Hearing loss in older adults: perspectives for rehabilitation with customised hearing aids and a follow-up fitting procedure

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***Abstract*— Hearing loss is a common problem in modern society due to the combined effects of noise, ageing, disease, and heredity. Approximately 31,4% of people over age 65 have hearing loss. We have designed new prototypes of CIC hearing aids based on the most advanced off-the-shelf technology. The hearing aid is fully customized to the patient needs. Very positive results in terms of functional recovery and acceptability have been obtained. The hearing aids used have showed enhanced features in term of rehabilitation for hearing loss in older adults.**

I. Introduction

Hearing loss is a common problem in modern society due to the combined effects of noise, aging, disease, and heredity. Hearing is a complex sense involving both the sensitivity of the ear as well as the ability to understand speech. Determining the prevalence of hearing loss depends on the type and degree of the loss, the area(s) of abnormality in the auditory system (middle ear, inner ear, brain, e.g.), noise exposure, and age [1]. Mild losses may not be noticed and even moderate losses may not impose a problem for people with excellent perceptual abilities and good coping skills. Hearing loss may be defined by self-report, by report of friends and family, and by hearing testing. Formal audiometric testing is the gold standard for diagnosis and treatment monitoring. Testing may be done at any age. Formal audiometry provides relatively precise information displayed by frequency and hearing level. A convenient summary of the audiogram is the pure-tone average (PTA) of the cardinal speech frequencies (500, 1000, 2000, 3000 Hz). As the PTA increases, the hearing ability decreases. Normal hearing for speech is observed for people with PTAs of 25 dB or less. At a PTA of around 40 dB in both ears, most people are functionally handicapped and benefit from amplification. Severe to profound losses range from PTAs of 75 dB and greater. At this level, hearing aids provide limited benefit and consideration of cochlear implants is generally given. According to 2005 estimates by the World Health Organization (WHO), 278 million people worldwide have moderate to profound hearing loss in both ears [2]. 80% of deaf and hearing-impaired people live in low- and middle-income countries. The number of people worldwide with all levels of hearing impairment is rising mainly due to a growing global population and longer life expectancies. Incidence increases with age. Approximately 31,4% of people over age 65 have hearing loss and 40 to 50 percent of people 75 and older have a hearing loss. Only 1 out of 5 people who could benefit from a hearing aid actually wears one [1].

Modern technology offers individuals with hearing loss options for rehabilitation and assistance with hearing. There are many types of hearing technologies, the main difference is in the type of energy transmitted to the hearing system. With the acoustic hearing aids the energy is transmitted by acoustic waves; with the bone hearing aids the energy is in the form of mechanical vibration transmitted to the mastoid bone. With the cochlear implant an electromagnetic signal is distributed by the intracochlear electrodes to the cochlea.

Acoustic hearing aid styles have continuously evolved over the past 50 years. From the body-style hearing aids available in the mid-1900s, through the behind-the-ear style hearing aids that became available in the 1960s, and through the smaller and smaller custom instruments that were developed in the 1970s, 1980s and 1990s, an emphasis has been placed on reduction in size and visibility. Today, the smallest hearing aids available are the completely-in-the canal (CIC) style hearing aids, which are worn deep within the ear canal. Besides being very cosmetically appealing, CIC style hearing aids provide significant acoustic benefit because the hearing aid delivers sound to a point very near the tympanic membrane (ear drum). This results in excellent high frequency amplification (good amplification of the high-pitched sounds that are difficult for most individuals with hearing loss to hear) [3]. The outer part of the ear, the pinna, provides amplification for the ear system, about 5 dB. The CIC hearing aids does not obstruct the outer ear, allowing to benefit from the natural acoustic amplification of the pinna. A deep fit in the ear canal leads to a reduction of the occlusion effect. The occlusion effect is caused by an increase in low frequency amplification and leads to the "head in a barrel sound" that you hear when your ear canal is plugged [4], [5].

There are also disadvantages to the CIC style hearing aid. The CIC cannot by worn by all hearing-impaired individuals because sometimes it cannot fit into the size and shape of their external auditory canals.

Because of the size of the CIC style hearing aids

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directional microphones cannot be incorporated. The benefits of directional microphones include improved signal-in-noise ratios. On the other hand the CIC hearing aids are placed into the ear channel and they use the natural directionality of the external ear.

Like the ITC style of hearing aids, CICs exhibit mechanical problems because they are worn completely within the warm, moist environment of the ear canal and are constantly exposed to ear wax [6]. Because CICs fit deeply in the ear canal, there is a decrease in bone-conducted signals and vibrations that create "hollow" quality to speech [7].

In the last years a new type of hearing aids have been developed, the Open Fit Hearing Aids. They are similar in style to BTE (behind the ear) aids: a shell sites above the ear and a wire travels down from there into the ear canal, but that's where the similarities end. Open Fit BTEs use a much newer technology than traditional BTEs, the case above the ear is much smaller and the whole aid is lighter.

The *"open"* in the name comes from the fact that aid's earpiece does not fit tightly into the ear canal, as with traditional BTEs, CIC, ITC and ITE models. The earpiece of an open fit hearing aid is a small, soft rubber cap, which is much more comfortable than the tightly fitting traditional earpieces.

