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Hearing Rehabilitation by Cochlear Implant in Post-Meningitis Deafness

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HEARING REHABILITATION BY COCHLEAR IMPLANT IN POST-MENINGITIS DEAFNESS

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ABBREVIATIONS

CI - Cochlear implant

SPSS - Statistical Package for the Social Sciences

Hz - Hertz

dB - Decibels

ABSTRACT

Introduction: Deafness is considered a common and severe complication of bacterial meningitis, particularly in children due to its increased implications on language development. In cases of profound hearing losses, cochlear implantation is the only means for hearing rehabilitation, even though its placement may be hampered by cochlear fibrosis and ossification derived from the infection spreading into the inner ear. Post-implantation hearing outcomes are variable and influenced by some factors, not yet totally described.

Objective: To evaluate the impact in the hearing rehabilitation tests results of variables such as meningitis aetiology, age at meningitis diagnosis, age at cochlear implantation, age group and time lapse between diagnosis and implantation.

Materials and methods: 47 cochlear implants were surgically placed at Centro Hospitalar e Universitário de Coimbra. A retrospective non-interventional study was conducted. The variables were categorised, individuals were grouped into these categories and general characteristics of the sample were registered. The results of 23 hearing tests were analysed in the light of the categories of variables.

Results: Among the known aetiologies of meningitis, *Streptococcus pneumoniae* was the most common (17%), followed by *Neisseria meningitidis* (10,6%). A statistically significant relation arose in 6 hearing tests when comparing some groups of the variable age at meningitis diagnosis. In individuals diagnosed until 2 years, there were more positive results in the "telephone use" test. Comparing the hearing outcomes with the age at implantation, 6 tests presented significant results. Concerning the use of the telephone, it was 100% on those implanted aged 3 years or under and 50% in the others. Regarding a cut-off of 18 years for the age at implantation, 11 tests showed significant differences among children and adults, whose percentages of using the telephone were 85,2% and 35%, respectively. A p value < 0,05 emerged in 3 tests when comparing some groups of the variable time lapse between diagnosis and implantation. The maximum capacity for using the telephone was 85,7% (in the group who waited 1 to 3 years before implantation) and the minimum was 22,2% (in those who waited > 3 years).

Discussion and conclusion: Improved hearing outcomes are associated with surgery at younger ages and, in a similar vein, are usually better in children, comparing to adults. A shorter auditory deprivation period also showed better hearing results. The sample didn't allow

the study of meningitis aetiology nor the finding of a connection between the age at meningitis diagnosis and the hearing outcomes.

RESUMO

Introdução: A surdez é considerada uma complicação comum e severa da meningite bacteriana, particularmente em crianças, pela implicação acrescida no desenvolvimento da linguagem. Em caso de perda de audição profunda, a implantação coclear é o único método de reabilitação auditiva, embora a sua colocação possa ser dificultada por fibrose e ossificação cocleares, devidas à extensão da infeção ao ouvido interno. Os resultados auditivos pós-implantação são variáveis e influenciados por alguns fatores, ainda não totalmente descritos.

Objetivo: Avaliar o impacto, nos resultados dos testes de reabilitação auditiva, de variáveis como: etiologia da meningite, idade ao diagnóstico de meningite, idade à implantação coclear, grupo etário e lapso temporal entre o diagnóstico e a implantação.

Materiais e métodos: 47 implantes cocleares foram colocados, via cirúrgica, no Centro Hospitalar e Universitário de Coimbra. Realizou-se um estudo retrospetivo não intervencional. As variáveis foram categorizadas, os indivíduos agrupados nestas categorias e as características gerais da amostra registadas. Os resultados dos 23 testes auditivos foram analisados à luz destas categorias.

