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REVIEW

Rehabilitation of Hearing Function with Hearing Aids

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Abstract

Aerial conduction hearing aids (conventional) are the most commonly used devices for the rehabilitation of residual hearing loss after tympanoplasty. Patients with dry, safe ears with mild to moderate conductive hearing loss typically achieve excellent hearing rehabilitation with these devices. Although recent conventional hearing aids have improved technically, there are still shortcomings: distortion of sound and voice, irritation of the external ear canal, acoustic *feedback*, discomfort and exacerbation of existing conditions of the outer and middle ear.

Bone-anchored hearing aids are excellent devices that have proven their usefulness over time if candidates were properly selected and surgery was performed meticulously. In audiological terms, bone-anchored hearing devices are clearly superior to conventional aerial conduction devices and passive bone conduction devices. The major drawbacks of this hearing aid are the relatively high financial costs and the need for the implantation surgical procedure.

Cochlear implant is one of the most effective rehabilitation methods for sensorineural hearing loss, especially in cases where there is no functional effect with other hearing aids. The benefits of cochlear implantation, including for severe-profound hearing loss in children and adults, have been significant improvements in post-implant audiological test scores, cognitive domains, and quality of life, including long-term. Cochlear implants showed the greatest improvements in speech perception and production, clear speech recognition in noisy environments, and audiometry performance compared to conventional hearing aids.

Keywords: hearing loss, conventional aerial hearing aid, implantable hearing device, cochlear implant

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INTRODUCTION

Hearing loss, also known as deafness, is a decrease in hearing acuity, which can affect one or both ears. It is a major public health problem, which frequently goes unnoticed or untreated, associated with a huge impact on mental health, social life, cognitive abilities, educational status and employment. Patients with hearing loss face a number of problems – reduced quality of life, negative outcomes on social interaction, independence, interpersonal relationships, communication and mental well-being. Hearing loss can lead to secondary problems such as learning difficulties, social stigma, depression, and early dementia, all of which affect quality of life[1,2,3,4,5].

There are three main types of hearing loss: conductive, sensorineural and mixed. Sensorineural hearing loss is the result of damage to the cochlear or vestibulo-cochlear nerve caused by infection and trauma. Conductive hearing loss is caused by physical or mechanical obstruction of air conduction that inhibits the transmission of sound waves from the outer/middle ear to the inner ear. Some causes of conductive hearing loss include trauma (perforated eardrum) or infections (otitis externa and acute or chronic otitis media). In the case of a combination of lesions in the outer or middle ear with lesions of the inner ear and/or the vestibulo-cochlear nerve and its neural pathways, mixed hearing loss occurs[1].

Hearing technology, in order to improve or enable auditory perception, is a key element of hearing rehabilitation. Hearing aids are electronic devices worn in the ear or behind the ear that amplify and transmit sound to the ear to improve hearing function. This is achieved through three basic components: a microphone, an amplifier and a speaker. Analog hearing aids capture sound energy, convert it into electrical signals that are amplified and transmitted through the ear canal to the eardrum. Digital hearing aids perform the same key function as analog hearing aids, but they can be programmed to suit individual audiological needs, allow for many additional features, and are generally the preferred option[1,5].

The bone-anchored hearing aid (BAHA) requires surgical implantation – a small vibrator is connected to a titanium screw (fixation) that is implanted behind the ear. These two components convert sound into a vibration via the screw, which then stimulates the cochlea. BAHA is used as an alternative to conventional hearing aids for conductive or mixed hearing loss. The cochlear implant is another alternative electronic hearing device that is used when a conventional hearing aid cannot be used. The cochlear implant is used to bypass the lack or damage of the hair cells of the inner ear[1].

In the context of the above, **the purpose** of this article is the narrative synthesis of the latest data on different types of hearing rehabilitation and the effectiveness of hearing devices.

MATERIAL AND METHODS

In order to achieve the set objective, an initial search was carried out for specialized scientific publications, identified from the *databases of PubMed, Hinari (Health Internet Work Access to Research Initiative*), *SpringerLink, National Center of Biotechnology Information* and *Medline*. The article selection criteria included contemporary data on hearing aids by the following keywords: „hearing loss", „unilateral hearing loss", „conductive hearing loss" and „sensorineural hearing loss", used in different combinations with the words „implant", „conventional aerial hearing aid", „implantable hearing device with bone conduction" and „cochlear implant" to maximize search yield.