There are two types of open ear hearing aids, acoustic thin tube open fit and speaker-in the ear (SIE) hearing aids. The acoustic thin tube hearing aid incorporates all of the electronic components in the plastic case behind the ear. The sound then travels down the acoustic thin tube into the ear canal. The SIE hearing aid moves the speaker from the plastic case down into the sound tip of the acoustic thin tube, thus requiring less gain at the ear level to produce the same output in the canal.

Acoustic thin tube open fit hearing aids are not appropriate for many people with a more severe hearing loss, but are ideal for those who have normal low frequency hearing and who are experiencing problems with high frequencies, which usually occurs with early hearing loss.

SIE hearing aids are appropriate for both a sloping high frequency hearing loss as well as a wide range hearing loss. Also, because the sound does not have to travel down a thin tube, the quality of the signal is improved so they become available to people with more severe hearing loss [8].

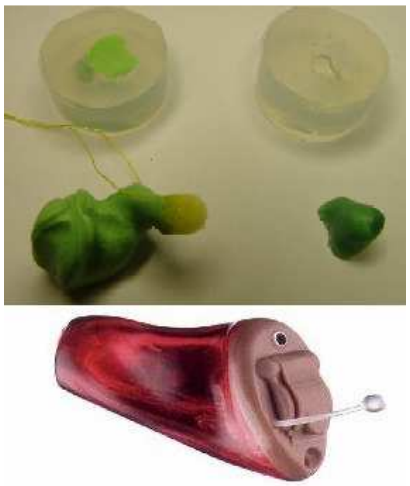

Fig. 1. The design of the shell is made from the ear channel impression, with the inner part laying in the bony zone of the ear channel, reducing the occlusion effect.

The use of acoustic hearing aids for compensating neurosensorial hearing loss is an effective solution for rehabilitation, but a specific effort should be devoted to customization and follow-up procedures in order to guarantee the best effectiveness and long-term acceptability.

II. Materials and Methods

Every hearing aid is equipped with four basic circuitry components, which include a microphone, an amplifier, a receiver, and a battery. The hearing aid microphone picks up sound waves, or acoustic energy, in the air. The microphone converts these sound waves from acoustic energy to electrical energy. The electrical signal enters the amplifier which elaborates and increases the intensity of the signal in proportion to the needs of the listener. The hearing aid receiver then converts the electrical signal back into acoustic energy perceived by the tympanic membrane, and then processed by the ear. The battery of a hearing aid supplies power to the hearing aid and can vary in size depending upon the style of hearing aid. In general, the larger the battery, the longer it will last [9].

We have designed CIC hearing aids (Completely In the Channel) with microphones, receivers and DSPs (Digital Sound Processors) of the latest technology. The DSP has enhanced features: 32 independent channels of signal processing, fine frequency resolution, adaptive fast feedback canceller and suppressor (time of reaction less than 1 s) and 8kHz bandwidth. The DSP compression system automatically reduces background noise levels and ensures speech at an audible and intelligible level [10]. The hearing aid is customised to the patient. The choice of the circuit components and the output power is based on the patient hearing audiometry (HTL hearing threshold level, UCL uncomfortable loudness level and MCL most

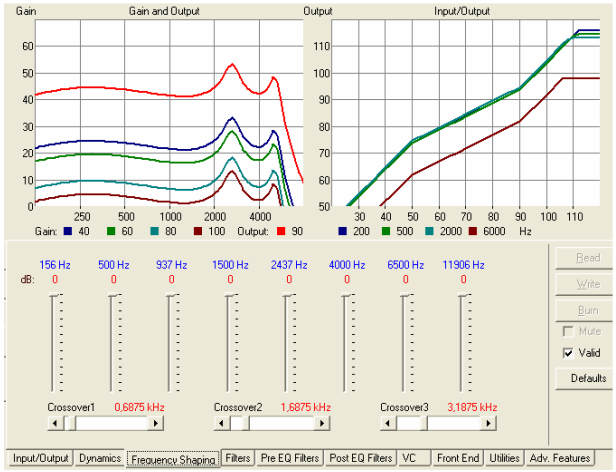

Fig. 2. The fitting software: here is showed one of the regulation windows. The frequencies range is divided in 8 channels, and the amplification can be regulated for each channel. The charts show the amplification gain (on the left) and the output/input (on the right).

comfortable level) and bone conduction test. The design of the shell is made from the ear channel impression (Fig. 1), with the inner part laying in the bony zone of the ear channel, reducing the occlusion effect [5].

The microphone and the receiver are electromagnetic and they have a limitation over the 9 kHz frequencies. The microphone sensibility is highly reduced above 9 kHz and so the receiver output. This limitation is common in all hearing aid available on the market, but considering that the voice frequencies are between 125 Hz and 6 kHz, the communication ability of the patient can be restored pretty well.