Resultados: Das etiologias conhecidas de meningite, *Streptococcus pneumoniae* foi a mais comum (17%), seguida por *Neisseria meningitidis* (10,6%). Uma relação estatisticamente significativa surgiu em 6 testes quando comparados alguns grupos da variável idade ao diagnóstico de meningite. Em indivíduos diagnosticados até aos 2 anos, houve melhores resultados no teste "uso do telefone". Comparando os resultados auditivos com a idade à implantação, 6 testes apresentaram resultados significativos. Considerando o uso do telefone, este foi de 100% nos implantados com 3 anos ou menos e de 50% nos restantes. Admitindo um *cut-off* de 18 anos para a idade à implantação, 11 testes mostraram diferenças significativas entre crianças e adultos, cujas percentagens de uso do telefone foram 85,2% e 35%, respetivamente. Um valor $p < 0,05$ surgiu em 3 testes quando comparados alguns grupos da variável lapso temporal entre o diagnóstico e a implantação. A capacidade máxima de uso de telefone foi de 85,7% (no grupo que esperou 1 a 3 anos até à implantação) e a mínima foi de 22,2% (naqueles que esperaram > 3 anos).

Discussão e conclusão: Melhores resultados auditivos estão associados a cirurgia em idades mais precoces e, similarmente, são, regra geral, melhores em crianças do que em adultos. Um período de privação auditiva menor também demonstrou melhores resultados

auditivos. A amostra não permitiu estudar a etiologia da meningite nem estabelecer uma correlação entre a idade ao diagnóstico de meningite e os resultados auditivos.

KEYWORDS

Deafness
Cochlear Implants
Meningitis
Labyrinthitis
Hearing Tests

PALAVRAS-CHAVE

Surdez
Implantes Cocleares
Meningite
Labirintite
Testes auditivos

INTRODUCTION

Meningitis is considered the major cause of acquired profound deafness in adults and children.[1] Depending on its aetiology, meningitis is associated with different long-term consequences and, in case of bacterial meningitis, whose victims are predominantly children, as many as 25% of survivors are left with sequelae such as hearing loss.[2] Even in developed countries, about 10% of children who survive meningitis live with permanent sensorineural hearing loss, turning deafness into the commonest serious complication of bacterial meningitis in childhood.[3]

Regarding the main pathogens responsible for this disease, *Neisseria Meningitidis*, *Haemophilus Influenzae* and *Streptococcus Pneumoniae* play a major role in the origin of bacterial meningitis,[4] with the latter being related with most neurological complications and sequelae (including hearing loss).[5] Overall, these three microorganisms account for approximately 75% of the community acquired acute bacterial meningitis.[4] In what concerns postmeningitic deafness, the site of the lesion is almost always cochlear and not the auditory nerve[1] as it was thought before. It is precisely the survival of the cochlear nerve that allows the possibility of cochlear implantation,[1] which is nowadays the only means for hearing restoration in case of profound hearing loss.[6]

The cochlear aqueduct has been proposed as a possible channel that allows the spreading of infection into the inner ear.[6] This supposed route of infection is thought to be more patent in children, a fact that could explain the higher incidence of postmeningitic hearing loss in childhood.[3] The cochlear aqueduct connects the subarachnoid space and the scala tympani, where ossification tends to begin.[6] This process of cochlear osteoneogenesis is a result of the cochlear infection which produces a reaction in the endosteum of the cochlea with a resultant overgrowth of new bone.[1] Meningococci and pneumococci are the pathogens most associated with ossification of the cochlea and the only ones present in cases of partial or strong ossification.[6] Besides rapid bony obliteration of the cochlea due to osteoneogenesis,[1] fibrous cochlear obliteration can also occur as the infection spreads, in result of a process of labyrinthitis.[6] In children with meningitis related-deafness, bony or fibrous obliteration occurs in around 34% of cases.[6] Together, they may become an obstacle to cochlear implant (CI) insertion, which makes the early diagnosis essential for obtaining a prompt treatment, in order to achieve the best hearing outcomes. The postmeningitic deafness is not always apparent, especially in young infants due to their inability to communicate and the possible cognitive effects of infection.[7] Nevertheless, age at the time of meningitis occurrence doesn’t seem to influence markedly the hearing outcomes after disease.[8] However, if the hearing deficit takes a long time to be diagnosed, it may affect the auditory and linguistic development.[7] Thereby, individuals at risk of becoming deaf after meningitis should be subjected to a hearing assessment by whatever means considered appropriate to their ages.[1]

