Extraoral Osseointegration in Children

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Abstract Osseointegration is the described phenomenon of bonding between bone and certain metals, in particular, titanium. The "inert" bond is of significant strength and longevity and has been clinically applied in the different clinical disciplines for their varied applications. This article explores the extraoral applications of osseointegration in the anchorage of hearing aids and cosmetic prostheses. It covers the basic concepts, the indications for surgery and outlines the alternative options available and their advantages and disadvantages. In addition with regards to children, it outlines the contemporary approach, issues and controversies applicable to the paediatric population.

Key words Bone-anchored hearing aid; Osseointegration; Prosthesis implantation

Introduction

Osseointegration – this is the term that commonly describes the phenomenon of bonding that takes place between bone and certain metals, in particular, titanium. The "inert" bond so formed is of significant strength and longevity that its clinical use has long been exploited by clinicians especially dental surgeons in the retention of dental prosthetic crowns.

Osseointegration – How It All Began

The story began back in the 1950s when a Swedish researcher was then studying the behaviour of bone, bone marrow and the micro-circulation. These studies involved inserting titanium inspection chambers into rabbits ears. This allowed for the micro-circulation and bone to be studied *in vivo*. Titanium was used instead of the original tantalum for the inspection chambers as the latter was expensive and difficult to obtain – this was the first stroke of luck. To ensure that the observations were not affected by tissue damage, the inspection chambers were purposely screwed into the bone as gently as possible – this was the second dose of luck. After several months and having concluded his observations, the researcher now had to retrieve his "expensive" chambers. What happened next is indeed history and evolved our conceptual understanding of metals and bone, and especially titanium; the rabbit's bone had grown into the threads of the titanium chamber. The titanium chamber and bone behaved as a single unit; it was impossible to remove the chamber without drilling it off the bone. This was unheard of at the time; never before had bone formed such an intimate and strong bond with any metal.

Thankfully this outstanding turn of events was not dismissed by the researcher, Professor Per-Ingvar Branemark. An orthopaedic surgeon by training, he ascribed the term "osseointegration" to describe the titanium-bone bonding. The luck of using titanium, a gentle surgical insertion technique and the recognition of the significant

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Received August 6, 2003

accidental findings has led development into the different applications of osseointegration in medicine and dentistry to what we know today.

What is Extraoral Osseointegration?

Extraoral osseointegration harnesses this bone-titanium bonding property but applies its clinical use to regions outside of the oral cavity. Here it has been successfully utilised as an anchor and/or conduit for sound conduction for a variety of purposes conveniently categorised as follows:-

- Craniomaxillofacial implants and cosmetic prostheses.
- Osseointegrated bone-anchored hearing aid (BAHA™).
- Orthopaedic implants and prostheses.

This article will be focusing on the extraoral applications of osseointegration in the craniomaxillofacial region for cosmetic prostheses and audiological rehabilitation in general and special reference will be made to address the more specific issues pertaining to children.

Craniomaxillofacial Implants

Osseointegrated craniomaxillofacial rehabilitation is mainly concerned with cosmetic rehabilitation. Titanium implants can be strategically placed in any region of the facial skeleton or cranium whereby they form anchors onto which cosmetic prostheses can be attached securely to mask craniofacial defects.

Who Would Benefit?

The child who would benefit may have any of the following conditions which have resulted in the absence or loss of an eye, ear or nose.

- Congenital causes – anotia or microtia.
- Trauma e.g. road traffic accidents with significant tissue loss.
- Malignancy of the craniomaxillofacial region.

Of the above, in the paediatric setting, we are far more likely to encounter potential patients with congenital deformities like microtia than any of the other categories (Figure 1). The cosmetic prosthesis is tailored to each individual patients need. These prostheses can be uni-structural i.e. prosthesis of the external ear, or more complex multi-structural cosmetic prosthesis which may contain an eye, cheek and nose. The art of crafting the prosthesis is known as anaplastology and is discussed later.

What Are the Possible Options, Pros and Cons?

Several options are available when considering cosmetic rehabilitation.

1. Doing nothing.
2. Soft tissue reconstruction.
3. Cosmetic prosthetic rehabilitation.
   - Conventional method.
   - Osseointegration method.

Do Nothing

This option is usually the best default option to offer the child and their parents. Many a times the need for treatment arises from parental anxiety and their wish for their child to appear, understandably, like other children. As the other outlined forms of treatment do carry inherent risks of failure and a potential failure to satisfy expectations, doing nothing and waiting for the child to reach a consensual age to actively decide what he/she would like, is a very reasonable course of action.

