nerve palsy, epileptic seizures and hearing loss, post meningitis infection (Rajasingham, Bonsu, Chapman, Cohen, & Barson, 2008). With specific reference to neonates, *N. meningitidis, S. pneumoniae*, and *H. influenzae* rarely cause meningitis in this population. Instead, the commonest pathogens detected in cerebrospinal fluid of neonates with BM in LMICs are *S. pneumoniae*, Group B *Streptococcus*, *Listeria monocytogenes*, *Escherichia coli (E. coli)*, and other Gram-negative enteric bacteria (Chang Chien, Chiu, Li, & Huang, 2000; Gaschignard et al., 2011; Holt,

Halket, de Louvois, & Harvey, 2001). In contrast, studies in LMICs have shown that *Staphylococcus aureus*, *Streptococcus pyogenes* and *E. coli* were the commonest causes of neonatal meningitis, with *S. pneumoniae* being a prominent cause in the late neonatal period (WHO Young Infants Study Group, 1999a, 1999b). It is clear, therefore, that the spectrum of meningitis-causing pathogens in high-income countries is different from those in LMICs, such as South Africa, although Group B *Streptococcus* remains a prominent cause (Osrin, Vergnano, & Costello, 2004).

Globally, meningitis spreads sporadically and in small clusters, occurring more frequently in milder climates with seasonal increases in winter and early spring (Department of Health, 2011). There are no reliable estimates of the BM global burden of disease due to inadequate surveillance (WHO, 2018). The highest burden of BM is reported to occur in the *"meningitis belt"* in sub-Saharan Africa, which runs from Senegal in the west to Ethiopia in the east. This is because BM often manifests as an upper respiratory tract infection – frequently seen in the latter half of the year when dust storms in these regions are a common occurrence. Approximately 300 million people reside in the *"meningitis belt"* region, where roughly 30 000 new cases of BM are reported annually (Department of Health, 2011).

Presentation of BM

According to Furyk, Swann, and Molyneux (2011), neonatal sepsis and meningitis are significant contributors to the childhood disease burden in LMICs (Furyk et al., 2011). Neonatal meningitis is one of the primary causes of neonatal mortality and morbidity in LMICs. The immature immune systems of neonates predisposes them more to meningitis than in any other childhood period (Merkus et al., 2010; Polin & Harris, 2001). However, researchers suggest that the statistics surrounding neonatal meningitis are under-reported in

LMICs. This is largely attributed to the difficulty in diagnosing meningitis in neonates and young children (Osrin et al., 2004).

Initially, BM may present as flu-like symptoms (fever, muscle pain, headaches, nausea, vomiting and malaise), which may be accompanied by nuchal rigidity, physical weakness and fatigue, hypotension, photophobia, raised intracranial pressure, and impaired consciousness (Department of Health, 2011). However, unlike older children and adults, neonates and infants are challenging to diagnose because they do not display typical BM findings (Klein, Feigin, & McCracken, 1986; Lipton & Schafermeyer, 1993). Instead, symptoms in neonates are usually non-specific and less severe. Common symptoms in neonates include fever, malaise, irritation, jaundice, vomiting, diarrhoea, and decreased eating. Only a minority of neonates present with nuchal rigidity, seizures, and a raised fontanelle (National Collaborating Centre for Women's and Children's Health (UK), 2010).

Polin and Harris (2001) found low birth weight and prematurity to be prominent neonatal risk factors for meningitis. Maternal risk factors included premature rupture of membranes, prolonged rupture of membranes (>18 hours), maternal colonisation with Group B *Streptococcus*, maternal chorioamnionitis, and a low socio-economic status. Furthermore, researchers have investigated risk factors for poor outcomes related to meningitis. These included low birth weight, prematurity, and infections caused by Gram-negative organisms such as *E. coli* (Osrin et al., 2004; Polin & Harris, 2001).

BM is the most prevalent cause of acquired hearing loss in children (Fortnum, 1992). Hearing loss resulting from BM can have a negative impact on a child's development. According to Tye-Murray (2014), children's auditory, communication, linguistic, and learning abilities can be considerably affected by hearing loss. These negative effects can have a significant impact on the child's quality of life, which extends into adulthood. Early

identification of BM-related hearing loss is therefore vital, as many of these children are at a critical age for language acquisition and linguistic development (Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007). Failure to ensure the early identification and management of hearing loss has been shown to result in several negative implications, such as compromised language and cognitive development, impaired psychosocial behaviour, and lifelong stigmatisation and isolation (Fellinger, Holzinger, & Pollard, 2012; Theunissen et al., 2014). Furthermore, hearing loss has also been found to result in long term difficulties obtaining, succeeding in, and maintaining a job (Moeller, 2000; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). In terms of financial implications later in life, Jung and Bhattacharyya (2012) reported that, in a high-income country setting, adults with hearing loss will earn approximately 25% less than those with normal hearing. This discrepancy may be even more evident in LMICs, such as South Africa, where average income is lower compared to high-income countries (Kose, Prasad, Rogoff & Wei, 2006).

Early Identification of BM-Related Hearing Loss

Early identification of children with BM-related hearing loss can be challenging in LMICs such as South Africa, due to limited access to audiology services. The number of practicing hearing healthcare professionals in South Africa's public sector is inadequate to effectively serve the majority of communities that make use of government health care services (Swanepoel, 2006). In South Africa, diagnostic audiology services are primarily limited to secondary and tertiary health care facilities (Swanepoel, Louw, & Hugo, 2007). This creates access barriers for patients who do not reside in urban areas where these facilities are located and, as a result, children with BM-related hearing loss may not have access to the hearing healthcare they require. This can significantly affect the prognosis of a child who does not receive early intervention post-hearing loss diagnosis.

Economically, early identification of childhood hearing loss as a consequence of BM can result in decreased financial expenditure in the long term when considering the special education and social welfare required for children who did not receive early intervention (Yoshinaga-Itano & Gravel, 2001). A study by Emmett et al. (2015) compared the costs related to pre-lingually deaf children who receive cochlear implants and attend mainstream schooling, with the costs related to deaf children who receive deaf education with sign language. The lifetime costs associated with the cochlear implant (CI) group was approximately US$118 317, compared to the sign language group where a cost of US$132 433 was estimated for deaf education over a period of 14 years.

It is therefore imperative that hospital protocols for the management of children diagnosed with BM should include mandatory audiological referral to ensure early detection, appropriate management, and favourable long-term outcomes for these patients (Karanja, Oburra, Masinde, & Wamalwa, 2013; Roine et al., 2014). However, while there is international consensus about the need for audiological testing in meningitis patients (American Academy of Pediatrics, 2007), there is currently no internationally accepted, evidence-based protocol detailing hearing evaluation and follow-up in BM cases (Merkus et al., 2010; Rodenburg-Vlot, Ruytjens, Oostenbrink, & van der Schroeff, 2018). The present study therefore aimed to explore the audiological management of paediatric populations diagnosed with BM. It was anticipated that this study would generate evidence that would lead to recommendations to set protocols for the audiological management of children diagnosed with BM in LMICs, specifically South Africa. The implementation of such protocols has the potential to increase the early identification of hearing loss in children with BM and facilitate appropriate audiological management. This in turn could bring about associated benefits, such as an option for placement in mainstream schools.

Chapter 2: Literature Review

Introduction: In this chapter, existing literature on the relationship between BM and hearing loss will be critically reviewed. To provide the rationale for the present study, gaps in BM-related hearing loss literature and audiological management of children who are diagnosed with BM will be presented.

BM is a common cause of acquired hearing loss in children. Children infected with BM typically develop hearing loss, specifically sensorineural hearing loss (SNHL), as one of the sequelae of the infection (Fortnum, 1992). The reported incidence of BM-related hearing loss in children varies significantly in existing literature. Incidence rates reported from previous studies have fluctuated between 7 and 31% (Baraff, Lee, & Schriger, 1993; Fortnum, 1992; Husain et al., 2006; Koomen et al., 2003; Oostenbrink, Maas, Moons, & Moll, 2002; Wellman, Sommer, & McKenna, 2003; Worsoe, Caye-Thomasen, Brandt, Thomsen, & Ostergaard, 2010). This variability in reported incidences of BM-related hearing loss may be attributed to various factors, including differences in population characteristics in which these studies were conducted, differences in study designs such as hearing testing methods, test interpretation, and definitions of hearing loss (BCCH, 2014).

In terms of population characteristics, causative pathogens for meningitis have been found to vary according to context, and therefore vary between populations (Chang Chien et al., 2000; Gaschignard et al., 2011; Holt et al., 2001). This variation in causative pathogens for BM may partially explain the variability in hearing loss incidence reported in different studies. For example, a study by Rodenburg-Vlot et al. (2018), conducted in the Netherlands, reported that the commonest causative pathogen was *S. pneumoniae*. In their study, the incidence of BM-related hearing loss was 28% (Rodenburg-Vlot et al., 2018). In another study, conducted in England and South Wales, the commonest causative pathogen was *N. meningitidis*, and

incidence of BM-related hearing loss was 17% at baseline and 2.4% at discharge (Richardson, Reid, Tarlow, & Rudd, 1997). Furthermore, the type of causative pathogen for BM has been shown to determine the risk for BM-related hearing loss.

de Jonge et al. (2013) speculate that the incidence of BM-related hearing loss may be considerably higher in LMICs, such as South Africa. Any underestimation is partly due to physicians only considering certain characteristics of BM relevant for audiometric referral (de Jonge et al., 2013), but may also be related to how disabling hearing loss was defined (Olusanya & Newton, 2007) and an overall lack of research in this region.

In terms of study designs, the Rodenburg-Vlot et al. (2018) study used a retrospective cohort study involving 655 medical folders and BM-related hearing loss was diagnosed in 69/252 (27%) patients for whom audiological data were available. A study by Richardson, Reid, Tarlow, et al. (1997) used a multicentre prospective design, with a sample size of 124 patients. Incidence of BM-related hearing loss in this study was 2.4%.

With regard to hearing testing methods, the specific audiological test battery used to diagnose hearing loss is often not specified in the literature, such as in studies by Husain et al. (2006) or de Jonge et al. (2013). Consequently, reported incidence rates of BM-related hearing loss in these studies could be an underestimation if sensitive tests for diagnosing BM-related hearing loss were not included as part of the test battery. As a result, hearing assessment interpretation and hearing loss definitions are also affected. For example, some studies report "normal hearing" where only an otoacoustic emissions (OAE) screening test was used, as opposed to a diagnostic hearing test such as auditory brainstem response (ABR) testing or pure tone audiometry testing. Conservative measures for normal hearing, such as a passed screening OAE, and lack of clarity when reporting type and degree of hearing loss can negatively impact reported hearing loss incidence. For instance, with reference to definitions of hearing loss,

Husain et al. (2006) did not indicate the level at which a hearing loss diagnosis was made. Hearing loss was defined as thresholds > 25dB by Koomen et al. (2003) and de Jonge et al. (2013), but as > 20dB by Worsoe et al. (2010). In terms of type of hearing loss, Worsoe et al. (2010) did not specify whether conductive hearing loss was included in the incidence rate, whereas de Jonge et al. (2013) excluded all conductive hearing loss cases from their research. Conductive hearing loss is not characteristic of BM-related hearing loss and therefore studies that include conductive losses as part of their research may over-report the incidence of BM-related hearing loss.

Pathophysiology of BM-related Hearing Loss

BM-related hearing loss occurs as a result of infection and accompanying inflammation of the cochlea during the course of the disease. Infection from the meninges can enter the cochlea through the cochlear aqueduct via the subarachnoid space. This cochlear infection and concomitant inflammation causes damage to the intracochlear structures. When this happens, the cochlea may be partially or completely ossified, which is a direct cause of SNHL (Nichani et al., 2011). There are two mechanisms for cochlear ossification as a result of infectious meningitis: (1) endotoxin-induced inflammation in the cochlear aqueduct may cause partial ossification in the basal turn of the scala tympani; and (2) suppurative labyrinthitis from bacterial invasion into the perilymphatic scalae may result in complete ossification (Axon, Temple, Saeed, & Ramsden, 1998). Inflammatory destruction in the cochlea has varying effects, as certain cochlear turns are more vulnerable than others (Nichani et al., 2011; Tokat, Catli, Bayrak, Bozkurt, & Olgun, 2018). For instance, the basal turn of the cochlea is conjectured to be more affected, based on the common high-frequency configuration of BM-related hearing loss (De Barros et al., 2014; Du, Wu, & Li, 2006).

Causative pathogen has also been found to affect BM-related hearing loss occurrence and severity. *S. pneumoniae*, *N. meningitides* and *H. influenza* meningitis in particular put patients at a higher risk for cochlear ossification (Roukema et al., 2011). The commonest pathogens causing BM-related hearing loss are also most likely to cause cochlear ossification, with *S. pneumoniae* being more likely than *N. meningitides, and H. influenza* being the least likely (BCCH, 2014). Studies have reported a significant relationship between *S. pneumoniae* meningitis and SNHL (Wellman et al., 2003; Worsoe et al., 2010).