The sensorineural hearing loss develops early in the course of bacterial meningitis but Richardson et al. described some cases of children who had a reversible hearing loss within the first two days of disease,[3] which prompts the question of whether there is a temporal link between the beginning of treatment and the progression to permanent deafness. Following this topic, the optimal timing to perform cochlear implantation surgery after meningitis in case of profound deafness also remains controversial.[9] In any case, when profound deafness is present, a computed tomography of the cochlea is mandatory,[1] and it is useful to assess the degree of bony ossification.[6] A magnetic resonance can also be used to differentiate bone and normal cochlear fluids.[1] The extent of fibrous obliteration is determined intraoperatively.[6]

There is also no consensus on the ideal age and optimal timing for cochlear implantation in children with profound sensorineural hearing loss after meningitis. In case of congenitally deaf infants, clinical practice suggests that the surgical placement of the CI should occur within the first 12 months of life. On the other hand, in postmeningitic profound deafness, there is the increased risk related to cochlear fibrosis and ossification which requires an adequate assessment and may also lead to an implantation in infants younger than 9 months of age (despite the higher risks, for example, related to anesthesia).[7] There is growing evidence that early implantation may provide superior language development outcomes compared with patients who have prolonged auditory deprivation, and that early rehabilitation facilitates developmental outcomes in line with normal-hearing peers.[10] Therefore, when a decision is made on the implantation in younger children, specific diagnostic, anesthesiological, and surgical considerations related to the early age at implantation and the possible sequelae of bacterial meningitis apply.[7] In any age, the outcome of cochlear implantation in postmeningitic infants depends on many factors: the proper CI placement, the depth of electrode insertion (compromised by cochlear obliteration), the possible additional sequelae of meningitis (for example, the damage of cochlear spiral ganglia, which may result in failure of the neuronal response), the cognitive and linguistic abilities of the recipient, among others.[7] As expected, Roukema et al. described the best outcome in a case with no other complaints besides hearing loss; on the other hand, the child with the worst outcome had also severe neurological sequelae.[7] Nevertheless, one cannot fail to mention that even in case of incomplete insertions or comorbidity associated with meningitis, it is still preferable to place a CI.[7]

Most of the literature turns its attention to the issue of cochlear implantation due to postmeningitic deafness in children but this is also a problem in adulthood. In the latter case, meningitis might have occurred during childhood (with late implantation) or already in adult age (with a shorter time interval until surgery). Either way, literature mentions poorer performance in adults with postmeningitic deafness[11] and refers that, regardless of the hearing impairment cause, an increased age at implantation may reduce effectiveness.[12] Besides, it has been described a negative correlation between duration of deafness and effectiveness,[12] which could impact on implantation particularly in adults with hearing loss since childhood.

Against the background outlined above, it is considered appropriate to study a population of adults and children with cochlear implants due to postmeningitic deafness, concerning their results in different hearing assessments. The purpose of this study is, then, to investigate if the outcomes of the hearing tests after cochlear implantation are influenced by factors like the meningitis aetiology, the age at the time of meningitis diagnosis, the age at the time of cochlear implantation, the age group and the time lapse between meningitis diagnosis and cochlear implantation. The registry of the surgeries for cochlear implantation performed at Centro Hospitalar e Universitário de Coimbra from March 1985 until July 2020 provided a suitable sample for this retrospective study.

MATERIALS AND METHODS

An observational, non-interventional, retrospective study was conducted including 47 cochlear implants (43 patients) whose surgeries were performed at Centro Hospitalar e Universitário de Coimbra from March 1985 to July 2020.