Soft Tissue Reconstruction

If treatment is required, then invariably an autologous solution using the patient's own tissue would be the ideal

Figure 1 Microtia of left ear (Reproduced with the kind permission of Medical Progress[5]).

choice. Soft tissue reconstruction techniques with free tissue flaps, sculptured autologous cartilage grafts or local tissue flaps, etc. can be considered. The advantages are that they are usually maintenance-free and the use of autologous tissue reconstruction alleviates problems that may be encountered by foreign tissue reaction.

However it has to be realised that an excellent cosmetic result which duplicates the original form is rarely achieved, and function never achieved. Multiple re-fashioning surgical procedures are usually required in an effort to achieve an acceptable result, which in a child will require a general anaesthesia at each occasion. It is important here that parents receive a realistic appraisal of what is achievable and that surgical management may takes a course of few years to keep in step with the child's growth.

Cosmetic Prosthetic Rehabilitation – Conventional and Osseointegration Methods

Prosthetic rehabilitation may not be the most immediate solution that comes to mind for most parents, but to date, it remains the only method which can achieve a consistently satisfactory cosmetic result. Well made prostheses can be skillfully crafted to remain almost undetectable until removed. The prostheses do need to remain secure to provide their users with the confidence to wear them. The only investment that the patient is required to make would be to attend outpatient sittings to allow the anaplastologist time to craft the prosthesis and camouflage-match to his/her skin colour.

Secure retention of the prosthesis remains a key to success with this form of rehabilitation – it imparts confidence upon the patient to use them at all occasions. Conventional methods of retention may employ bands, glue, undercuts etc. All have their peculiar disadvantages. Bands can be dislodged if not tightly secured and they loosen with time and wear. Because of the tightness necessary for retention, they can cause pain and pressure necrosis at points of maximal contact. Another method of anchorage is to use glue; however glue can be irritant to skin. Undercuts (or grooves) cut onto the prosthesis as a retention technique is another method used. It is particularly good with hollowed defects with a rim e.g. orbital socket and the eye prosthesis, but this is not ideal for the ears or nose.

It is this aspect of rehabilitation that extra-oral osseointegrated titanium implants remain superior as an alternative anchoring method (Figure 2) . It provides a basis for a secure anchor if and when other methods are not considered appropriate. A gold alloy bar fixed onto at least two titanium abutments form a scaffolding onto which a prosthesis e.g. an artificial ear, can then be clipped on. Without pressure contact onto skin, this is painless.

The disadvantages of titanium implants are that daily toileting of the abutments and skin are essential to prevent infection supervening. This is not as difficult as it sounds as the implants can be treated very much like teeth, half within bone and half without, and a daily routine of gentle cleansing with soap and a soft toothbrush usually when taking their daily shower would normally suffice.

Cost remains an added factor. The implants and the gold alloy framework do not need to be changed. This is not so for the prosthesis which is required to be replaced approximately every 2-3 years as the colour fades. Many patients also request for two prosthesis with different skin complexions, one for Summer which is darker as their skin tans and another lighter coloured prosthesis to match their paler skin tone in Winter. However we need to balance the security of retention it provides against the cost bearing in mind that a cosmetic prosthesis is only invisible if it does not drop off. This certainly allows the child to fully participate and socialise more actively and physically e.g. in play and non-contact sports with confidence.

Anaplastology

Anaplastology is the art and science of restoring malformed or absent parts of the face or body by artificial means. In prosthetic craniomaxillofacial rehabilitation, this

Figure 2 Completed craniofacial surgery for osseointegrated ear prosthesis (Reproduced with the kind permission of Medical Progress[5]).

cosmetic art combines a variety of artificial materials e.g. silicone, glass etc. which are sculptured, worked and coloured with the artistic eye of the anaplastologists to recreate a life-like prosthesis for the defective region.

Taking an Impression (Figure 3)

Impressions are first taken of the defect area to recreate a "workbench" plaster replica of the defect area with its titanium implant sites.

Figure 3 Taking an impression (Reproduced with the kind permission of Medical Progress[5]).

This "workbench" replica allows work on the prosthesis to be done without the patient present as it may take days to craft a satisfactory prosthesis.

Frame-working (Figure 4)

A gold alloy framework onto which the prosthesis is to be fitted is designed using the workbench plaster replica.