For the advanced selection of bibliographic sources, the following filters have been applied: full-text articles, articles in English, articles published in the period 2000-2024. After a preliminary analysis of the titles, original articles, editorials, narrative synthesis, systematic and meta-analysis articles were selected, which contained relevant information and contemporary concepts regarding research and development activities and the effectiveness of hearing devices. In addition, a search was carried out in the bibliographic reference lists of the identified sources in order to highlight additional relevant publications, which were not found during the initial search in the databases.

The extracted data was systematically classified into sections, highlighting the main aspects of the contemporary view on advances in the development and efficiency of hearing devices.

In order to minimize the risk of systematic errors (bias) in the study, we carried out thorough searches in the databases to identify a maximum number of publications relevant to the purpose of the study, we evaluated only those studies that meet the validity criteria, we used reliable criteria for excluding articles from the study.

RESULTS

After processing the information, identified from the databases *PubMed, Hinari*, *SpringerLink, National Center of Biotechnology Information*, *Medline,* according to the search criteria, 265 articles were found that address the topic of management of patients with OMCS. After the primary analysis of the titles, 34 articles were qualified as possibly relevant for the given synthesis. After repeatedly reviewing these sources, 21 publications relevant to the intended purpose were finally selected. In the final bibliography of the paper, 21 articles were included, which were considered representative of the materials published on the theme of this synthesis article.

Definitions of degrees of hearing impairment for use in Europe were proposed by the European Commission in 1996. Hearing loss is defined as the average value of the pure tone of the four frequencies 0.5, 1, 2 and 4 kHz for the better ear. A hearing threshold ≤20 dB indicates normal hearing, while a hearing threshold of 21-39 dB marks mild hearing loss, 40-69 dB – moderate hearing loss, 70-94 dB – severe hearing loss, and ≥95 dB – profound hearing loss[6].

In developed countries, after high blood pressure and arthropathy, hearing loss (conductive and/or sensorineural) is considered the third predominant chronic disease and one of the main causes of disability among older adults, which considerably affects their physical and mental well-being. Worldwide, hearing loss affects about 466 million people (6% of the total population), including 34 million children. According to estimates, in 2050 this figure will increase to 700 million people. In Europe, the prevalence of mixed and conductive hearing loss is about 5%. Over 35% of people aged 60 and about 50% of those aged 70 have difficulty in daily activities as a result of hearing loss[3,7].

Clinical management of patients with chronic suppurative otitis media is focused on eradicating chronic mastoiditis and middle ear lesions to achieve a safe and dry middle ear space. Once this has been achieved, any resulting hearing loss can be treated. Patients are usually offered surgical reconstruction (tympanoplasty, osiculoplasty) and/or hearing aids depending on the type and severity of hearing loss[4,8].

A recent systematic review of tympanoplasty results confirmed that the air-bone gap is closed by ≤20 dB in only 70% of patients at long-term follow-up (≥12 months). Not all patients with chronic suppurative otitis media tolerate a conventional hearing aid, and they are contraindicated for patients with chronic otorrhea. Additionally, patients with more severe conductive hearing loss and mixed hearing loss may require bone-anchored hearing aids or even cochlear implants[4,7].

Hearing loss is a major public health problem and is associated with many negative outcomes, such as difficulties in communication, socialization, independence, interpersonal relationships, and poor quality of life. Hearing rehabilitation (conventional overhead hearing aids, implantable hearing devices with bone conduction or cochlear implants) in all types of hearing loss has a positive impact on quality of life, significantly improves hearing, speech intelligibility and patient satisfaction. Bone conduction hearing aids and cochlear implants produce greater improvements in quality of life than conventional overhead hearing aids[1,3,4,5,8,9,10,11].

Aerial conduction (conventional) hearing aids are the most commonly used devices for the rehabilitation of a patient's residual hearing loss after tympanoplasty. These devices are placed inside the external ear canal, capture and amplify sounds entering the outer ear to compensate for hearing loss. Patients with dry, safe ears with mild to moderate conductive hearing loss typically achieve excellent hearing rehabilitation using these devices[4,8].

The results of one study found that patients with hearing loss and conventional hearing aids significantly improved their social and emotional function ($p<0.0001$), communication function ($p<0.0001$), cognitive function ($p<0.01$) and depression ($p<0.05$). These results confirm the hypothesis that hearing loss affects quality of life, but these negative effects are reversible with conventional hearing aids[1].