The analysis focused on both adults and children selected for CI due to postmeningitic sensorineural hearing loss with a follow-up program that included completing a battery of tests to monitor the individual evolution of hearing rehabilitation. Initially, these data were obtained through consultation of a digital hospital database. In a second phase, to complete the data, 22 paper-based processes were requested.

23 hearing tests were performed, including: free-field tone audiometries between 250 and 6000 hertz (Hz); disyllabic discriminations between 20 and 80 decibels (dB); discrimination of monosyllables, numbers, sentences, sentences on the phone, 100 words, 100 words on the phone, vowels, minimal pairs, consonants; and assessment of the ability to use the telephone.

The results of post-implantation hearing tests were compared taking into account variables such as meningitis aetiology, age at the time of meningitis diagnosis, age at the time of cochlear implantation, age group and time lapse between meningitis diagnosis and cochlear implantation. Besides, variables such as gender, implanted ear and laterality of implantation were also registered. Most of these variables were categorised in order to facilitate statistical analysis, except the results of the tests which were mostly assumed as continuous variables. All the results of the tests were expressed in percentage except one (the assessment of the ability to use the telephone), defined by a yes or no answer. It was not possible to obtain information regarding all variables in all patients, but this was not considered a criterion for exclusion, with a view to improving the global statistic power of the sample.

Statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS) version 23.0 for Macintosh. The data were presented using tables. The Kolmogorov-Smirnov test was used to determine the normality of distribution and homogeneity of variance. When these were verified, a t-test for paired/independent samples was used. When these conditions were not fulfilled, the Mann-Whitney test for independent samples was used. A cross-tabulation was used to describe the relationship between two categorical variables. Statistical significance was defined as $p < 0,05$.

RESULTS

General sample characteristics

Table 1 shows some characteristics of the population analysed.

Table 1 – Demographics and characteristics of the study sample

Cochlear implants		47
Gender	Male	25 (53,2%)
	Female	22 (46,8%)
Age groups	Children (< 18 years)	27 (57,4%)
	Adults (≥ 18 years)	20 (42,6%)
Meningitis aetiology	*Streptococcus pneumoniae*	8 (17,0%)
	Neisseria meningitidis	5 (10,6%)
	Haemophilus influenzae	2 (4,3%)
	Streptococcus suis	2 (4,3%)
	Unknown	30 (63,8%)
Age at the time of meningitis diagnosis	< 6 months	4 (8,5%)
	6 months to 1 year	9 (19,1%)
	1 to 2 years	8 (17,0%)
	> 2 years	13 (27,7%)
	Unknown	13 (27,7%)
Implanted ear	Right	34 (72,3%)
	Left	13 (27,7%)
Laterality	Unilateral	39 (83,0%)
	Bilateral sequential	6 (12,8%)
	Bilateral simultaneous	2 (4,2%)
Age at the time of cochlear implantation	≤ 3 years	12 (25,5%)
	> 3 years	34 (72,4%)
	Unknown	1 (2,1%)
Time lapse between meningitis diagnosis and cochlear implantation	< 1 year	13 (27,7%)
	1 to 3 years	14 (29,8%)
	> 3 years	9 (19,1%)
	Unknown	11 (23,4%)
	Range (days)	9203 (48-9251)
	Mean ± Std deviation (days)	1444,33 (± 2326,029)
	Median (days)	702

A total of 47 cochlear implants were included in this study. 53,2% of the patients were male and 46,8% were female. 57,4% were under 18 years and 42,6% were adults. Most of the cases (63,8%) had unknown meningitis aetiology but, among the known ones, the most common pathogen was *Streptococcus pneumoniae* (17%), followed by *Neisseria meningitidis* (10,6%). 44,6% had meningitis aged 2 years or under. The vast majority of patients received an unilateral implant (83%) and most of these were on the right side (72,3%). More than half (72,4%) was implanted older than 3 years. In what concerns the time lapse between meningitis diagnosis and cochlear implantation, most patients (29,8%) belong to the intermediate group, waiting 1 to 3 years before having surgery. The mean waiting time was about 1444 days (approximately 4 years).