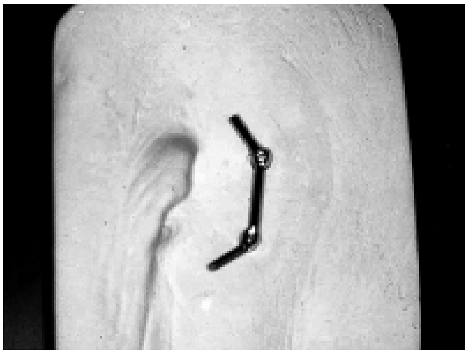

Figure 4 Workbench plaster replica with gold alloy bar framework (Reproduced with the kind permission of Medical Progress[5]).

The prosthesis would then be secured onto the gold alloy bar using clips. In defect regions with particularly difficult access e.g. shallow orbital defect, the magnetic cap retention technique may be used instead.

Acrylic Plating (Figure 5)

An acrylic plate is made which will be incorporated into the finished prosthesis. Clips are embedded on the medial surface of this acrylic plate so allowing the prosthesis to be securely held to the framework design.

Figure 5 Acrylic plate clipped onto gold alloy frame work (Reproduced with the kind permission of Medical Progress[5]).

Prosthetic Crafting

First a wax model of the patient's other good ear or from an ear of a close relative, is sculptured (Figure 6). From this wax sculpture, a plaster mould of the desired ear can be made.

Figure 6 Template of left ear made from wax. This wax template will be used to form the plaster mould (Reproduced with the kind permission of Medical Progress[5]).

The plaster mould (Figure 7) forms the basis from which a silicone prosthesis can be casted. The plaster mould can be used repeatedly to produce future identical casts for replacement protheses.

Figure 7 Plaster mould cast of left ear (Reproduced with the kind permission of Medical Progress[5]).

Colouring of the high grade silicone prosthesis involves intrinsic colouring (mixing colours into the silicone before curing), the addition of coloured flocking to imitate dermal vessels, etc which are essential before the silicone prosthesis is cured (Figure 8).

Figure 8 Colour matching of the silicone prosthesis to the patient's skin tone (Reproduced with the kind permission of Medical Progress[5]).

The cured prosthesis can then be given the final touches of realism by extrinsic colouring (painting the prosthesis to achieve a colour-match), addition of coloured hair, eyebrows, artificial glass eye, etc. before final delivery to the patient (Figure 9).

Figure 9 Securely attached left ear prosthesis (note that a small remnant of the microtia had been retained to serve as the tragus) (Reproduced with the kind permission of Medical Progress[5]).

Considerations of Extraoral Osseointegration in Children

Children are different from adults due to a variety of reasons. Congenital causes remain the commonest indication for seeking an osseointegrated solution, and practically, the reference here is almost always with regards to management of unilateral microtia, or bilateral microtia as seen in syndromic children e.g. Treacher-Collins. In general, childrens' cranial bones are softer and thinner than adults and hence the decision to implant is often ideally delayed until after the age of 10 years. By then, the bone should be sufficient thick to take the preferred 4 mm deep implant fixtures and of sufficient density (hardness) to achieve the expected implant success rate of 94% as seen in the adult population. In addition, by that age or thereafter, the child should also be relatively more matured and it is hope that they will be able to take an active part of the decision process together with their parents.

Another issue that sometimes the clinician may encounter is the decision dilemma when child and parents are certain that they wish a surgical reconstruction for their microtia. However, in spite of balanced counseling, they may remain undecided between choosing either an autologous cartilage reconstruction of the ear or an osseointegrated cosmetic prosthesis. The correct decision then is to reconstruct with autologous cartilage first. This is because extensive excision of the microtic ear remnant and the thinning of the peri-implant skin is vital to successful long term osseointegration of the titanium implants and achieving a seamless, contoured fitting of the prosthetic ear/s to the cranium. A failed and unsatisfactory autologous reconstructed ear/s can be surgically removed, the overlying skin thinned to the desired thickness and the area prepared to receive a successfully retained osseointegrated prosthesis.

The converse situation of converting an existing osseointegrated prosthetic solution to a remedial autologous cartilage reconstructed ear is not as simple; it would place the surgeon and patient at a distinct disadvantage as the existing thin and/or insufficient skin with fixed osseointegrated implants *in situ* do not form the ideal starting point for a successful autologous reconstruction.

Bone-Anchored Hearing Aid (BAHA™)

In otology, the titanium implant can be used to connect a hearing aid to the skull (Figure 10). It acts as anchorage as well as a vital conduit for conducting sound from the hearing aid to the patient's functioning cochlea via the implant and cranial bone (Figure 11).