Although recent conventional hearing aids have improved technically, there are still shortcomings. Limitations include distortion of sound and voice, irritation of the external ear canal by the mold or ear tube, acoustic *feedback*, frequent need for device maintenance, discontinuation of use due to discomfort, exacerbation of existing external ear conditions and environments caused by obstruction of the ear canal externally by the device. Despite the presence of failures and the fact that 15% of patients cannot use these hearing aids, the use of a conventional hearing device is possible after revision and obliteration of the unstable mastoid cavity. In the case of prolonged instability, initiated by the use of conventional hearing aids, a hearing aid with bone

conduction was used[12,13,14]. Additionally, patients with mixed hearing loss, especially those with higher degrees of sensorineural hearing loss, may experience greater benefit from a bone conduction hearing aid[4,8].

Bone conduction hearing aids transmit sound to the intact cochlea, bypassing the affected outer ear or middle ear. In terms of the vibration pathway to the skull, bone conduction hearing aids can be classified as supracutaneous or passive devices (Baha attract, Cochlear, Australia; Sophono Alpha, Medtronic, USA) and with direct or active bone stimulation (Baha connect, Cochlear, Australia; Ponto, Oticon Medical, Sweden; Bonebridge, MED-EL, Austria; Osia System, Cochlear, Australia) (figure). Devices that use the skin to transmit vibrations do not have a direct connection to the bone, and sound vibrations are transmitted to the skull through a transducer (vibrator) that is continuously pressed on the skin over the temporal bone by the pressure exerted by the helmet or glasses[9,14,15,16,22].

There are three main problems associated with passive bone conduction hearing aids: 1) discomfort associated with persistent pressure on the mastoid region to maintain good contact between the transducer and the bone with sufficient sound transmission, which can cause headaches, skin irritation, pressure wounds and head deformity, 2) cosmetic unacceptability, and 3) inconsistent sound quality due to attenuation and distortion as you passes through the skin and soft tissues and displacement of the transducer[2,9,16,17].

Direct-acting or active devices transfer vibration to the skull through direct contact through a abutment screw that penetrates the skin, while transcutaneously actuated devices use a magnetic coupling and transfer vibration stimuli through intact skin. The latter device is more aesthetically appealing, but it has some transmission losses. Direct-acting devices can be subdivided into: percutaneous active (Baha connect, Cochlear, Australia; Ponto, Oticon Medical, Sweden), transcutaneous active (Bonebridge, MED-EL, Austria; Osia System, Cochlear, Australia) and transcutaneous passives (Baha Attract, Cochlear, Australia; Sophono, Boulder, USA)[9,14,15,16,18].

The sound processor of percutaneous direct-drive devices is located externally and connected directly to the skull by means of a stump screw. These devices directly vibrate the temporal bone through the surgically implanted osseointegrated titanium screw and a skin penetration abutment. Although percutaneous direct-acting devices have favorable audiological outcomes, they are associated with certain disadvantages: the mechanism of skin penetration can cause infections, wound dehiscence, loss of fixation installation, and/or the need for revision surgery[15].

By comparison, transcutaneous bone conduction devices benefit from the fact that the skin on top of the implanted device remains intact. In the case of passive transcutaneous bone conduction devices, the actuator is located in an external housing, and the external vibration is transmitted transcutaneously to a skin-covered implant. Although these devices do not have the percutaneous abutment and associated complications, they require significant contact force and generate a lower gain than percutaneous devices. The force exerted by the sound processor can cause traces of pressure or skin pain, which have been associated with reduced adhesion of the device [15, 18]. Passive transcutaneous bone conduction devices are semi-implantable, so vibratory energy does not have to be transmitted through the skin. For many patients, a transcutaneous stimulation system with intact skin is a clear advantage over the percutaneous stimulation system[9,14,15,16].

The main disadvantages of direct-acting hearing aids are high contact pressure, screw extrusion, more difficult surgery caused by the large size of some implants, possible exposure of the sigmoid sinus and/or dura *mater*[16].

Therefore, bone conduction hearing devices are widely used for patients with persistent otorhea, otitis externa, and patients who cannot wear conventional air conduction hearing aids. Compared to bone conduction hearing aids held on the skull with a band, implantable bone conduction hearing aids have advantages – better tolerability and improved sound quality [10]. Patients with modest sensorineural impairment typically benefit from transcutaneous bone conduction implants, while those with intermediate hearing loss may also benefit from percutaneous bone conduction devices. For hearing impairment with moderate and severe cochlear hearing loss, active middle ear implants are recommended[16].