The ear wax is one of the most critical issues for a CIC hearing aid. The ear wax tend to obstruct the speaker hole reducing the output level, or even making the hearing aid silent. We solved this problem with a ear wax filter that can be changed by the patient himself, reducing then the hearing aid stops (Fig 3). The filters can be changed very easily. They need to be changed depending form the patient ear wax secretion, but usually they need to be changed every three months.

In some cases, behind the audiologists prescription, a ventilation is made. Thanks to the feedback cancellation system of the DSP, we can make a ventilation from 2mm to 4mm, obtaining great results especially in terms of the reduction of the occlusion effect.

The hearing aid is adjusted by a fitting software with a enhanced number of regulations. The range of frequencies is divided into 8 independent channels, so the amplification can be regulated for each channel (Fig. 2).

The amplification function (output/input) is divided into four ranges. For these ranges there is the possibility to change the amplification intensity for the different input sound powers. Then a compression can be set, in order to compress the external sound into the patient audible range. Also a set of filters can be activated by the software, like low-cut and high cut filters.

The fitting of the hearing aid is based on a follow-up procedure. The hearing aid is regulated firstly from the patient audiometry using the NAL-NL1 (National Acoustic Laboratory, Non Linear, Version1 [11]) formula, and then from 3 tests: the free field pure tone audiometry, speech understanding and the subjective measures of hearing aid performance [12]. The hearing aid is fitted again after 2 days, and then every month, for four months. Usually with the first two regulations we are able to set the hearing aid maching the patient needs. The other regulations have the aim to optimize the fitting and follow the patient changing conditions.

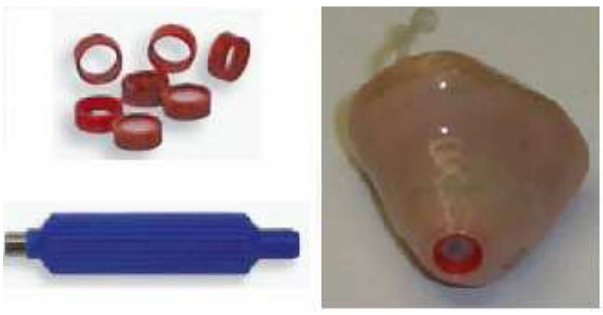

Fig. 3. Ear wax filtering system: ear wax filters (red) and filter change tool (blue). The filters can be changed very easily and fast, they usually need to be changed every 3 month.

The CIC hearing aid has been tested over 35 patients with age between 45 and 85, with the fitting follow-up procedure.

III. Results and Discussion

Very positive results in terms of functional recovery and acceptability have been obtained so far. The hearing aids used have showed enhanced features in term of rehabilitation for hearing loss in older adults. The follow-up fitting procedure lead to an optimized tuning of the hearing aid, e.g. the sound level is always optimized to be within the most comfortable dynamic range of the listener.

The fitting after the first month has been considered optimized by over the 80% of the patient, needing no more regulations in the other. The best results we obtained are on those patient that had a mono or bilateral hearing loss up to 70 dB. We are able to choose the smallest electrical component and to produce a very small and esthetical CIC hearing aid, practically invisible. The HTL (hearing threshold level) was restored between 10 and 15 dB, which is a very positive result. The patients were able to normally participate in a conversation and restored their communication capabilities. Some patient that already had other commercial devices, after they have tried our hearing aid, they decided to substitute the old one.

The hearing aid provides added benefit in suppressing background noise, enhanced speech intelligibility and has improved sound quality compared to state-of-the-art hearing aids. Due to the DSP that provides up to 18dB of additional stable gain the ventilation can be up to 4 mm, thus reducing the occlusion effect.

IV. Conclusion

The hearing aids continue to be developed to enhance the characteristics in terms of rehabilitation and acceptability. One important task is to extend the bandwidth to 8kHz, and make sound more natural. The DSP capabilities have to be developed, like the compression system that automatically reduces background noise levels and ensures speech at an audible and intelligible level. They should be able to better suppress background noise, enhance speech intelligibility, improve sound quality and reduce the occlusion effect. It's obvious that hearing aid technology and wireless technology will converge quickly.

The use of acoustic hearing aids to compensate some types of hearing loss is an effective solution for rehabilitation, but a specific effort should be devoted to customization and follow-up procedures in order to guarantee the best effectiveness and long-term acceptability. Hearing loss is highly prevalent in the older adult population [1]. Of those persons who would benefit from the use of hearing aids, only a small number actually own and use them.

The styles of hearing aids have drastically changed

over the past 50 years. The new technology that is on the market may allow hearing-impaired individuals who can not use CIC instruments (because of degree of hearing loss, irregularly shaped ear canals, or frustration with frequent repairs) to wear discreet instruments that provide acoustic benefits that are comparable to that of current CIC technology.

Technological advances in hearing aids and HATS (hearing aid technologies systems) have expanded the range of options available to improve the success of device use. Older adults today are more technologically familiar than in previous generations, and may be more receptive to the use of technology when it is matched to their specific needs. It is also important that older adults set goals for rehabilitation in partnership with the audiologist. Appropriate and comprehensive assessment, selection, verification, and follow-up by the audiologist are critical. Primary care physicians can assist older adults with hearing loss by ensuring they have access to the services of an audiologist.

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