Analysis of valid and missing results of the hearing tests

Regarding the 23 hearing tests performed and the statistical power of their results, free-field tone audiometries presented 45 valid results (95,7%) and 2 missing ones (4,3%), in each frequency. Disyllabic discriminations exhibited 41 valid results (87,2%) and 6 missing ones (12,8%), in each decibels category. Regarding the other tests, the ratio 'valid results/missing results' is variable, with the "100 words on the phone" test presenting the minimum of valid results – 28 (59,6%) – and the maximum of missing results – 19 (40,4%) – and the "telephone use" test showing the maximum of valid results – 43 (91,5%) – and the minimum of missing results – 4 (8,5%). On average, excepting free-field tone audiometries and disyllabic discriminations, each test had approximately 36 valid results and 11 missing ones.

Age at the time of meningitis diagnosis

[< 6 months I 6 months to 1 year I 1 to 2 years I > 2 years]

Table 2 presents the hearing tests whose results showed statistically significant relations with some comparisons of the age at the time of meningitis diagnosis.

Table 2 – Comparison between hearing tests results and age at the time of meningitis diagnosis (only statistically significant results)

Name	< 6 months vs 1-2 years	< 6 months vs > 2 years	6 months-1 year vs > 2 years	1-2 years vs > 2 years
FFTA1000Hz	-	-	-	p = 0,045
DD60dB	-	p = 0,037	-	-
DD70dB	p = 0,049	p = 0,029	-	-
DD80dB	-	p = 0,048	-	-
Vowels	-	-	p = 0,024	p = 0,024
Consonants	p = 0,027	-	-	-

FFTA1000Hz - 1000 Hz free-field tone audiometry; DD60dB - disyllabic discrimination at 60 dB; DD70dB - disyllabic discrimination at 70 dB; DD80dB - disyllabic discrimination at 80 dB.

After comparing the 4 categories (< 6 months, 6 months to 1 year, 1 to 2 years, > 2 years) of the age at the time of meningitis diagnosis with one another in what concerns the results of the different hearing tests, only 6 different tests showed statistical significance (in some comparisons), as expressed in **table 2**. Individuals whose diagnosis occurred under 6 months, when compared to patients whose diagnosis was from 1 to 2 years, showed a p value < 0,05 in the "disyllabic discrimination at 70 dB" and the "consonants" tests. The group with a diagnosis under 6 months, compared to patients with a diagnosis above 2 years, expressed a statistically significant result in three tests from the group of disyllabic discriminations – 60, 70 and 80 dB. Individuals with a diagnosis from 6 months to 1 year, compared to those with a diagnosis above 2 years, showed a significant p value in the "vowels" test. The group diagnosed between 1 to 2 years, compared with the ones diagnosed above 2 years, appeared with statistically significant results in the "1000 Hz free-field tone audiometry" and the "vowels" tests.

Table 3 compares the capacity of using the telephone and the age at the time of meningitis diagnosis.

Table 3 – Comparison between the "telephone use" test results and age at the time of meningitis diagnosis

Age at the time of meningitis diagnosis	Telephone use			
	Yes	No	Unknown	Total
< 6 months	3 (75%)	1 (25%)	0 (0%)	4
6 months to 1 year	6 (66,6%)	1 (11,1%)	2 (22,2%)	9
1 to 2 years	6 (75%)	2 (25%)	0 (0%)	8
> 2 years	5 (38,5%)	7 (53,8%)	1 (7,7%)	13
Unknown	10 (76,9%)	2 (15,4%)	1 (7,7%)	13
Total	30	13	4	47

In the groups whose diagnosis occurred under 6 months or from 1 to 2 years, 75% of the patients manage to use the telephone. When diagnosis occurred from 6 months to 1 year, 66,6% of the individuals can use the telephone. In the group diagnosed above 2 years of age, the majority (53,8%) is not able to use the telephone.