Cochlear inflammation can quickly progress into ossification of the cochlear lumen. The inflammatory process involves acute infection, fibrosis, and finally ossification, where the endolymphatic and perilymphatic regions in the cochlea are destroyed (Philippon, Bergeron, Ferron, & Bussieres, 2010). The possibility of hearing restoration with cochlear implantation could disappear within weeks due to ossification (Merkus et al., 2010). Early diagnosis of BM-related hearing loss is therefore critical because it increases chances of successful CI placement and electrode insertion into the cochlea before ossification (Rodenburg-Vlot et al., 2018).

Predictors of Hearing Loss Acquisition Following a Diagnosis of BM

While knowledge of prediction factors for hearing loss may aid physicians in making prompt referrals for audiological assessment (Khoza-Shangase & Rifkind, 2010), researchers have not reached a consensus on specific symptoms of BM as hearing loss predictors. Kutz, Simon, Chennupati, Giannoni, and Manolidis (2006) found that BM-related hearing loss is related to the presence of cranial nerve neuropathy, which in turn is related to meningitis severity. While studies show that late onset hearing loss is very rare, the exact onset of hearing loss remains unclear (Rodenburg-Vlot et al., 2018). Several studies have explored symptomology during BM as predictors for hearing loss in children (Karanja et al., 2013; Koomen et al., 2003; Kutz et al., 2006). Using a risk prediction model, Koomen et al. (2003)

established five risk factors for hearing loss in school-aged BM survivors: *S. pneumoniae* as a causative pathogen, ataxia, duration of BM symptoms prior to admission (longer than two days), cerebrospinal fluid glucose ≤0.6 mmol/L, and the absence of petechiae. Kutz et al. (2006) on the other hand reported lengthy hospitalisation (≥16 days), seizures, fever, decreased cerebrospinal fluid glucose, and elevated cerebrospinal fluid protein to be predictors of BM-related hearing loss. In addition, a study by Karanja et al. (2013) found seizures and a Glasgow Coma Scale (GCS) score of <8 to be significant predictors of BM-related hearing loss. The Koomen model was later validated by de Jonge et al. (2013) and was found to have value in clinical practice as a screening tool for audiology referral.

Certain co-morbidities may increase susceptibility to BM infection which therefore increases susceptibility to BM-related hearing loss. For example, children with HIV are more prone to contracting bacterial infections, including BM (Molyneux et al., 2003). A study by Veltman, Bristow, and Klausner (2014) found BM to be more common in HIV-positive patients than in the general population in LMICs. When compared to the general population, people with HIV are 8 times more likely to develop BM (van Veen, Brouwer, van der Ende, & van de Beek, 2016). This likelihood was observed to be far higher in a study by Domingo et al. (2009), who found the risk of BM development in HIV infected patients to be 19 times higher when compared to the general population. These statistics are of vital importance in the management of children infected with HIV in the South African context because of the increased susceptibility to BM. Also, given that HIV alone can have negative consequences for a child's development, co-infection with BM and subsequent hearing loss can further reduce their developmental potential. This co-infection has also been found to be predictive of recurrent BM infection and leads to a high mortality rate (Sherr, Hensels, Tomlinson, Skeen, & Macedo, 2018). HIV therefore becomes an important contextual factor to consider in BM

management, given the susceptibility it creates for contracting BM and, therefore, BM-related hearing loss.

Characteristics of BM-related Hearing Loss

Hearing loss resulting from infection with BM is typically a SNHL, which can range in severity from a mild to profound SNHL and can be unilateral or bilateral (Fortnum, 1992; Karanja et al., 2013). Audiometric patterns of hearing loss in patients with BM vary, with research documenting BM-related hearing loss as differing between assessments and patients (Kanji & Kara, 2013). A study by Roine et al. (2014) determined that there is a possibility of both significant improvement as well as deterioration in hearing thresholds in the days, weeks, and even months following initial onset of BM. Their results showed substantial changes in hearing thresholds post-admission in approximately half their sample of children with BM. This is in contrast to findings in a study by Rodenburg-Vlot et al. (2018) which showed that all patients with normal hearing at baseline assessment remained normal across future assessments. Rodenburg-Vlot et al. (2018) therefore suggested that repeated audiometry is unnecessary for the "normal at baseline" group. Given the varying degrees and instability of hearing loss that can arise as a consequence of BM, the formulation of a protocol for audiological management of these children is particularly difficult (BCCH, 2014). It is nonetheless evident that a customised audiological protocol for children with BM is required.

Two common audiological protocols that are often cited in literature and have been recommended by several studies for managing children with meningitis are the British Columbia Children's Hospital (BCCH) Audiology Clinical Practice Guideline for Meningitis (BCCH, 2014) and the Dutch Cochlear Implant Group (CI-ON) Consensus Protocol on Postmeningitis Hearing Evaluation and Treatment (Merkus et al., 2010).

The BCCH protocol (Table 1) recommends that children with normal hearing at baseline assessment have a follow up assessment three months later, a third assessment six months after the baseline assessment and then be discharged if normal. BCCH defines normal hearing as 25dB or less at 500Hz, 2000Hz and 4000Hz bilaterally. For children with a SNHL detected at baseline, the BCCH protocol recommends urgent referral for medical investigation and that audiological reassessment takes place within two weeks. In cases where hearing remains stable between the two tests (stable hearing was defined as less than or equal to a 10dB change at 500Hz, 2000Hz and 4000Hz), specific timelines are recommended. The protocol suggests that reassessment should take place every three months for the first year after meningitis diagnosis, and then every six months after that, until they are three years post-meningitis and annually thereafter. For children with a fluctuating or worsening SNHL, referral to the child's physician for urgent medical investigation is recommended. The protocol suggests that the schedule for reassessment of these children be established on a case-by-case basis (BCCH, 2014).

Table 1. Summary of *BCCH Audiology Clinical Practice Guideline for Meningitis*

BCCH Protocol	
Abnormal at baseline	• Refer for urgent medical investigation. • Retest in 2 weeks.
Stable between assessments	• Retest every 3 months for 1 year post-meningitis diagnosis. • Retest every 6 months until 3 years post-meningitis diagnosis. • Retest annually thereafter.
Fluctuating/worsening thresholds	• Refer for urgent medical investigation. • Custom protocol on case-by-case basis.

The CI-ON protocol (Table 2), on the other hand, recommends that when normal hearing or mild SNHL (≤ 30dB) is diagnosed upon baseline assessment, patients need to be followed up at 1, 2, 6 and 12 months post-diagnosis (Rodenburg-Vlot et al., 2018). In cases where mild to profound SNHL (> 30dB) of any laterality is diagnosed, urgent referral for radiographic assessment as well as repeated assessment is recommended (Merkus et al., 2010). As with the BCCH protocol, Merkus et al. (2010) suggest that the frequency of follow-up assessments be determined on an individual basis.

Table 2. Summary of the *Dutch Cochlear Implant Group Consensus Protocol on Post-meningitis Hearing Evaluation and Treatment*

CI-ON Protocol	
SNHL < 30dB at baseline	• Retest 1, 2, 6 and 12 months after BM diagnosis.
SNHL > 30dB at baseline	• Refer for urgent radiographic assessment. • Repeated audiometric testing. • Custom protocol on case-by-case basis.

While the CI-ON protocol is more conservative in its definition of hearing loss (>30dB as opposed to >25dB), the BCCH protocol is more stringent in the frequency of its follow-up appointment timelines. The BCCH calls for regular interval follow-ups up to three years post-meningitis diagnosis, compared to the CI-ON protocol which only requires follow-up until 1-year post-BM diagnosis. Deterioration or fluctuation in BM-related hearing is reportedly rare (Roine et al., 2014; Woolley et al., 1999). Therefore, long-term follow up for meningitis-related hearing loss as suggested by the BCCH may be warranted in LMICs, but is not viable in

resource-strained health care settings, such as those in South Africa. Instead, follow-ups up to one year post-BM diagnosis may be more feasible for LMICs.

Referral For Audiology Assessment following BM Diagnosis

Despite the known association between BM and hearing loss, referral rates for audiological assessment of patients diagnosed with BM is still relatively low (Khoza-Shangase & Rifkind, 2010). A study in England by Riordan, Thomson, Hodgson, and Hart (1993) found a lack of referral to be the main reason for children with BM not having a hearing assessment. Their research showed that 135 out of 181 cases included in their study underwent audiological evaluation. Of the remaining children, 31 (17%) did not receive audiological evaluation because they were never referred to audiology after BM diagnosis. Similar findings were obtained in another English study by Fortnum and Davis (1993), who found that almost 15% of children (n = 59) were not referred for audiological assessment. A Canadian study by Wellman et al. (2003) showed that only 11.4% of children diagnosed with BM were not referred for audiological assessment. South African studies on referral to audiology after BM-diagnosis have found referral rates ranging from 23.5% to 60% (Khoza-Shangase & Rifkind, 2010; Kuschke, Goncalves, & Peer, 2018).

Previously, researchers emphasised the need for referral for audiological assessment whilst patients are still hospitalised to decrease loss to follow up and ensure early identification of hearing loss (Fortnum, 1992; Riordan et al., 1993). Drake et al. (2000) found that referral for audiological assessment on an outpatient basis results in high rates of non-attendance, with almost 25% of patients not attending their appointment. While in-patient/in-hospital audiological testing prior to discharge has been recommended by several researchers (Karanja et al., 2013; Roine et al., 2014), follow-up testing has also been proposed at 2-4 or 4-6 weeks after discharge (Dodds, Tyszkiewicz, & Ramsden, 1997; Fortnum, 1992; Richardson, Reid,

Williamson, Tarlow, & Rudd, 1997). The BCCH protocol recommends that all children who have meningitis, regardless of the causative pathogen or symptom profile, should be tested, at least until further evidence is available indicating otherwise (BCCH, 2014). As part of the CI-ON protocol, Merkus et al. (2010) advocate that all children should ideally undergo at least a baseline assessment before discharge, regardless of the causative pathogen.

Audiological Management of BM

Cochlear ossification as a result of BM often results in severe-to-profound SNHL. In children with BM-related hearing loss, cochlear implantation is the preferred method in terms of amplification options. This is due to the fact that hearing aids cannot provide sufficient amplification for such severe hearing impairments and due to the cochlear site of lesion (Dillon, 2012). The CI process for children with hearing loss involves various steps to determine candidacy, including a hearing aid trial (Young & Tan, 2010). In South Africa, candidacy criteria for cochlear implantation includes determining economic viability of the CI for families, as well as whether there are CI support and rehabilitation services within a reasonable distance of the patient (Müller & Wagenfeld, 2003). In a South African context, these specialised audiological services are often not available in decentralised areas and patients are required to travel substantial distances using multiple modes of transport (Olusanya, Neumann, & Saunders, 2014; Swanepoel, 2006). In children with BM-related hearing loss, the operative time frame for cochlear implantation is significantly shorter and more urgent. This is due to the risk of imminent fibrosis and ossification that may result in profound SNHL (Roukema et al., 2011). Consequently, these children need to be fast tracked through cochlear implantation candidacy procedures to ensure implantation before ossification. Given that the public health sector is already burdened with a high patient load (Swanepoel, 2006), fast tracking children

with BM-related hearing loss for cochlear implantation requires health professionals involved in this process to be flexible in seeing these emergency cases.

Radiologic evidence of ossification may be found as early as two months after BM onset, which suggests that the intracochlear process begins much earlier than this (Novak, Fifer, Barkmeier, & Firszt, 1990). In fact, research has shown that cochlear ossification can occur as early as 2-4 weeks after BM onset (Merkus et al., 2010). The timing of computed tomography (CT) and magnetic resonance imaging (MRI) to assess the status of the cochlea is therefore vital since once this brief "window of opportunity" has passed, success rates of cochlear implantation may substantially decrease (Dodds et al., 1997). Approximately 1 in 3 patients with profound hearing loss following meningitis will show signs of ossification on imaging. Of the patients with no initial signs of ossification, 10% will have evidence of ossification in future scans (Roland, Coelho, Pantelides, & Waltzman, 2008). Of greater concern is that patients with initial signs of ossification have approximately 80% chance of progressive ossification evident in future scans (Caye-Thomasen, Dam, Omland, & Mantoni, 2012). It is therefore recommended that radiological evaluation to determine the status of the temporal bone and cochlea be performed within 2 weeks of meningitis diagnosis (Roukema et al., 2011). This further emphasises the need for patients to be fast tracked through the CI process (Axon et al., 1998). Dodds et al. (1997) recommend that hearing aid trials should be aborted when ossification is already evident, to ensure a faster implantation process.