Bone anchor hearing aids (BAHA) were developed by Hakansson (Entific Medical Systems, Gothenburg, Sweden) and became available in the early 1980s. BAHA was subsequently acquired by Cochlear Ltd., Sydney, Australia. These devices arean alternative to conventional hearing aids with air conduction when physical complications (stenosis of the external auditory canal due to congenital malformation with agenesis or atresia of the middle ear) or medical complications (chronic otorhea, cavity after wall-down canal

mastoidectomy) interferes with the proper functional improvement of hearing. Bone-anchored hearing aids are indicated for use in people over 5 years of age with conductive or mixed hearing loss or unilateral profound sensorineural hearing loss (unilateral deafness). They are taken into account when the use of a conventional hearing aid with aerial conduction is not possible or is ineffective. Contraindications to the use of BAHA are unsatisfactory audiological criteria, poor bone quality (immature or abnormal bone) that could lead to osseointegration failure, susceptibility to infections, and chronic skin reactions[1,16,17,19,20].

BAHA is a percutaneous, semi-implantable, osseointegrated, bone conduction hearing device that includes a titanium fixation device permanently implanted in the mastoid bone of the skull and an external percutaneous sound processor (transducer). The sound processor is attached to the device with a titanium screw and a abutment that penetrates the skin. There are several models of sound processors available, the use of which depends primarily on the average thresholds of the patient's bone conduction. The BAHA system propagates sound directly to the inner ear through the skull, transforming the sound into the vibration of the titanium screw, thus bypassing the conductive mechanisms of the external auditory canal and the middle ear, pathological conditions of which do not interfere with hearing. BAHA has been developed to overcome the disadvantages of conventional bone conduction hearing aids – eliminating skin compression problems and improving rehabilitation by improving high-frequency sound transmission. BAHA devices involve more sophisticated signal processing to improve the clear perception of speech in the noisy environment. In addition, perfecting hearing aids in terms of aesthetics and size (to be as undetectable as possible) are two directions in which their design progresses. Recently, a more compact version of the sound processor has been created, increasing its visual appeal[9,14,16,17,19,20].

Currently, the surgical procedure of implanting BAHA devices takes 15-30 minutes and is performed under local anesthesia. The operative technique includes two components – the reduction of the subcutaneous tissue to create thin and immobile skin around the stump and the bony work to place the fixation device, made in such a way as to maximize the opportunity for osseointegration[20].

The bone conduction hearing aid has proven performance and advantages for patients with chronic otorrhea who cannot wear conventional air conduction hearing aids. Patients with bone conduction hearing aids were particularly impressed with the comfort, ease of use, cosmetic acceptability, reduction of otorea and/or skin irritation, and improved quality of life. In general, the result of direct bone stimulation is more effective than through supracutaneous stimulation, as soft tissues and skin dampen sound pressure at higher frequencies[2,9,15,19].

The sound quality of the BAHA is superior to traditional overhead hearing aids and passive bone conduction devices, and pain and/or discomfort is greatly diminished with the BAHA. The major requirements for implants are reduced auscultative defects, low failure rate, high reliability, low visibility, minimal surgical risk, and affordable price. BAHAs have a number of psychological and personal benefits: improved quality of life, comfort, practicality, cosmetics, anxiety and depression, more social interactions, and reduced social isolation, including in the elderly. Many studies have documented a high level of satisfaction in relation to sound amplification, listening to radio, television or music, clear perception of speech in quiet conditions, during conversation and in a noisy environment. The sooner the patient was equipped with BAHA, the more beneficial the results. In addition, BAHA devices usually do not require intensive hearing training after implantation and quickly provide the patient with a satisfactory hearing sensation[1,2,14,15,17,19,20].

The bilateral application of BAHA devices allows binaural sound processing. Binaural stimulation leads to an improvement in sound by 3-6 dB, a significant improvement in hearing, sound localization, clear perception of speech in silence and noisy environment. In addition, the use of bilateral BAHAs has been shown to significantly improve the patient's overall well-being (benefit) and subjective health status (quality of life)[2,17].

BAHA also has some disadvantages: it is more expensive than a conventional device and surgery is required for implantation. The complications reported in the literature were minor, and major complications are missing. Local skin reactions (2.4-38.1%), skin growth over the abutment (3-10%), osseointegration failure (0-18% in adult and mixed populations, 0-14.3% in pediatric populations), total implant loss (1.6-17.4% in adult and mixed populations, 0-25% in pediatric patients) are the most common side effects, which may require revision surgery (1.7-34.5% in adult and mixed populations, 0-44.4% in pediatric patients)[1,2,14,15,17,19,20,21].

According to the results of a systematic review of the literature, no major complications were found in patients with BAHA, only minor, with 33% reporting minor temporary skin infections and 17% – thickening of the skin around the implant. Thus, BAHA remains a safe, effective and reliable long-term treatment with minimal risks, even when administered in a smaller district general hospital[1].