<u>Age at the time of cochlear implantation</u>

[≤ 3 years I > 3 years]

After having compared all the hearing tests results and the age of implantation (≤ 3 years and > 3 years), there were 6 tests whose comparison presented a statistically significant p value – disyllabic discriminations at 70 and 80 dB, monosyllables, numbers, 100 words, consonants.

Table 4 presents the capacity of using the telephone and its relation with the age of implantation.

Table 4 – Comparison between the "telephone use" test results and age at the time of cochlear implantation

Age at the time of cochlear implantation	Telephone use			
	Yes	No	Unknown	Total
≤ 3 years	12 (100%)	0 (0%)	0 (0%)	12
> 3 years	17 (50%)	13 (38,2%)	4 (11,8%)	34
Unknown	1 (100%)	0 (0%)	0 (0%)	1
Total	30	13	4	47

All the surgeries in patients aged 3 or under reflect a capacity of using the telephone of 100%. When surgeries occurred in patients over 3 years, 50% referred being able to use the telephone, 38,2% referred not being able to use it and 11,8% weren't even tested on this parameter.

Age groups

[< 18 years I ≥ 18 years]

After comparing hearing tests results and the 2 age groups defined (children – < 18 years – and adults – ≥ 18 years), statistically significant relations appeared in 11 tests: 4000 and 6000 Hz free-field tone audiometries; disyllabic discriminations at 60, 70 and 80 dB; monosyllables; numbers; 100 words; vowels; minimal pairs; consonants.

Table 5 shows the relation between the capacity of using the telephone and the age groups defined (children – < 18 years – and adults – ≥ 18 years).

Table 5 – Comparison between the "telephone use" test results and age groups

Age groups	Telephone use			
	Yes	**No**	**Unknown**	**Total**
Children (< 18 years)	23 (85,2%)	2 (7,4%)	2 (7,4%)	27
Adults (≥ 18 years)	7 (35%)	11 (55%)	2 (10%)	20
Total	30	13	4	47

In line with **table 5**, 85,2% of the individuals implanted under 18 are able to use the telephone and only slightly over a third (35%) of the individuals aged 18 or above at the time of the surgery have this capacity.

Time lapse between meningitis diagnosis and cochlear implantation

[< 1 year I 1 to 3 years I > 3 years]

After comparing the 3 categories (< 1 year, 1 to 3 years, > 3 years) of the time lapse between diagnosis and implantation with one another in what concerns the results of the different hearing tests, only 3 different tests showed statistical significance (in some comparisons). The group with a time lapse under 1 year, compared to patients who waited above 3 years, expressed a statistically significant result in two tests – "sentences on the phone" and "100 words on the phone". Individuals who waited 1 to 3 years until surgery, when compared to patients whose time lapse was above 3 years, showed a p value < 0,05 in the "disyllabic discrimination at 80 dB" test.

Table 6 establishes a comparison between the capacity of using the telephone and the time lapse between diagnosis and implantation.

Table 6 – Comparison between the "telephone use" test results and time lapse between meningitis diagnosis and cochlear implantation

Time lapse between diagnosis and cochlear implantation	Telephone use			
	Yes	No	Unknown	Total
< 1 year	10 (76,9%)	3 (23,1%)	0 (0%)	13
1 to 3 years	12 (85,7%)	2 (14,3%)	0 (0%)	14
> 3 years	2 (22,2%)	4 (44,4%)	3 (33,3%)	9
Unknown	6 (54,5%)	4 (36,4%)	1 (9,1%)	11
Total	30	13	4	47

When surgery occurred up to 3 years after the diagnosis, the vast majority of the patients manage to use the telephone (76,9% and 85,7%, respectively in each group). When implantation occurred 3 years or more after meningitis diagnosis, only 22,2% of the individuals can use the telephone.