However, these timelines may be difficult to achieve in the public health sector in a South African context, given the costs and waiting times associated with radiology and cochlear implantation. The average cost of a CT brain scan in South Africa is between R3000 (USD 219.44[1]) and R5000 (USD 365.73[1]) (Bennimahadeo & Maharajh, 2016). Following this,

[1] USD amount is based on 2019 exchange rates

the cost of a single CI device is approximately R250 000 (USD 18286.50[1]), which excludes anaesthesia and other surgery-related costs, as well as pre- and post-surgical costs (including lifelong maintenance). In the public sector, these costs are the responsibility of the child's parents. This places a large financial strain on households of a low socio-economic status who utilise public health care services, where average annual household income is R32 812 – R59 928 (USD 2400.07[1] – USD 4383.49[1]) (Statistics South Africa, 2015). Other than medical costs, costs for transportation and accommodation also need to be considered for patients who do not reside in one of the six major cities where cochlear implantation services are available (Kerr, Tuomi, & Muller, 2012).

Audiological Rehabilitation Outcomes

Accurate auditory prognosis in children with BM is difficult because of the risk of cochlear ossification (Nichani et al., 2011). This makes the appropriate selection of amplification, hearing aids or CI's, challenging for audiologists (Yeat, Mukari, Said, & Motilal, 1997). Currently, there is no evidence to suggest that hearing loss secondary to BM results in a worse prognosis for CI outcomes compared to non-BM-related hearing loss (de Brito et al., 2013). In a three-year follow-up of children with BM-related hearing loss with partial CI insertion, researchers found that early electric stimulation provided by the CI enhances survival rates of cochlear spiral ganglion neurons. It was also demonstrated that early electric stimulation averts post-deafness neural degeneration to some extent (Rotteveel, Snik, Vermeulen, & Mylanus, 2005). Axon et al. (1998) reported no correlation between the extent of ossification and patient factors, BM features, or the time delay between BM diagnosis and cochlear implantation.

In terms of patient factors, a study by Roukema et al. (2011) indicated that, although children under 9 months of age with BM-related hearing loss benefitted from CI's, audiological

and linguistic outcomes varied greatly between patients. Variability of outcomes was attributed to some patients having additional complications (other than hearing loss) secondary to BM. Similar findings were recorded by de Brito et al. (2013), who looked at auditory performance of CI patients with BM-related hearing loss compared to CI patients with hearing loss from other causes. Aided speech recognition threshold scores differed greatly between the two groups, with BM-related hearing loss patients performing significantly worse in both open- and closed-set activities. While the researchers acknowledged that these differences may be due to different CI amplification technologies, 25% of BM-related hearing loss patients had aided thresholds worse than 40dBHL. De Brito et al. (2013) inferred that BM-related hearing loss patients may not possess good speech detection abilities even with cochlear implantation. However, these results may have been affected by whether electrode insertion during implantation was partial or complete. Nichani et al. (2011) suggested that the number of active electrodes after implantation may affect CI prognosis. In a study by Philippon et al. (2010), speech and language performance was poorer in patients who only received partial electrode implantation when compared to those who received complete electrode implantation.

Studies have, however, found both complete and partial electrode insertion to yield good long-term results for speech perception and intelligibility performance (Tokat et al., 2018). Given the risk of ossification, early bilateral cochlear implantation is vital (Nichani et al., 2011). Successful cochlear implantation can significantly decrease the handicap of bilateral profound SNHL (Novak et al., 1990). It would therefore appear that even in cases of complete ossification, speech and language acquisition is still viable and significant benefits as a result of cochlear implantation have been found in children with BM-related hearing loss (Nichani et al., 2011).

Chapter 3: Methodology

Introduction: This chapter will outline the aims, objectives, and methodology as well as ethical considerations of the study. Furthermore, the chapter will describe the data management and analysis techniques utilised in the study. Finally, threats to reliability and validity as well as measures implemented to mitigate those threats will be outlined in this chapter.

Aims and objectives

Aim 1: To investigate the audiological management of young children (0-6 years) diagnosed with BM in the Western Cape, South Africa. Specific objectives of this aim were:

1.1. To determine the patterns of referral for audiological assessment following a diagnosis of BM with respect to the following:

1.1.1. Proportion of children who were referred for audiological assessment following diagnosis of BM.

1.1.2. Average duration between diagnosis of BM and audiological referral.

1.1.3. Profile of patients (age, sex and BM symptoms) diagnosed with BM who were referred for audiological assessment.

1.1.4. Referrals appointment attendance.

1.2. To determine the audiological protocols for the management of children diagnosed with BM with respect to:

1.2.1. Audiological test battery.

1.2.2. Audiological interventions.

Aim 2: To describe the hearing loss in young children (0-6 years) diagnosed with BM. Specific objectives of this aim were:

2.1. To determine the incidence of hearing loss in children with BM.

2.2. To characterise the hearing loss in these children with BM according to laterality, severity (see Appendix A) and stability/fluctuation.

Aim 3: To determine audiological interventions utilised for young children (0-6 years) who acquired hearing loss after BM diagnosis.

Research Design

A retrospective record review study design was used to review medical folders of young children aged 0-6 years old who were seen with BM at Red Cross War Memorial Children's Hospital (RCWMCH) during the period May 2016 to May 2018. This design was advantageous in that it allowed for analysis of data already on file, thereby saving time and resources. Furthermore, it allowed for data from a lengthy period to be accessed simultaneously. Ethically, retrospective record reviews are also advantageous in that the data abstracted usually limits or eliminates patient-identifying information (Worster & Haines, 2004).

However, this type of study design also has some disadvantages, the main one being that the data in patient folders were not initially collected for research purposes and therefore may lack sufficient and quality information (Sarkar & Seshadri, 2014). Furthermore, given that two types of folders needed to be accessed for most patients (medical and audiology), there was the risk of conflicting data reported in the folders (Wu & Ashton, 1997). Worster and Haines (2004) suggest that to combat conflicting information between patient folders, the patient's medical file information should be considered a more reliable source, as this would be the information that was originally recorded. In cases of conflicting medical information, medical folders were considered to be more reliable, while audiology files were considered to be more reliable in cases of conflicting audiological information.

Sampling Method

Non-probability purposive sampling was utilised. For this sampling method, data were abstracted based on the present study's objectives, including patient characteristics to meet these objectives. This sampling strategy does not require very large sample sizes and is therefore appropriate for the small sample size of the present study. An acknowledged disadvantage of non-probability purposive sampling is that results are not always generalisable (Vassar & Holzmann, 2013).

Recruitment

Since this study did not involve direct interaction with patients, access to patients' folders was obtained by contacting relevant authorities from RCWMCH to request permission to access patients' medical and audiology folders (Appendix B).

Sample size

According to information obtained verbally from clinical staff at RCWMCH, about 100 children are diagnosed with meningitis annually at this hospital. It was therefore anticipated that at least 200 medical folders of children diagnosed with meningitis would be available for review during the two-year period (2016 - 2018) planned for review. Due to the exploratory nature of the study, a target sample size of 100 children was set. Furthermore, the exploratory nature of the study meant the sample size was not powered to make any generalisation.

Inclusion criteria

- Children under the age of 6 years with a confirmed diagnosis of BM. This age group typically has the highest incidence of BM and would therefore benefit the most from the recommendations made by this study.

- Children who were treated at RCWMCH for BM between May 2016 and May 2018. The time span was set to ensure sufficient sample size.

Exclusion criteria

- Concurrent or previous treatment with ototoxic drugs (a confounding variable for incidence of hearing loss).
- Middle ear pathology (a confounding variable for causing conductive hearing loss) during their hospital stay.

Participants

Medical and audiology folders of children under the age of 6 years who were admitted and treated for BM and unspecified meningitis during May 2016 – May 2018 at RCWMCH, which has paediatrics medical wards and an audiology department, were accessed for review.

Data Collection

Data Collection Tools

The primary data collection tool for this study was a self-developed data abstraction form (Appendix C) on Microsoft Excel. This form helped to ensure a measure of consistency when capturing data and also reduced capture error (Gearing, Mian, Barber, & Ickowicz, 2006). The form consisted of three sections: demographic information, BM-related medical information, and audiological information (Appendix C). An electronic version (Excel spreadsheet) was used as it allowed for centralised and password protected data storage. A laptop was used as the primary tool for data collection and all data were backed up on the researcher's password-protected Microsoft OneDrive account.

Data Collection Procedure

1. Ethical approval was first sought and obtained from the Faculty of Health Sciences Human Research Ethics Committee, University of Cape Town (HREC/Ref 298/2018, Appendix D).
2. Relevant authorities at the hospital were contacted (Appendix B) and institutional approval was granted to access patient folders at the facility (Appendix E).
3. Following ethics approval and institutional permission to conduct this study, a pilot study was conducted at the research site. According to Vassar and Holzmann (2013), a pilot study allows the researcher to assess the study design, the methodology, and the data abstraction forms, as well as the overall feasibility of the study. It also allowed for the inclusion and exclusion criteria to be tested, provided insight into how medical and audiology folders were stored, and clarified how information in these folders is recorded. Based on recommendations by Vassar and Holzmann (2013), the number of patient folders selected for the pilot was 10% (10 folders) of the proposed sample size and the pilot study folders were selected at random. This allowed for a more realistic and generalisable view of the folders that were analysed during the actual data collection phase of the study (Vassar & Holzmann, 2013).
    a. The outcome of the pilot study revealed that additional space on the data abstraction form was required to record audiological data (such as tympanometry results). As a result, the data abstraction form was modified to ensure all audiological testing results could be recorded.
    b. Furthermore, the pilot study revealed that patients' BM symptoms and date of confirmed diagnosis were not clearly recorded in their medical folders. As a result, columns initially created for recording BM symptoms were removed and confirmed diagnosis dates were inferred from lumbar puncture dates. This date is considered

a reliable diagnosis date since the gold standard for BM diagnosis is a lumbar puncture with Gram stain and CSF culture (Lin & Safdieh, 2010).

4. Data were collected from both the patients' medical folders and their audiological folders. Medical folders at RCWMCH are kept in the Medical Records room, while audiological folders are kept at the Audiology Department.
    a. Patient files were searched on the RCWMCH Excel data base, using their International Classification of Diseases 10th Revision (ICD-10) diagnosis codes, specifically: G03.9 (meningitis, unspecified), G00.9 (bacterial meningitis, unspecified), G00.0 (Haemophilus meningitis), A39.0 (meningococcal meningitis), G00.1 (pneumococcal meningitis), G00.3 (staphylococcal meningitis) and G00.8 (other bacterial meningitis).
    b. Based on these results, the relevant patient numbers generated were then searched in the Audiology Department's Excel database. This confirmed whether these patients were seen at audiology. Audiology codes for the relevant patients were then obtained from the system and the relevant data were retrieved from the department.
    c. Demographic and audiological data from each patient file were captured on the electronic data abstraction form (Appendix C) and stored on a password protected laptop.
    d. Patient names, dates of birth, sex and any other personal identifiers were coded into study numbers to ensure anonymity.

Data Collection Personnel

Data were collected and managed by the primary investigator. For quality assurance purposes, an additional Masters student was asked to compare a random sample of abstracted data from 10 patients' folders against the data recorded by the primary investigator.

Data Management

Confidentiality of the data were ensured by storing it on a password protected laptop that was only accessible to the primary investigator, additional Masters student, and research supervisors. Data from the main research results were distributed to the research site on request.

Data Analysis

Data were analysed using descriptive statistics, proportions and frequency tables, which allowed the researcher to describe variables in a sample. Given the small sample size, more detailed data analysis that included inferential statistical tests could not be performed. The researcher had initially planned to determine the nature of the relationship between meningitis, hearing loss, and other patient variables, and to make inferences about the greater population (Christensen, Johnson, & Turner, 2014). To examine statistical relationships between these variables, inferential tests would have included the Chi-square test (to test for evidence of a relationship between type of meningitis and hearing loss) (McHugh, 2013) and logistic regression analysis (to explain the relationship between patient variables and meningitis, as well as patient variables and hearing loss) (Sperandei, 2014).

Reliability and Validity

Reliability refers to the extent to which a variable consistently, accurately, and repeatedly measures what it intends to measure. It assesses whether the process and the results obtained from the process are accurately replicable (Leung, 2015). In the present study, the biggest threats to reliability were researcher error during the data collection phase, as well as researcher bias (subjectivity). To mitigate these reliability threats, data abstraction was performed reliably and unbiasedly as follows:

To ensure inter-rater and intra-rater reliability, 10% of the abstracted data in both the pilot and official data collection phase were re-checked in random samples by the primary investigator (intra-rater reliability), as well as one other Masters student (inter-rater reliability) (Allison et al., 2000). For inter-rater reliability, Cohen's kappa (κ) was used as a measure of inter-rater agreement, where a score of +1 indicates perfect agreement and a score of -1 indicates perfect disagreement (Cohen, 1968). According to Vassar and Holzmann (2013), the minimum acceptable κ coefficient for retrospective reviews is +0.6. This minimum value was adhered to during inter-rater reliability checks, with a score of +0.9, a result indicating near perfect agreement.

Subjectivity was reduced with explicit criteria for variable abstraction, thereby increasing intra-rater reliability. To do this, unambiguous variable definitions (such as definitions for degrees of hearing loss – Appendix A), were established, and clear inclusion and exclusion criteria were set (Boyd et al., 1979).