Cochlear implants. A cochlear implant is an alternative electronic device used in severe or profound sensorineural hearing loss when a hearing aid with conventional amplification has not had or had little benefit or cannot be used. A cochlear implant includes an external system (microphone for sound detection; sound processor to convert acoustic information into a sequence of electrical stimuli and transmitter for transmitting stimuli through the skin to the implanted system) and a system implanted behind the ear (internal receiver for processing received stimuli; multiwire cable for connecting the receiver to the electrodes; and an electrode array that is inserted into the cochlea and stimulates neurons in the inner ear). The microphone picks up sounds that are converted into electrical signals by the stimulator receptor and sent by electrodes placed in the inner ear to the brain by directly stimulating the auditory nerve, bypassing the injured hair cells of the cochlea[1,3,5].

Cochlear implant is one of the most effective rehabilitation methods for sensorineural hearing loss, especially in cases where there is no functional effect with other hearing aids. The benefits of cochlear implantation, including for severe-profound hearing loss in children and adults, have been supported in recent studies, which have shown significant improvements in post-implant scores on audiological tests, cognitive domains, and quality of life, including in the long term. Cochlear implants showed the greatest improvements in speech perception and production, clear speech recognition in noisy environments, and audiometry performance compared to conventional hearing aids[1,3,5].

A retrospective study, conducted on 57 patients with cochlear implants, found that 24.6% of patients reported minor complications, the most common being vestibular disorder, and 17.5% – major complications, the most common being device failure. Thus, the cochlear implant remains a safe surgical technique for the rehabilitation of hearing loss[1].

Chronic suppurative otitis media was previously considered a contraindication to cochlear implantation. Recently, various surgical options have been adopted (the implant electrode can be inserted through the transcanal or middle fossa approach, bypassing the diseased middle ear and mastoid bone, elimination of inflammation by tympanoplasty, tympanomastoidectomy, followed by cochlear implantation, the implanted electrode can be inserted into the cavity without inflammation 3-6 months later – cochlear implantation in stages or elimination of inflammation and cochlear implantation can be performed simultaneously – implantation cochlear implantation in a single stage) for cochlear implantations in patients with chronic suppurative otitis media with a low complication rate[11].

In patients with a cavity after radical mastoidectomy, various potential problems should be considered: extrusion of the electrode matrix, the risk of recurrent cholesteatoma, and the possibility of spreading inflammation at the implant with the development of labyrinthitis and meningitis. However, these problems can be overcome by performing obliteration of the mastoid cavity. Thus, cochlear implantation is a safe and effective treatment for patients with severe to profound hearing loss secondary to chronic suppurative otitis media, as long as the appropriate surgical option is selected (depending on the type of disease, the presence of the open mastoid cavity and mastoid pneumatization)[11].

CONCLUSIONS

Hearing rehabilitation is performed with conventional overhead hearing aids, implantable hearing devices with bone conduction, or cochlear implants. Depending on the path of transmission of vibrations to the skull, bone conduction hearing aids are divided into two groups: supracutaneous or passive and with direct or active bone stimulation. Direct-acting devices are subdivided into: percutaneous active, transcutaneous active, and transcutaneous passive.

Aerial conduction (conventional) hearing aids are the most commonly used devices for the rehabilitation of a patient's residual hearing loss after tympanoplasty. Patients with dry, safe ears with mild to moderate conductive hearing loss typically achieve excellent hearing rehabilitation with these devices. Although recent conventional hearing aids have improved technically, there are still shortcomings: distortion of sound and voice, irritation of the external ear canal, acoustic *feedback*, discomfort and exacerbation of existing conditions of the outer and middle ear.

Bone-anchored hearing aids are excellent devices that have proven their usefulness over time if candidates were properly selected and surgery was performed meticulously. In audiological terms, bone-anchored hearing devices are clearly superior to conventional aerial conduction devices and passive bone conduction devices. The major drawbacks of this excellent hearing aid are the relatively high financial costs and the need for the implantation surgical procedure.

Cochlear implant is one of the most effective rehabilitation methods for sensorineural hearing loss, especially in cases where there is no functional effect with other hearing aids. The benefits of cochlear implantation, including for severe-profound hearing loss in children and adults, have been significant improvements in post-implant audiological test scores, cognitive domains, and quality of life, including long-term. Cochlear implants showed the greatest improvements in speech perception and production, clear speech recognition in noisy environments, and audiometry performance compared to conventional hearing aids.

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