DISCUSSION

Sensorineural hearing loss is the most common severe consequence of bacterial meningitis in childhood.[13] The mechanism of infection spread begins with a connection between the subarachnoid space and the inner ear with a consequent suppurative labyrinthitis that may affect both the vestibular and cochlear portions of the labyrinth.[14] The suppurative stage can be followed by fibrosis and later by new bone formation which may result in obliteration of the labyrinth.[14] Dense ossification can hinder the adequate placing of the CI,[14] which is the only means for hearing restoration when there is a profound hearing loss.[6]

Even though the incidence of bacterial meningitis has decreased for the last 20 years,[15] the hearing prognosis of individuals with postmeningitic deafness is still a matter of substantial debate. When it comes to children, specially affected prelingually, hearing loss diagnosis presents a challenge because cochlear ossification may occur years after meningitis and affect the individuals during the phase of language acquisition.[15] This may result in severe implications for development and education.[16]

Although many pathogens may be involved in meningitis origin, several studies[5, 17] suggest that pneumococcal meningitis has the highest mortality and highest risk of developing hearing impairment.[15]

The main aim of this study was the comparison of the post-implantation hearing tests results with different variables such as the aetiology of meningitis, the age of meningitis occurrence, the age of cochlear implantation, the age group and the time lapse between meningitis and surgery. In accordance with most of the scientific evidence, some of these factors influence future hearing outcomes so it was considered appropriate to develop a study with a sample which includes cochlear implantations surgeries performed at Centro Hospitalar e Universitário de Coimbra from March 1985 until July 2020.

The study sample (n = 47), obtained essentially through consultation of a digital hospital database, contemplated a good age and gender distribution, adding statistical power to the analysis performed. The main inclusion criterion for this study was the existence of recorded results of post-implantation hearing tests.

The characterisation of meningitis aetiology established that more than half of the cases were registered as having unknown origin. Among the known ones, *Streptococcus pneumoniae* and *Neisseria meningitidis* emerged as the main pathogens involved in meningitis origin, which coincides with the results of several studies.[4,5] Pneumococci is associated with higher mortality rates and serious sequelae,[5,15,17] causing the worst hearing prognosis with permanent losses in up to 30% of survivors.[18]

According to Karanja et al., age at illness was found not to be a significant determinant of hearing loss following bacterial meningitis.[8] However, the comparison between hearing tests results and the age at the time of meningitis diagnosis in this sample showed some statistically significant differences. The "disyllabic discrimination at 70 dB" test and the "consonants" test showed a p value < 0,05 when the groups "< 6 months" and "1 to 2 years" (regarding the age at meningitis diagnosis) were compared. Concerning the comparison of the "< 6 months" group with the "> 2 years" group, the disyllabic discriminations at 60, 70 and 80 dB tests presented significant p values. The comparison between "6 months to 1 year" group and "> 2 years" group revealed a p value of 0,024 in the test "vowels". The "1000 Hz free-field tone audiometry" test and the "vowels" test showed a significant difference when "1 to 2 years" group was compared with "> 2 years" group. The capacity of using the telephone in the groups whose diagnosis occurred under 6 months or from 1 to 2 years was 75%. The individuals with diagnosis from 6 months to 1 year showed a capacity of approximately 66% for using the telephone. 38,5% of the patients diagnosed above 2 years were capable of using the telephone. Although statistically significant results were reached, they don't show a clear trend which favours one age group (in each comparison) in what concerns best hearing results. Bearing this in mind, the results of this study are in line with the conclusions exposed in Karanja et al.'s analysis.

The ideal age for surgery is a widely debated issue which lacks definitive conclusions.[7] Unlike congenitally deaf infants, children with postmeningitic deafness raise the issue of possible fibrosis and ossification with subsequent cochlear obliteration, which can make adequate placing of the implant impossible.[7,14] Thus, it is crucial to identify the early stages of labyrinthine ossification with an adequate assessment, both for evaluating the chances of hearing recovery and for choosing the right time for cochlear implantation.[14] Either way, increasing evidence suggests that early implantation yields better long term results for hearing acuity.[10] The results of this study showed that, out of 22 hearing tests, 6 of them had a statistically significant relation with the age at the time of cochlear implantation (p < 0,05). In the case of the "telephone use" test, results exposed that 100% of the individuals who undergone surgery aged 3 or less were able to use the telephone, in contrast to the patients implanted later, whose capacity for using the telephone halved (50%). These results possibly support the thesis that early implantation (in this case, ≤ 3 years) is associated with better hearing outcomes.