Validity refers to the extent to which a scientific test or piece of research measures what it intends to measure (Khorsan & Crawford, 2014). It looks at whether the study design is appropriate for the study methodology, as well as the appropriateness of the sampling procedure and the conclusions drawn from the study (Leung, 2015). In the present study, the biggest threats to validity were the cogency of the data abstraction forms, as well as selection bias when looking for patient folders. To mitigate these validity threats, the following steps were taken:

To ensure that the conclusions drawn from the data of the present study were in line with what the study aimed to achieve, the actual data abstraction forms were validated for face and content validity. This was done by having three audiologists independently review the data abstraction forms to ensure that the data abstracted would be useful in answering the research

questions. All three audiologists deemed the form acceptable to address the aims and objectives of the present study. Through the careful selection and implementation of inclusion and exclusion criteria, the probability of selection bias and confounding variables was decreased, thereby increasing internal validity ((Khorsan & Crawford, 2014).

Ethical considerations

Ethical principles adhered to were based on those outlined by the Declaration of Helsinki (World Medical Association, 2013) as well as by considering the seven requirements for ethical research proposed by Emanuel, Wendler, and Grady (2000).

Autonomy

Autonomy was ensured by providing the relevant hospital authorities from RCWMCH (including hospital superintendents and heads of the wards) with sufficient information regarding the study. This was done in order for them to give permission to the primary investigator to access patients' medical folders. The participating hospital was informed that they were able to withdraw their consent to participate at any given time, with no consequences (Orb, Eisenhauer, & Wynaden, 2001).

Confidentiality

Confidentiality was achieved by using coding data for personal information and ensuring that no personal identifiers were used in this research report. All data were kept confidential through storage on a password protected laptop that was only accessible to the primary investigator, one research assistant, and the research supervisors.

Justice

Justice was ensured through fair subject selection using pre-determined inclusion criteria. These criteria did not allow for exploitation, and did not favour participants based on race, sex, language, religious beliefs, ethnic or social origin, or socio-economic status (Orb et al., 2001). Folders of children under the age of 6 were part of the inclusion criteria, as this age group has the highest incidence of BM (Meiring et al., 2009) and would therefore benefit the most from the recommendations made by this study. In terms of distributive justice, this study was foreseen to improve service delivery in the hospital used for data collection, and therefore the communities serviced by this hospital could directly benefit in the future (Emanuel et al., 2000).

Beneficence

There were no direct benefits to the participants of this study, given that it was a retrospective record review. However, the study has social value in that it aimed to enhance future health care services to patients in local communities, as well as to those in the broader South African health sector. Scientific validity was ensured by following a meticulous methodology, which ensured that data were reliable and valid (Orb et al., 2001).

Non-maleficence

The knowledge that would be gained from this study was determined to outweigh any possible risks. There was no direct harm to participants due to the retrospective record review design of the study and the outcomes of this study were foreseen to benefit future patients who will make use of those health care services. This indicated a favourable risk-benefit ratio (Orb et al., 2001; Zavascki & Fuchs, 2007).

Conflicts of Interest

The researcher had no conflicts of interest to declare at the time of this study.

Chapter 4: Results

Introduction: This chapter will present the study findings according to the stated aims and objectives. Results will include demographics, referral information, medical and audiological information of patients, as well as specific audiological tests used.

Participant description

A total of 291 folders of patients who were diagnosed with meningitis (all types of meningitis) at RCWMCH between May 2016 and May 2018 were accessed for review. After removing folders of patients that did not meet the inclusion criteria (251 folders), a total of 40 patient folders were left for review. Figure 1 depicts the process of selection and inclusion of patients' folders.

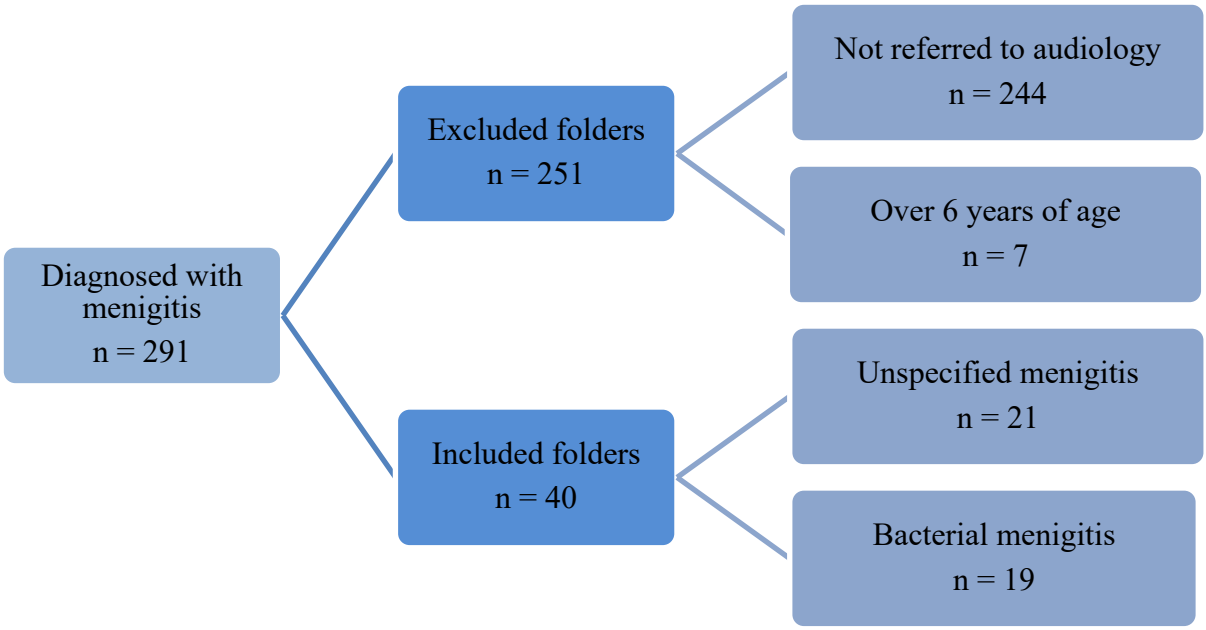

Figure 1. Inclusion and exclusion process for patient folders

Patient demographics

Patients' folders were subsequently divided into two groups: Group 1 consisted of patients with a confirmed diagnosis of BM, who were referred to audiology after meningitis diagnosis (n = 19). Group 2 consisted of patients with a diagnosis of unspecified meningitis (UM), who were referred to audiology after meningitis diagnosis (n = 21). Demographics of the patients in the different groups are shown in Table 3.

Table 3. *Patient demographics*

Description	**Group 1: BM (n = 19)**	**Group 2: UM (n = 21)**
Sex [n, (%)]		
Males	14 (74)	16 (76)
Females	5 (26)	5 (24)
Age [n, (%)]		
0-6 months	11 (57)	11 (52)
7-11 months	2 (11)	4 (19)
12-24 months	2 (11)	5 (24)
25-59 months	4 (21)	1 (5)
Referral Source [n, (%)]		
RCWMCH[1]	16 (84)	15 (71)
Other facility	3 (16)	6 (29)

[1]RCWMCH: Red Cross War Memorial Children's Hospital

Most of the patients whose folders were reviewed during this study lived far from the hospital and often had to take more than one form of transportation (i.e. bus and train) to get to the hospital.

The majority of patients referred to audiology were those with either unspecified type meningitis (n = 21) or unspecified type bacterial meningitis (n = 10). No patient with

pneumococcal meningitis was referred. Only one patient with haemophilus meningitis was referred and one with staphylococcal meningitis (Figure 2).

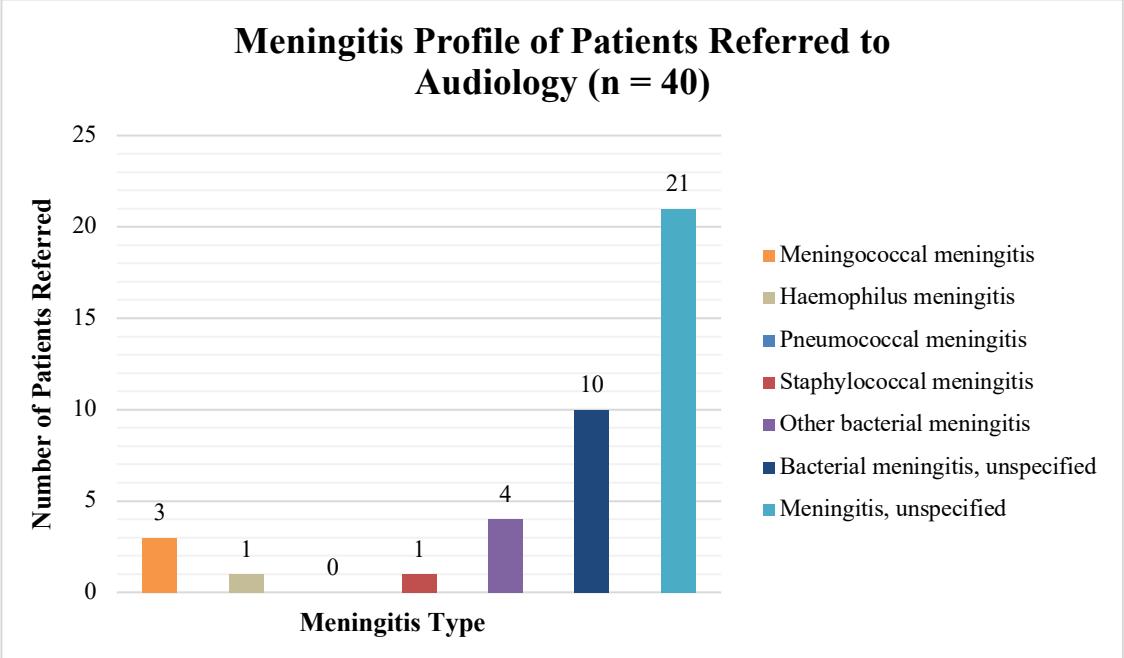

Figure 2. Referral information

Time Between Meningitis Diagnosis and Referral to Audiology

Date of meningitis diagnosis was defined as the date that a lumbar puncture was performed. Mean referral time for audiology assessment after meningitis diagnosis was 15 days (SD = 24 days). The shortest referral time was 0 days (i.e. immediate referral) while the longest time recorded was 122 days.

Audiology Appointments

Between May 2016 and May 2018, each patient attended an average of 2 audiology appointments (range = 1 - 5) and missed an average of 1 appointment (range = 0 - 3). The largest percentage of patients (42.5%) only attended 1 audiology appointment, with only 14 of the 40 patients (35%) attending more than 2 appointments (Figure 3).

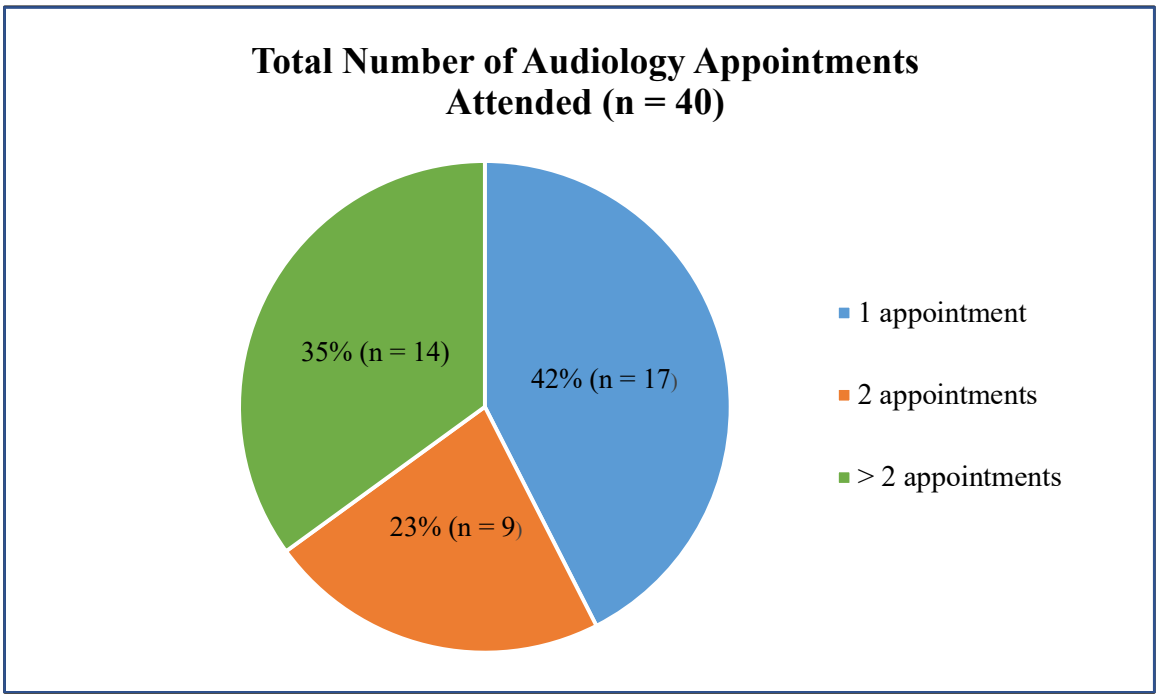

Figure 3. Appointment attendance

Audiological Assessments Performed

OAEs and tympanometry were the most commonly performed tests for the majority of patients at baseline, as well as the second and latest audiology appointments (Table 4). Otoscopy test results were recorded for less than 15% of all patients at each appointment.

Table 4. *Audiological assessments performed at baseline, second and latest appointments.*

Assessments	**Baseline (n = 40)**	**Second (n = 16)**	**Latest (n = 22)**
Otoscopy	5	1	3
Tympanometry	21	12	17
Acoustic reflex	4	3	3
Otoacoustic emissions	33	13	16
Automated auditory brainstem response	6	7	2
Auditory brainstem response	2	0	1
Visual reinforcement/conditioned play audiometry	8	0	8
Speech detection threshold	2	0	6

Audiological Results

Testing methods and results varied between patients within groups, as well as between groups. Tables 5 - 10 represent results obtained from each audiological assessment performed for each patient (where relevant) at three testing intervals: baseline, second, and latest assessment. Results have been divided into tables according to patients' meningitis diagnosis: either BM or UM. Each patient number represents an individual patient to allow tracking of all their audiological assessments. Information presented in bold is that of patients who developed BM-related hearing loss. The information displayed in tables 5 - 10 is also summarised in Appendix F.

Table 5. *Tympanometry and otoacoustic emission test results for bacterial meningitis patients at various testing intervals*

Bacterial Meningitis Patients						
	Tympanometry Results			OAE Results		
Patient Number	**Baseline**	**Second**	**Latest**	**Baseline**	**Second**	**Latest**
1	-	-	-	Bilateral pass	-	-
2	Bilateral Type A	Bilateral Type A	Bilateral Type A	-	Bilateral pass	Bilateral pass
3	-	-	Bilateral Type A	Bilateral pass	Bilateral pass	-
4	-	Could not evaluate	-	Bilateral pass	Right pass, left noise	Bilateral pass
5	Bilateral Type A	Right NT, left Type C	Bilateral Type B	Right pass, left refer [1]	Bilateral refer [2]	Bilateral pass
6	-	-	-	Bilateral pass	-	-
7	-	-	Bilateral Type A	Right refer, left pass	-	Bilateral pass
8	-	Bilateral Type C	-	-	Right refer, left pass	Bilateral pass
9	**-**	**Right NT [3], left Type A**	**Bilateral Type A**	**Bilateral pass**	**Right pass, left refer**	**-**
10	Bilateral Type A	-	Bilateral Type A	-	-	Bilateral pass
11	-	-	-	Bilateral pass	-	-
12	Bilateral Type C	Right Type C, left Type B	Right Type A, left Type B	Bilateral pass	Bilateral refer	-
13	Bilateral Type A	Bilateral Type A	Bilateral Type A	Right pass, left refer	Bilateral pass	Bilateral pass
14	-	-	-	Bilateral pass	-	-
15	**Bilateral Type A**	**-**	**Bilateral Type A**	**Bilateral refer**	**-**	**-**
16	Bilateral Type A	-	-	Bilateral pass	-	-
17	-	-	-	Bilateral pass	-	-
18	Bilateral Type A	Bilateral Type A	-	Bilateral pass	Bilateral pass	-
19	-	-	-	Bilateral pass	-	-

[1] Excessive wax
[2] Excessive movement from child
[3] NT = Not tested

Table 6. *Tympanometry and otoacoustic emission test results for unspecified meningitis patients at various testing intervals*

Unspecified Meningitis Patients						
	Tympanometry Results			OAE Results		
Patient Number*	**Baseline**	**Second**	**Latest**	**Baseline**	**Second**	**Latest**
1	Bilateral Type A	-	-	Bilateral pass	-	Bilateral pass
2	-	-	-	Right refer, left pass	-	-
3	Bilateral Type C	-	Right Type As, left Type B	Right pass, left refer	-	Bilateral pass
4	-	-	-	Bilateral pass	-	-
5	Right Type A/C, left Type B	Bilateral Type B	Bilateral grommets	Right pass, left refer	Bilateral refer	No seal, grommets
6	-	Bilateral Type A	Right Type C, left Type A	Right refer, left pass	Bilateral pass	Bilateral pass
7	-	-	-	Bilateral pass	-	-
8	Right Type C, left Type B	-	Bilateral Type A	Right pass, left refer	Bilateral pass	Bilateral pass
9	Results missing	-	Right Type A, left Type B	-	-	Bilateral pass
10	Bilateral Type A	CNE[1] bilaterally	Right Type B, left Type As	Bilateral pass	Bilateral refer [3]	Bilateral pass
11	Bilateral Type A	-	-	-	-	-
12	Bilateral Type A	-	-	Bilateral pass	-	-
13	CNE[1], excessive wax	-	-	Right refer [2], left pass	-	-
14	Bilateral Type A	-	-	Right pass, left refer	-	-
15	-	Bilateral Type B	Bilateral Type B	Bilateral pass	-	Bilateral refer
16	-	-	-	Bilateral pass	-	-
17	-	-	-	Bilateral pass	-	-
18	Bilateral Type A	-	Right Type B, left Type A	Bilateral pass	-	Right refer, left pass
20	Bilateral Type C	-	-	-	-	-
21	Right Type A, left Type C	-	-	Bilateral pass	-	-

* Where values are missing, the assessment was not performed

[1] CNE = could not evaluate

[2] Excessive wax

[3] Recovering OME

Table 7. *AABR and ABR test results for bacterial meningitis patients at various testing intervals*

Bacterial meningitis patients					
	AABR			ABR [1]	
Patient Number*	**Baseline**	**Second**	**Latest**	**Baseline**	**Latest**
2	-	Bilateral pass	-	-	-
5	Right pass, left refer [2]	Bilateral pass	-	-	-
6	-	-	-	-	-
7	Right pass, left NT [3]	Bilateral pass	-	-	-
8	Bilateral pass	Right refer, left NT	-	-	-
9	**-**	**Right pass, left refer**	**Right pass, left refer**	**-**	**Right normal hearing, left severe SNHL[5]**
15	**-**	**-**	**-**	**Right severe-profound SNHL, left mild SNHL[4]**	**-**
19	-	-	Bilateral pass	-	-

* Where values are missing, the assessment was not performed
[1] No second ABR performed
[2] Excessive wax
[3] NT = not tested
[4] Bilateral hearing aids fitted
[5] Unilateral hearing aid fitted

Table 8. *AABR and ABR test results for unspecified meningitis patients at various testing intervals.*

Unspecified Meningitis Patients			
	AABR		ABR[1]
Patient Number*	**Baseline**	**Second**	**Baseline**
4	Right pass, left refer	Bilateral refer	-
5	-	Right refer, left noise	-
8	-	-	Unilateral CHL (further information missing)
18	Bilateral pass	-	-
19	Child ++ busy	-	-

* Where values are missing, the assessment was not performed
[1] No second or most recent ABR performed

Table 9. *VRA/CPA and SDT test results for bacterial meningitis patients at various testing intervals*

Bacterial Meningitis Patients						
	VRA/CPA			SDT		
Patient Number*	**Baseline**	**Second**	**Latest**	**Baseline**	**Second**	**Latest**
1	-	-	-	-	-	25dB bilaterally
3	-	-	Normal hearing	-	-	15dB bilaterally
10	Normal hearing	-	-	10dB bilaterally	-	-
12	-	Normal hearing	Normal hearing	-	25dB bilaterally	Right 15dB, left 20dB
13	Normal hearing	Normal hearing	Normal hearing	-	-	-
14	-	-	-	-	-	-
15	**Bilateral prof SNHL[1]**	**-**	**Right mod to sev SNHL[2], left mild SNHL**	**-**	**-**	**-**
16	Normal hearing	-	-	-	-	-

* Where values are missing, the assessment was not performed
[1] Bilateral profound SNHL
[2] Right moderate to severe SNHL

Table 10. *VRA/CPA and SDT test results for unspecified meningitis patients at various testing intervals*

Unspecified Meningitis Patients						
	VRA/CPA			SDT		
Patient Number*	**Baseline**	**Second**	**Latest**	**Baseline**	**Second**	**Latest**
3	CNE [1], child crying	-	-	40dB	-	-
5	-	-	Normal hearing	-	-	10dB bilaterally
9	Results missing	-	Normal hearing	-	-	Right 10dB, left CNE
15	-	Poor FF reliability	Normal hearing	-	15dB bilaterally	-
18	-	-	Right mild HL [2], left normal hearing	-	-	15dB bilaterally
20	Poor FF [3] responses	-	-	-	-	-
21	Normal hearing	-	-	-	-	-

* Where values are missing, the assessment was not performed
[1] CNE = could not evaluate
[2] Queried conductive hearing loss (CHL)
[3] FF = free field in audiometric testing

Meningitis and Hearing Loss Findings

Of the 40 patients whose folders were analysed, two patients (both diagnosed with BM) were found to have SNHL. Both patients identified with SNHL were fitted with hearing aids. Given the low number of hearing loss cases diagnosed and fitted with amplification, an in-depth review of each patient will be presented according to case history (presentation), audiological management (assessment and amplification), and outcome following audiological intervention.

Patient X (patient number 9 in Table 5, 7 and 9 above)

Case History

Patient X is a boy who was 3 months old at the time of diagnosis. He was diagnosed with meningococcal septicaemia and meningitis, and treated with ceftriaxone for 10 days. He also initially presented with persistent temperature spikes. At 4 months old, the patient presented with right sided focal seizures, then multifocal seizures, left hemiplegia and left gaze palsy. He was started on Vigabatrin for his epilepsy, which resolved his seizures at the time.

Audiological Assessment

Baseline OAE screening two weeks after initial BM diagnoses indicated a bilateral pass, suggesting normal cochlear functioning. A 3-month follow-up screening date was subsequently booked. One month before the scheduled follow-up, however, the patient was scheduled for a brain-evoked auditory response (BAER) assessment to investigate his seizures. Tympanometry was required before BAER testing could be performed. During tympanometry assessment, additional OAE screening was conducted given the patient's history of BM. Screening results indicated normal middle ear function bilaterally, with abnormal cochlear function in the left ear. As a result, a diagnostic ABR assessment was booked, which the patient did not attend.

Follow-up Assessments

At the rescheduled appointment, the patient referred a left AABR screening with bilateral normal middle ear function, indicating abnormal cochlear or vestibulocochlear nerve function. AABR screening in the right ear indicated normal middle ear, cochlear and vestibulocochlear nerve function. A neurodiagnostic assessment revealed good neural synchrony bilaterally and frequency-specific tone burst ABR testing commenced, indicating a severe sensorineural hearing loss in the left ear.

Audiological Intervention

A left earmould impression was taken on the day and a left ultra-power hearing aid was fitted at a follow-up appointment. Five months post-BM diagnosis, the patient was re-admitted again for myoclonic seizures and treated accordingly. By this time, the patient had developed a severe left-sided palsy. Eight months post BM-diagnosis, age-appropriate behavioural testing showed stable normal hearing in the right ear. Data logging of the left hearing aid showed only 0.2 hours of average daily hearing aid use.

Post-audiological intervention

Poor data logging was noted at three subsequent follow-up appointments and after counselling and discussion with the patient's caregiver, the left hearing aid was taken back. At the time of data collection, the patient was patient was noted to be babbling and was booked for a 6-month follow-up appointment.

Patient Y (patient number 15 in Table 5, 7 and 9 above)

Case History

Patient Y is a boy who was 3 years old at the time of diagnosis. He presented with symptoms of neck stiffness, fever, headaches, drowsiness, lethargy, loss of appetite and difficulty walking. He was also noted to squint. He presented with symptoms of neck stiffness, fever, headaches, drowsiness, lethargy, loss of appetite and difficulty walking. He was also noted to squint. A computed tomography (CT) scan revealed global brain swelling with basal and leptomeningeal enhancement. He was diagnosed with meningococcal meningitis based on CSF results and treated with ceftriaxone.

Audiological Assessment

A baseline assessment five days post-BM diagnosis revealed normal middle ear function (bilateral Type A tympanograms), no responses for all reflexes tested bilaterally. OAE screening revealed a refer result, indicating abnormal cochlear function. Age-appropriate behavioural testing indicated a bilateral profound sensorineural hearing loss. As a result, an emergency sedated diagnostic ABR was scheduled for the following day.

Follow-up Appointments

On this day, tympanometry again indicated normal middle ear function with no reflexes present bilaterally. OAE screening indicated abnormal cochlear function bilaterally. A neurodiagnostic ABR was performed, indicating good neural synchrony bilaterally. Frequency-specific tone burst ABR indicated a moderate-to-mild reverse slope SNHL in the left ear. The right ear could not be evaluated as the child woke up. A diagnostic ABR was again scheduled for the following day to complete threshold estimation testing. On this day, the left ear results were confirmed as a moderate-to-mild reverse slope SNHL, and the right ear was

found to have a profound SNHL. Bilateral earmould impressions were taken and the patient was referred to the local cochlear implant unit for evaluation.