Considering another type of age-reading – dividing individuals in two groups (children, < 18 years, and adults, ≥ 18 years) according to the age of implantation – a higher number of comparisons with hearing tests results appeared with statistical significance. In particular, 11 out of 22 hearing tests had a significant relation ($p < 0,05$) with the age groups. 2 of these 11 tests (4000 and 6000 Hz free-field tone audiometries) showed better hearing outcomes in individuals implanted at 18 years or above. The other 9 revealed a significant difference favouring implantation in children. A possible explanation for this difference is the fact that the development of listening and oral language skills and their pace of development are not the same for all children,[19] and this diversity may affect the homogeneity of the outcomes. In fact, this variety of prognosis may hinder the reaching of significant conclusions. The "telephone use" test showed a greater capacity of using the telephone among children (85,2%), when compared to adults (35%). Despite the 2 tests which favour implantation at older ages, the general trend shows better hearing outcomes in individuals implanted during childhood.

Studies reveal that prolonged auditory deprivation, associated with longer waiting time until surgery, is related with a worse evolution after CI including worse language development outcomes.[10] When comparing hearing tests results with the time lapse between meningitis diagnosis and cochlear implantation, some comparisons appeared with a statistically significant relation. Concerning the comparison of the "< 1 year" group with the "> 3 years" group, the "sentences on the phone" test and the "100 words on phone" test presented with p values of 0,022 and 0,034, respectively. The "disyllabic discrimination at 80 dB" test showed a p value of 0,047 when "1 to 3 years" group was compared with "> 3 years" group. These 3 statistically significant differences revealed better hearing outcomes in the groups whose time until surgery was shorter, supporting the theory that shorter waiting times for implantation are probably associated with better hearing results. The "telephone use" test showed greater capacities for using the telephone in the individuals who waited up to 3 years until surgery ("< 1 year" group with a capacity of 76,9% and "1 to 3 years" group with a capacity of 85,7%). On the contrary, only about 22% of patients whose surgery occurred > 3 years after meningitis diagnosis were able to use the telephone. These results also show the trend of having better outcomes with shorter auditory deprivation.

A significant limitation of this study has probably close links with the fact that the analysis performed was retrospective and non-interventional. Thus, the analysed data were those who had been previously collected and missing data were difficult or impossible to replace, which complicated the statistical analysis. Besides, probably the major limitation of this study is that the sample was not very extensive making it hard to achieve meaningful statistic conclusions. Consequently, the categorisation of variables brought together relatively different individuals into the same category, to enable the statistical comparison between groups. The fact that all the analysed patients had surgery and follow-up done in the same hospital centre may also be one factor limiting the success of the analysis due to the existence of different protocols stemming from different surgical centres.

CONCLUSION

The results of this work show that hearing rehabilitation outcomes after cochlear implantation are improved with earlier ages at surgery and tend to be better in children than adults (also concerning the time of implantation). Shorter waiting times for cochlear implantation surgery also appeared to provide better hearing results. On the other hand, age at the time of meningitis diagnosis didn't reveal a suggestive correlation between some age groups and the hearing outcomes.

Meningitis aetiology was supposed to be another variable under analysis but due to the high number of missing reports it was only possible to describe the different pathogens frequencies, not comparing them with the results of the hearing tests.

Bearing in mind that this was a retrospective study, it would be appropriate to carry out a prospective analysis using, if possible, a more extended sample, to reinforce and corroborate the results obtained with an increased statistical power. In this case, categorisation of variables could be performed more judiciously and in detail. It could also be useful to collect data from different hospital centres.

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