Audiological Intervention

The patient was subsequently fitted with hearing aids bilaterally: an ultra power hearing aid in the right ear and a power hearing aid in the left ear. After missing several follow-ups due to being in the Eastern Cape, the patient returned to the audiology department. Follow-up monitoring indicated stable hearing bilaterally.

Post-audiological intervention

At the time of data collection, the patient had been lost to follow-up for 6 months after several attempt to contact the patient's caregiver.

These two cases highlight not only the importance of early identification of hearing loss and early intervention, but also the challenges of assessing children diagnosed with BM, as well as losing patients to follow-up which may compromise their long-term outcomes. Given that Patient Y was lost to follow-up, the long-term effects of missed early intervention are unknown and there is a risk that his right cochlea may have already ossified, given the profound SNHL in the right ear.

Chapter 5: Discussion and Conclusion

Introduction: This chapter will discuss the findings of the present study in relation to the existing literature. Strengths and limitations of the study will also be considered, followed by implications for future practice, recommendations for future research, and conclusions drawn directly from the study findings.

The present study aimed to explore the audiological management of young children (0-6 years) diagnosed with BM at a tertiary public hospital in Cape Town, South Africa. Overall, the findings of this study revealed the following: few children diagnosed with meningitis are referred for audiological assessment; those who are referred for audiological assessment are not adequately followed up, due mostly to missed follow-up appointments; and there is no standardised audiological testing protocol for children with BM in South Africa.

Patterns of Referrals

The findings of the present study showed that out of the 291 patients who were diagnosed with BM or unspecified meningitis between May 2016 and May 2018, only 13.7% (n = 40/291) were seen for assessment and management by the audiology department. This was consistent with the findings of previous studies. For instance, in their recent RCWMCH study, Kuschke et al. (2018) also found a low referral rate of 23.5% (n = 16) among patients diagnosed with meningitis. Low referral was also reported by a study conducted in England where out of the 46 cases who did not undergo audiological assessment, 32.6% (n = 15) were never referred for assessment (Riordan, Thomson, & Hodgson, 1995). A higher referral rate of 60% (n = 28) was reported in one South African study, which also looked at children between birth and 6 years diagnosed with meningitis (Khoza-Shangase & Rifkind, 2010). However, this study's sample size, as in the case of the present study, consisted of only 47 participants and so the referral rate should be interpreted with caution.

An attempt to improve referral of children diagnosed with BM for audiological assessment was initiated by the Western Cape Department of Health (WCDoH). In 2017, the WCDoH released a protocol for managing meningitis in children at a hospital level. The protocol stipulates that all children with proven or likely BM need to be referred for an audiological assessment (Western Cape Department of Health, 2017). However, findings of the present study do not seem to indicate that clinicians are following those guidelines closely.

In addition, the present study found that the majority of patients were referred as inpatients from RCWMCH (n = 31). Findings by Wilson, Roberts, and Stephens (2003) revealed that children who were not referred for audiological testing prior to discharge had increased risk of being lost to follow up. Similarly, Khoza-Shangase and Rifkind (2010) inferred that patients who are not referred within 3 months from discharge date, if not already referred as in-patients, are likely to never be referred for audiological assessment. These findings highlight the importance of early referral to audiology, before patients are discharged.

To ensure timely referral of all patients a meningitis registry should be kept at all health care facilities, which records all patients diagnosed with meningitis, including causative pathogen and symptoms. BM is considered a notifiable disease by the South African National Department of Health (Department of Health: Republic of South Africa, 2011), and therefore the formulation of a meningitis registry at health care facilities would not place an additional burden on health care staff. This registry should be accessible to audiology staff at the facility to ensure that no patient is left unseen and untested. Theodoridou et al. (2007) are also of the view that meningitis surveillance, which includes a meningitis registry, is crucial for monitoring the trend of meningitis to implement effective public health interventions.

With regard to the remaining 244 patient folders that were excluded from the present study for not being referred to audiology (84%), it is possible that some patients may have been

referred for audiological assessment but never attended their appointments. In the present study, referral to audiology was not consistently recorded in patients' medical folders. Instead, the referral rates reported here were based on whether or not the audiology department had a record of the relevant patient folders initially identified for review (n = 291). It is therefore possible that this low referral rate reflects uptake of referral by patients and does not necessarily indicate the actual referral rate.

Due to the nature of the design of this study (i.e. a retrospective folder review), it was not possible to determine or further explore the reasons for the low rate of referral of patients for audiological assessment. However, a key factor to consider may be that South Africa is known to have a low ratio of health professionals to population when compared to other countries. In 2018, the latest WHO report indicated that South Africa has 0.818 medical doctors per 1000 population. This is similar to countries such as Sri Lanka (0.881) and Egypt (0.814), but significantly lower than ratios in countries such as Canada (2.539), Switzerland (4.248), and Cuba (7.519) (WHO, 2018). SA's doctor-to-population ratio may negatively impact referral to audiology, where high patient volume per doctor may influence medical management decisions. For instance, non-life threatening consequences of meningitis, such as hearing loss, may be overlooked during initial treatment. Furthermore, referral to audiology can be significantly affected if hearing loss prevention is not considered a priority by medical practitioners during the early medical management of BM (Khoza-Shangase & Rifkind, 2010).

Liu et al. (2015) argued that health care priorities need to shift from focusing solely on child survival to an approach that reduces morbidity and impairment, while ensuring healthy development (especially in the early childhood development stages). This is in line with Sustainable Development Goal 4.2, part of which is to "ensure that all girls and boys have access to quality early childhood development" (United Nations, 2015). Audiologists therefore

need to take on the role of early childhood development advocates, to ensure that treatment and management of patients with meningitis includes referral to health professionals involved in early childhood development.

Another important factor that could potentially help explain low referral rates to audiology is that South African guidelines for meningitis management do not include referral to audiology as part of management of patients diagnosed with meningitis (Boyles et al., 2013). Khoza-Shangase and Rifkind (2010) recommend providing all health care professionals, not just medical practitioners, with information about risk factors for hearing loss, in an attempt to increase referral rates. Kanji and Kara (2013) investigated paediatricians' referral practices for audiological evaluation. In their study, one physician proposed the development of a poster illustrating a table of the commonest conditions causing hearing loss, as well as the referral process for audiological evaluation. To ensure testing takes place as soon as possible after meningitis diagnosis, the BCCH also recommends giving a meningitis information sheet to all physicians to ensure timely audiological referral (BCCH, 2014).

The Koomen et al. (2003) model, which predicts hearing loss in children with BM, has great potential as a screening tool in helping identify children at risk for hearing loss, even when their hearing status is normal at baseline. If the Koomen et al. (2003) model is implemented, these children can be timeously referred for audiological assessment, especially when a child is found to be at increased risk for hearing loss. Furthermore, the model has performed well in cost-benefit analyses (de Jonge et al., 2013), which makes it an applicable model to use within South Africa's resource stricken health system. However, the Koomen et al. (2003) model was based on BM in high-income countries and before recommendations are made to utilise the model in South Africa, the formula would need to be adapted to account for the different profile of BM in the South African context (Furyk et al., 2011). Currently, referral

for risk-based screening in South Africa is generalised to culture-positive infections known to cause hearing loss in children, which includes BM and viral meningitis (Health Professions Council of South Africa, 2018). However, literature is not conclusive on the relationship between viral meningitis and hearing loss. A commonly cited study by Nadol (1978) found that, of the 304 cases of aseptic meningitis, none developed hearing loss.

On average, patients were seen for audiological baseline assessment 15 days after meningitis diagnosis. This was also consistent with the findings of previous studies. For instance, a United Kingdom study by Wilson et al. (2003) initially found that audiological testing typically took place 6 - 9 weeks post-meningitis diagnosis. However, after an intervention involving increased awareness among families about the importance of attending the audiology appointment, as well as increased communication between referring physicians and audiologists, referral time decreased dramatically, with 80% of patients assessed within 6 weeks of meningitis diagnosis. Similar trends were identified in a study by Kuschke et al. (2018) at the same hospital as the one scrutinised in the present study, where average time between diagnosis and referral was found to be 17 weeks. Upon their recommendations, the audiology department at the hospital proceeded to run an extensive referral campaign. Average referral time in the present study (15 days) was shorter compared to that in the Kuschke et al. (2018) study, which could possibly be a result of the referral campaign. However referral time of present study is still a concern given that ossification has been noted as early as 2-4 weeks following the onset of BM (Merkus et al., 2010).

The short- and long-term outcomes associated with delayed or no referral for early intervention in the case of hearing loss are well documented (Swanepoel, 2009; Theunissen et al., 2014). Importantly for children with BM, delayed or no referral can also have a significant impact on their CI candidacy when they are diagnosed with a severe-to-profound hearing loss

for which hearing aids would not be sufficient (Kuschke et al., 2018). Paediatricians need to be encouraged to prioritise in-patient hearing assessment referral, with follow-up referrals scheduled as part of the general medical post-discharge follow-up (Khoza-Shangase & Rifkind, 2010). Findings of the present study indicate the need for a well-defined clinical management protocol (including necessary referral pathways) for managing children diagnosed with BM to improve referral rates for hearing assessments of children with BM.

During the initial stages of patient folder analysis, it was found that patient diagnoses - neonatal sepsis, BM, viral meningitis, or unspecified meningitis - were inconsistently recorded in day-to-day medical notes. Currently, serum procalcitonin is regarded as the most sensitive marker for distinguishing between BM and non-BM (Lin & Safdieh, 2010; Vikse et al., 2015). It is crucial that medical practitioners clearly and accurately diagnose patients with meningitis using evidence-based, sensitive markers for differential diagnoses so that appropriate referrals for hearing assessment can be made. Inappropriate referrals for audiological assessment due to misdiagnosis of the type of meningitis may lead to inappropriate use of already oversubscribed audiological services in resource constrained countries such as South Africa. It is also important to consider the impact of continuous follow-up testing on the psychological well-being of families and on the caseload for audiologists. Therefore, clearly identifying children with specific meningitis types that have implications for hearing loss will ensure that limited audiological and human resources are used appropriately.

BM Characteristics and Hearing Loss

The only information available in the medical folders with regard to the characteristics of BM was limited to the type of meningitis (causative pathogen) diagnosed, based on ICD-10 codes. Therefore, known risk factors for hearing loss due to BM such as positive cultures for meningitis-causing bacteria on lumbar puncture results, fever, seizures, and neck stiffness

(Department of Health, 2011) were not routinely recorded. Previous literature has found positive correlations between hearing loss and the following factors: *S. pneumoniae* as a causative pathogen, duration of BM symptoms prior to admission (longer than two days), cerebrospinal fluid glucose ≤0.6 mmol/L, presence of ataxia, and the absence of petechiae (de Jonge et al., 2013).

The prevalence of BM-related hearing loss in this study was 10.5% (n = 2/19) which falls within the 7-31% incidence rate of BM-related hearing loss reported in other studies (Baraff et al., 1993; Fortnum, 1992; Husain et al., 2006; Koomen et al., 2003; Oostenbrink et al., 2002; Wellman et al., 2003; Worsoe et al., 2010). Similar incidence rates of 13.9% and 11.5% were reported in Canadian studies by Wellman et al. (2003) and Husain et al. (2006), respectively. A surprising finding in the present study was that although South Africa's meningitis incidence has reportedly decreased to approximately 500 cases per year (Department of Health, 2011), RCWMCH alone was found to have over 100 newly diagnosed cases per annum. This seems to suggest an underreporting of cases of meningitis in South Africa.

For both cases of BM-related hearing loss in the present study, *N. meningitidis* was identified as the causative pathogen. However, there is considerable variability in existing literature regarding the causative agent that is associated with a higher likelihood of BM-related hearing loss. For instance, in high-income countries, *S. pneumoniae* is reported to be more likely than *N. meningitidis* to cause BM-related hearing loss, and *H. influenza* is the least likely (BCCH, 2014). Therefore, pathogens resulting in BM-related hearing loss in high-income countries are not the same as in LMICs, such as South Africa (Chang Chien et al., 2000; Gaschignard et al., 2011; Holt et al., 2001). This is important to consider when using literature based on studies that were conducted in high-income countries as an evidence base for the

formulation of new protocols in LMICs. Because of these variations in causative agents, the BCCH recommends that all children diagnosed with meningitis need to be referred for audiological assessment, regardless of the causative pathogen (BCCH, 2014). This suggests that all types of meningitis should be included in meningitis management protocols, until sufficient research evidence indicating otherwise is available. However, the feasibility of implementing this recommendation is questionable in a country such as South Africa, due to the risk of further burdening the already resource-strained audiology services in the country. More research is required to determine which specific types of BM are associated with a higher likelihood of developing hearing loss.

Age and Sex Findings

The majority of patients diagnosed with BM in the present study were less than 6 months old (57%). These age range findings are similar to those documented in other literature, where the majority of meningitis cases are reported in children under the age of 5 years, with the bulk of these cases in children under the age of 1 year (Liu et al., 2015; Meiring et al., 2009). The prevalence of meningitis in the 0-1-year age range is important when considering the formulation of referral pathways and audiological management protocols. Given that these children are in a critical stage for speech and language development (Ptok, 2011; Werker & Hensch, 2015), there is an evident need for early identification and intervention, which rely on prompt referral to audiology.

Research by Fulcher, Purcell, Baker, and Munro (2012) documented the benefits associated with early intervention in cases of childhood hearing loss, which include prompt diagnosis and hearing aid fitting. Their findings showed that children in the early identification category (≤12 months old) outperformed children in the late identification category (12 months to 5 years old) for all degrees of hearing loss. As a result of early identification and, if

necessary, prompt amplification, children were able to "keep up" rather than "catch up" with normal hearing peers, even where a profound hearing loss was diagnosed (Fulcher et al., 2012). Ultimately, the extensively documented benefits of early intervention can only be achieved if children with BM are referred early for audiological assessment and intervention.

The most recent South African Early Hearing Detection and Intervention (EHDI) guidelines have identified both BM and viral meningitis as red flags that indicate non-optional referral for audiological assessment (Health Professions Council of South Africa, 2018). This is in contrast to the 2017 WCDoH draft protocol, which stipulates that only BM, and not viral meningitis, should be referred for hearing assessment (Western Cape Department of Health, 2017). The WCDoH released another guideline document in 2018 ("Guideline for the hospital-based management of hearing loss in children due to bacterial meningitis"), which stipulates that all children diagnosed with BM and TB meningitis should be referred for audiological testing (Western Cape Department of Health, 2018).

At present, existing guidelines in South Africa seem to contradict each other, which can have a negative impact on the management of BM-related hearing loss. It is therefore important that management protocols for meningitis, specifically relating to audiology, should communicate a consistent message to minimise potential mismanagement of patients. Specifically, agreement needs to be reached on which types of meningitis, if type even needs to be specified, need to form part of the management protocol for referral to audiology. Until more evidence around viral meningitis and hearing loss is available, the EHDI guideline may appear to be a more appropriate guideline to follow. However, as with BCCH's referral recommendations, audiology referral for multiple of meningitis may create additional strain on already limited resources. The WCDoH (2017) protocol, which only stipulates referral of children with BM, would be more appropriate for the South African context, until such time

that research is available indicating otherwise. This does, however, create challenges when considering that BM patients may have been formally diagnosed with unspecified meningitis. Consequently, in addition to the WCDoH (2017) protocol, children with meningitis diagnoses other than BM who are suspected to have a hearing loss should also be included in the referral protocol.

Of those referred to audiology, most patients (75%) in the present study were male. Research has shown that the incidence of meningococcal disease, pneumococcal disease, and *H. influenzae* is higher in males than in females, especially in children under 6 years (Dickinson & Perez, 2005; Juganariu, Miftode, Teodor, Leca, & Dorobat, 2012; Martin, Sadarangani, Pollard, & Goldacre, 2014). This could explain the differences in male and female referrals to audiology found in the present study.

In the present study, findings showed that males also made up all the patients diagnosed with hearing loss, which is similar to results obtained in a Kenyan study (Karanja et al., 2013). The sample size of the present study does not allow inferences to be made about sex differences in hearing loss. Previous research in this area is limited, with one study looking at sex differences in age-related hearing loss, where it was found that males are more susceptible to hearing loss than females (Pearson et al., 1995). Regardless of sex, research still stipulates that all children with meningitis should be referred for audiological assessment and management.

Follow-up Appointments

Most of the patients missed their scheduled appointments for audiology follow-up (Figure 3). Given the low average of appointments attended, it is not possible to make inferences about the effectiveness of long-term monitoring and audiological outcomes in children with meningitis. Furthermore, audiologists are not able to track fluctuating or

deteriorating hearing loss over only 2 appointments. Fluctuation and deterioration of hearing thresholds is not common in most patients, as recorded by Richardson, Reid, Tarlow, et al. (1997) and Roine et al. (2014). However, recorded incidence of these hearing threshold changes is significant enough for audiologists to be wary of them as part of audiological management. Multiple audiology appointments therefore remain vital in allowing audiologists to track the nature of BM-related hearing loss, whether stable, fluctuating, improving or deteriorating, over time.

Factors influencing appointment attendance are vital to consider in the formulation of a meningitis management protocol. When looking at factors found to influence adherence to follow-up appointments in the present study, many patients were recorded as living in communities without single-trip access to the hospital, suggesting that transport issues may have influenced follow-up attendance. Other than transport, another South African study found forgetfulness and finances to be among the contributors to missing outpatient appointments (Ngwenya, van Zyl, & Webb, 2009). A systematic review conducted by McLean et al. (2014) also highlighted factors that hindered appointment attendance: limited financial resources, having several appointments at different hospitals, having other more pressing health concerns, and not understanding the importance of the audiology appointment. These factors are important to consider when accounting for missed appointments and poor follow-up attendance. To improve appointment attendance, increased counselling on the importance of attending audiology follow-up appointments can be done as part of the audiological management of BM.

Audiological Testing

There was no consistent test battery used at the hospital for assessing children referred to the audiology department following BM diagnosis. Tests perfomed at initial assessment

when screening for hearing loss typically included tympanometry and OAE testing. Where OAE screening yielded abnormal results with Type A tympanograms, subsequent AABR screening and/or diagnostic ABR testing was performed as an objective measure of hearing thresholds. In some cases, follow-up age-appropriate pure tone testing was used as a subjective measure for identifying hearing loss.

Lack of consistency in tests used between appointments, as found in this study, created a challenge in terms of comparing findings over time. Lack of a consistent test battery as noted in this study could potentially be related to difficulties associated with hearing assessments in young children, where multiple assessments, some over multiple appointments, may be necessary to make a diagnosis or confirm a suspicion of hearing loss. A study looking at hearing screening in young children found that 45% of children in the three-year-old age category were recorded as "could not test" compared to 1% of children aged 6 and older (Halloran, Wall, Evans, Hardin, & Woolley, 2005). However, inconsistent test use may also be related to a lack of recommended test battery. While the BCCH guidelines make recommendations for the frequency of follow-up testing, no recommendations are made for an appropriate audiological test battery (BCCH, 2014). Merkus et al. (2010), however, recommend OAE testing for all children at baseline. In cases of OAE results that indicate a "refer" result, immediate referral should be made for ABR testing, which should occur within 2 weeks. No mention is made of a test battery that includes subjective testing, such as age-appropriate audiometry. As in the case of the BCCH guidelines, Merkus et al. (2010) also make clear recommendations for the frequency at which follow-up testing should occur (Table 2).

Audiological Outcomes Post-BM

In the cases of hearing loss identified in the present study (patients X and Y), varying hearing loss patterns were found between patients. Rodenburg-Vlot et al. (2018) found that,

where patients had been diagnosed with hearing loss after meningitis (n = 28), approximately 10% of these patients (n = 3) with hearing loss at baseline assessment showed deterioration over time. In their study, all patients with normal hearing at baseline had consistently normal results throughout testing intervals. Based on these findings, Rodenburg-Vlot et al. (2018) concluded that patients with normal hearing at baseline are at a very low risk of developing hearing loss at a later stage. The authors therefore suggest that repeated follow-ups are not necessary for the "normal at baseline" group (Rodenburg-Vlot et al., 2018). However, the findings of the present study do not support the findings of the Rodenburg-Vlot et al. (2018) study. For instance, one of the patients who developed hearing loss following BM diagnosis (patient X) had normal hearing at baseline assessment which later deteriorated to a unilateral severe-to-profound hearing loss in the left ear within 3 months of baseline assessment.

Meningitis sequelae for patient X extended beyond BM-related hearing loss (severe-to-profound SNHL in the left ear), as the patient developed a left sided palsy and non-permanent seizures. Despite being less commonly reported, other complications of BM (besides hearing loss) may occur and have been reported in previously published studies. A case study by Quintas, Silva, and Sarmento (2009) described the case of a 16-year-old female with meningococcal meningitis complicated by bilateral peripheral facial palsy. In addition, a case-control study of 139 survivors found one child who developed severe impairments secondary to meningitis, including cerebral palsy, uncontrolled seizures, blindness and a bilateral severe-to-profound SNHL (Fellick et al., 2001). These findings, although uncommon, are important when considering the implications of multiple sequelae of meningitis in the holistic management of patients with BM.

Patient Y was initially diagnosed with profound hearing loss in the right ear and a moderate-to-mild reverse slope SNHL in the left ear, both of which remained stable. These

findings are similar to those of Woolley et al. (1999) who found that, in cases where hearing loss was profound at discharge, no recovery of hearing thresholds occurred at follow-up assessments. Knowing the stability of profound hearing loss may aid audiologists in determining follow-up frequency as part of audiological management protocols. Rare findings of BM-related hearing loss fluctuating for months to years after BM onset (Roine et al., 2014; Woolley et al., 1999) warrant the CI-ON recommendation of monitoring the child's hearing status up to 1 year post-meningitis.

Strengths and Limitations of the Study

The findings of this study should be interpreted in light of its methodological limitations: a retrospective medical folder review involving a small sample size, as well as limited audiological data based on the low number of appointments attended per patient. With regards to data analysis, the small sample size of the study was found to be not sufficiently powered for statistical analysis in the form of inferential statistics. Therefore, only descriptive statistics were used, and as a result, statistical relationships between variables related to BM and hearing loss could not be explored. Future studies should explore the current topic with a larger sample size, which should in turn allow for the use of inferential statistics.

However, the strength of the present study is that it comprehensively followed patients from the time they were diagnosed with BM to their latest appointment at audiology, where other studies have not done this. Previously, studies have either investigated patients before audiology referral, up to baseline audiological assessment (Khoza-Shangase & Rifkind, 2010) or from baseline audiological assessment onwards (Rodenburg-Vlot et al., 2018).

Recommendations for Future Research

Future research studies should consider exploring the following areas of research:

- A prospective study with a larger sample size, with similar aims to the present study, where the researcher has control over the referral and monitoring protocol.
- A study to investigate factors that influence referral and follow-up attendance in a South African context.
- A study focused on a prediction model for hearing loss specific to meningitis in South Africa. Based on the prediction model results, management protocols for children diagnosed with meningitis in South Africa, including referral to audiology and an audiological test battery, can be formulated.

Clinical Implications

Based on present study findings of low rates of referral to audiology and delays in getting patients to undergo audiological evaluation after meningitis diagnosis, paediatricians need to be better informed of referral pathways for children at risk of hearing loss. Audiologists need to work closely with paediatricians and to advocate routine referral of all children diagnosed with BM for audiological assessment. Campaigns aimed at informing all doctors that diagnose meningitis are also warranted to increase referrals to audiology and decrease referral time. These referral campaigns should target medical doctors and other health care providers responsible for the medical treatment and management of patients with meningitis. This emphasises the need for multidisciplinary teamwork in the management of meningitis patients. Furthermore, health promotion campaigns and more effective parent counselling should be utilised to educate parents on the importance of timeous and continuous audiological testing for children with meningitis.

To ensure that all meningitis patients are referred before discharge, a stringent meningitis registry should be introduced in all healthcare facilities. A registry would allow for

all meningitis patients to be recorded in one book/system, where they can be tracked to audiology. It can therefore be ensured that, at a bare minimum, audiological screening is performed on all BM patients prior to discharge.

By using a standardised audiological test battery as part of the audiological management protocol, the hearing status of patients can be consistently monitored between appointments. However, given that many of these patients are under the age of five, BM monitoring tests, such as OAEs, that rely on patient compliance make it difficult to ensure a set test battery at each appointment. Furthermore, some patients may be too unwell to undergo audiological assessment outside of their ward and so noisy wards can also make OAE testing, which relies on a quiet testing environment, challenging. Instead, the test battery utilised should be determined on a case-by-case basis, while still aiming to achieve the "gold standard" BM monitoring test protocol. Furthermore, the fluctuating hearing status in patients with BM found in the present study warrants follow-up audiological testing at regular intervals until 1 year post-BM, as suggested by the WCDoH (2018) protocol, as well as Merkus et al. (2010). Additionally, urgent and timeous referral for CI candidacy assessment needs to be carried out for all patients who present with BM-related hearing loss of a severe-to-profound nature.

Conclusion

This study sought to explore the audiological management protocols utilised at RCWMCH for young children (0-6 years) diagnosed with BM. Overall, the findings of this study showed that effective audiological management of children diagnosed with meningitis was significantly hampered by low baseline audiological assessment uptake rates, where only 16% of patients diagnosed with meningitis were seen for audiological assessment. Poor adherence to scheduled follow-up audiology appointments was also found to be a major challenge in this study. There was no specific audiological management protocol noted for

children diagnosed with BM at the hospital that participated in this study, however, all children who were diagnosed with hearing loss received the necessary intervention at the time that they were seen at the RCWMCH Audiology Department.

It was evident from the findings of this study that effective management and prevention of unfavourable outcomes, such as BM-related hearing loss, is challenging in a developing country which is typically burdened with high patient numbers and resource-strained health care services and service providers. This study highlights the need for a well-defined referral pathway, as well as an evidence-based protocol, for audiological management of children with BM which is both effective and appropriate for the South African health care setting. If this could be developed, it has the potential for early identification of hearing loss in these children, which would provide them with a reasonable chance of developmental, scholastic, and working opportunities in line with those of children with normal hearing status.

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Appendices

Appendix A: Degrees of Hearing Loss in Children

Degrees of hearing loss based on hearing thresholds (Northern & Downs, 2014):

Average hearing level (dBHL) (500 – 2000Hz)	**Degree of hearing loss**
< 15	Normal
15 – 25	Slight
25 – 30	Mild
30 – 50	Moderate
50 – 70	Severe
70 +	Profound

Appendix B: Letter for Permission to Conduct Research

Division of Communication Science and Disorders
School of Health and Rehabilitation Sciences
Faculty of Health Sciences
F45 Old Main Building
Groote Schuur Hospital
Telephone: (021) 406 – 6401
Fax: (021) 406 – 6323
Email: Lebogang.Ramma@uct.ac.za

Dear _____

My name is Nikki Tromp and I am a MSc student researcher from the University of Cape Town. I am currently conducting a research study investigating the audiological management of children diagnosed with bacterial meningitis. I would like to please request permission to conduct this research at your hospital. Permission to conduct research can be withdrawn by the relevant authorities at any given stage.

The first part of this study is aimed at determining the current protocol for audiological management of children diagnosed with bacterial meningitis, as well as the audiological presentation and outcomes of these children. This aims to close the current knowledge gap on audiological management protocols for children diagnosed with bacterial meningitis and could help improve the service delivery and quality of life for the population under investigation.

I therefore plan to review medical and, where applicable, audiological folders of patients between birth and 6 years who were diagnosed with bacterial meningitis between 2000 and 2017 at Red Cross War Memorial Children's Hospital. These folders will be accessed via the bacterial meningitis registry at your institution. Data collection will take place from 15-31 July.

The data collection process will not interrupt the duties of the staff at the hospital and no contact will be made with any of the hospital's patients.

Strict ethical conduct will be upheld throughout the study, as guided by the World Medical Association Declaration of Helsinki, 2013. Data will be recorded on an electronic spreadsheet, which will be stored on the researcher's password protected laptop. Only the researcher and one research assistant will have access to personal identifiers of the patients and all efforts will be made to keep the patients anonymous and their information confidential. No patient folders will be removed from the hospital premises at any given time. All details pertaining to the hospital facility, including the name of the hospital, will also be kept confidential at request of the hospital, through a signed confidentiality agreement.

The UCT's Faculty of Health Sciences Human Research Ethics Committee can be contacted on 021 406 6338 in case you have any ethical concerns or questions about your rights or welfare as a participant on this research study. Should you be interested, a summary of the research findings, implications and recommendations will be presented to you as feedback upon completion of the study.

If you have any additional queries or concerns regarding this study, please feel free to contact myself or my supervisor at the numbers provided below.

Sincerely,

Nikki Tromp (Student)	A/Prof Lebogang Ramma (Supervisor)
076 903 0897	(021) 406-6954 / 073 153 3803

Appendix C: Data Abstraction Forms

Patient hospital code	Study code	Patient Age	Sex (M = male; F = female)	Place of residence	Referred for audiological assessment (1 = YES; 2 = NO)	Time (in days) between BM diagnosis and audiology referral

Test 1 (baseline audiogram)

Diagnosed with hearing loss (1 = YES; 2 = NO)	Hearing loss characteristics					Audiological test battery							
	Laterality (U = unilateral, B = bilater0)	Type (C = conductive, S = sensorineural, M = mixed)	Degree at baseline	Degree at latest test	I = Improved, F = fluctuated, W = worse, S = Stable	Otoscopy	Tympanometry	Otoacoustic emissions	Pure tone audiometry (incl. VRA and CPA)	ABR	ASSR	Other (specify)	Speech Detection Thresholds

Right ear (PTA =_____ dB)			Left ear (PTA =_____ dB)		
	AC	BC		AC	BC
500Hz			500Hz		
1000Hz			1000Hz		
2000Hz			2000Hz		
4000Hz			4000Hz		
6000Hz			6000Hz		

Test 2 (second audiogram)

Diagnosed with hearing loss (1 = YES; 2 = NO)	Hearing loss characteristics					Audiological test battery							
	Laterality (U = unilateral, B = bilater0)	Type (C = conductive, S = sensorineural, M = mixed)	Degree at baseline	Degree at latest test	I = Improved, F = fluctuated, W = worse, S = Stable	Otoscopy	Tympanometry	Otoacoustic emissions	Pure tone audiometry (incl. VRA and CPA)	ABR	ASSR	Other (specify)	Speech Detection Thresholds

Right ear (PTA =_____ dB)			Left ear (PTA =_____ dB)		
	AC	BC		AC	BC
500Hz			500Hz		
1000Hz			1000Hz		
2000Hz			2000Hz		
4000Hz			4000Hz		
6000Hz			6000Hz		

Test 3 (latest audiogram)

Diagnosed with hearing loss (1 = YES; 2 = NO)	Hearing loss characteristics					Audiological test battery							
	Laterality (U = unilateral, B = bilater0)	Type (C = conductive, S = sensorineural, M = mixed)	Degree at baseline	Degree at latest test	I = Improved, F = fluctuated, W = worse, S = Stable	Otoscopy	Tympanometry	Otoacoustic emissions	Pure tone audiometry (incl. VRA and CPA)	ABR	ASSR	Other (specify)	Speech Detection Thresholds

Right ear (PTA =_____ dB)			Left ear (PTA =_____ dB)		
	AC	BC		AC	BC
500Hz			500Hz		
1000Hz			1000Hz		
2000Hz			2000Hz		
4000Hz			4000Hz		
6000Hz			6000Hz		

Audiological intervention				Referrals					
None	Hearing Aid (1 or 2)	Cochlear implant (1 or 2)	Other (specify)	Speech Therapy	Occupational Therapy	ENT	Social Worker	Carel du Toit/CHAT	Other (specify)

Appendix D: Ethics Approval Letter, University of Cape Town HREC

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6626
Email: shuretta.thomas@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

09 May 2018

HREC REF: 298/2018

A/Prof Lebogang Ramma
Communication Sciences and Disorders
Health & Rehab
F-Floor, OMB

Dear A/Prof Ramma

PROJECT TITLE: EXPLORING THE AUDIOLOGICAL MANAGEMENT OF CHILDREN DIAGNOSED WITH BACTERIAL MENINGITIS (MSc Candidate - Ms N Tromp)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 May 2019.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

The HREC acknowledge that the student, Nikki Tromp will also be involved in this study.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical

Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI),and Declaration of Helsinki (2013) guidelines.
The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

HREC 298/2018

Appendix E: Approval Letter, Red Cross War Memorial Children's Hospital

Western Cape Government
Health

Dr Anita Parbhoo
Manager: Medical Services
Email: Anita.Parbhoo@Westerncape.gov.za
Tel: +27 21 658 5742 fax: +27 21 658 5166
RXH: RCC134

Ms N Tromp
Red Cross War Memorial Children's Hospital

Dear Ms N Tromp

APPROVAL OF RESEARCH

PROJECT TITLE: EXPLORING THE AUDIOLOGICAL MANAGEMENT OF YOUNG CHILDREN (0-6 YEARS) DIAGNOSED WITH BACTERIAL MENINGITIS

It is a pleasure to inform you that approval is hereby granted to conduct the above-mentioned study at Red Cross War Memorial Children's Hospital.

Yours sincerely

06/06/18

DR A PARBHOO
MANAGER: MEDICAL SERVICES
RCWMCH

DATE:

Appendix F: Summarised Test Results Per Patient at Various Testing Intervals

Table F1. *Tympanometry test results for bacterial meningitis patients at various testing intervals.*

Bacterial Meningitis Patients		
Tympanometry Results		
Baseline	**Second**	**Latest**
-	-	-
Bilateral Type A	Bilateral Type A	Bilateral Type A
-	-	Bilateral Type A
-	Could not evaluate	-
Bilateral Type A	Right NT, left Type C	Bilateral Type B
-	-	-
-	-	Bilateral Type A
-	Bilateral Type C	-
-	**Right NT [1], left Type A**	**Bilateral Type A**
Bilateral Type A	-	Bilateral Type A
-	-	-
Bilateral Type C	Right Type C, left Type B	Right Type A, left Type B
Bilateral Type A	Bilateral Type A	Bilateral Type A
-	-	-
Bilateral Type A	**-**	**Bilateral Type A**
Bilateral Type A	-	-
-	-	-
Bilateral Type A	Bilateral Type A	-
-	-	-

* Where values are missing, the assessment was not performed
[1] NT = Not tested

Table F2. *Tympanometry test results for unspecified meningitis patients at various testing intervals.*

Unspecified Meningitis Patients		
Tympanometry Results		
Baseline	**Second**	**Latest**
Bilateral Type A	-	-
-	-	-
Bilateral Type C	-	Right Type As, left Type B
-	-	-
Right Type A/C, left Type B	Bilateral Type B	Bilateral grommets
-	Bilateral Type A	Right Type C, left Type A
-	-	-
Right Type C, left Type B	-	Bilateral Type A
Results missing	-	Right Type A, left Type B
Bilateral Type A	CNE[1] bilaterally	Right Type B, left Type As
Bilateral Type A	-	-
Bilateral Type A	-	-
CNE[1], excessive wax	-	-
Bilateral Type A	-	-
-	Bilateral Type B	Bilateral Type B
-	-	-
-	-	-
Bilateral Type A	-	Right Type B, left Type A
Bilateral Type C	-	-
Right Type A, left Type C	-	-

* Where values are missing, the assessment was not performed
[1] CNE = could not evaluate

Table F3. *Otoacoustic emission test results for bacterial meningitis and unspecified meningitis patients at various testing intervals.*

Otoacoustic Emissions Bacterial Meningitis (n = 19); Unspecified meningitis (n = 20)								
	Bilateral pass		**Unilateral pass**		**Bilateral refer**		**Not tested**	
	BM	**UM**	**BM**	**UM**	**BM**	**UM**	**BM**	**UM**
Baseline	12	10	3	7	1	0	3	3
Follow-up	4	2	3	0	2	2	10	6
Latest	7	6	0	1	0	1	12	12

Table F4. *Automated auditory brainstem response test results for bacterial meningitis and unspecified meningitis patients at various testing intervals.*

Automated Auditory Brainstem Response Bacterial Meningitis (n = 8); Unspecified Meningitis (n = 5)								
	Bilateral pass		**Unilateral pass**		**Bilateral refer**		**Not tested**	
	BM	**UM**	**BM**	**UM**	**BM**	**UM**	**BM**	**UM**
Baseline	1	1	2	1	0	0	5	3
Follow-up	3	0	2	1	0	1	3	3
Latest	1	-	1	-	0	-	6	-

Table F5. *Auditory brainstem response test results for bacterial meningitis and unspecified meningitis patients at various testing intervals.*

Auditory Brainstem Response		
Bacterial Meningitis (n = 2)		
	HL diagnosed	**HL diagnosis**
Baseline	1	Right severe-to-profound SNHL, left mild SNHL
Latest	1	Right normal hearing, left severe SNHL
Unspecified Meningitis (n = 1)		
	HL diagnosed	**HL diagnosis**
Baseline	1	Unilateral CHL

Table F6. *Visual reinforcement audiometry/conditioned play audiometry test results for bacterial meningitis and unspecified meningitis patients at various testing intervals.*

Visual Reinforcement Audiometry / Conditioned Play Audiometry			
Bacterial Meningitis (n = 8)			
	Normal	**Other HL (specify)**	**Not tested**
Baseline	3	1 (Bilateral profound SNHL)	4
Follow-up	2	0	6
Latest	3	1 (Right moderate-to-severe SNHL, left mild SNHL)	4
Unspecified Meningitis (n = 7)			
	Normal	**Other HL (specify)**	**Not tested**
Baseline	1	1 (Poor FF responses)	5
Follow-up	0	1 (Poor FF responses)	6
Latest	3	1 (Right mild HL, left normal hearing)	3

Table F7. *Speech detection threshold test results for bacterial meningitis and unspecified meningitis patients at various testing intervals.*

Speech Detection Threshold			
Bacterial Meningitis (n = 8)			
	Tested	**Result**	**Not tested**
Baseline	1	10 dB bilaterally	7
Follow-up	1	25 dB bilaterally	7
Latest	3	25 dB bilaterally 15 dB bilaterally Right 15dB, left 20 dB	5
Unspecified Meningitis (n = 7)			
	Tested	**Result**	**Not tested**
Baseline	1	40 dB bilaterally	6
Follow-up	1	15dB bilaterally	6
Latest	3	10 dB bilaterally Right 10dB, left CNE 15 dB bilaterally	4