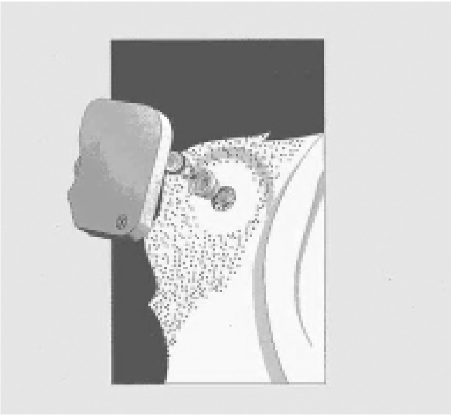

Figure 10 Schematics of BAHA (Reproduced with the kind permission of ENT ific).

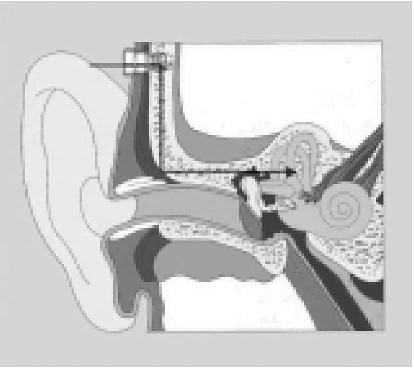

Figure 11 Simplified diagram demonstrating direct sound transmission through the BAHA implant to cochlea via bone (Reproduced with the kind permission of ENT ific).

By this route of sound conduction, the external and middle ear components are bypassed.

Who Would Benefit?

Any patient with a significant conductive hearing loss which requires aiding and who has a cochlear reserve hearing threshold up to about 60 dB HL and speech discrimination score better than 60%, could benefit. In children, the BAHA could be offered for the following conditions:-

- Congenital bilateral auditory canal atresia.
- Chronic discharging ears where a conventional air-conduction hearing aid would aggravate the discharge.

It should be noted that in children, otitis media with effusion of one or both ears are singly the commonest form of conduction hearing loss. The BAHA has no role in this condition as myringotomy and grommets are easy to do and very effective. The BAHA is indicated for the hearing rehabilitation of bilateral ear canal atresia e.g. as seen in syndromic cases like Treacher-Collins children. The audiogram (Figure 12) illustrates the hearing thresholds before and after aiding with a BAHA.

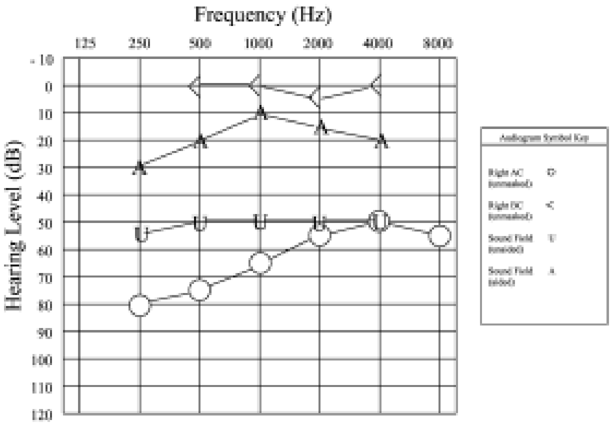

Figure 12 Audiogram demonstrating improvement in hearing before BAHA (U) and after BAHA (A) (Normal range of hearing -10 to +25 dB HL).

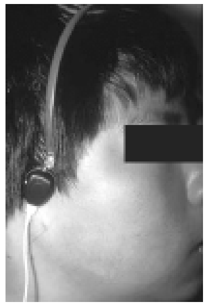

Figure 13 Conventional bone-conduction hearing aid (Reproduced with the kind permission of Medical Progress[5]).

My Patient Has Bilateral Ear Canal Atresia – What Can Be Offered?

The options available are:-

1. Do nothing.
2. Conventional bone-conduction hearing aid.
3. Surgical reconstruction of the ear canal.
4. Bone-anchored hearing aid.

Do Nothing

Our individual needs vary. In spite of their measured hearing impairment and potential hearing disability, some children cope and develop speech and language skills well and would not insist on a hearing aid; so to do nothing is a very reasonable and realistic option. Something can always be offered later if the patient's circumstances change.

In my opinion and practice, I do offer a hearing appliance rather than observe. A hearing aid/s can be used when the hearing situation demands it e.g. in school, and speech and language development remains uppermost in our minds as caregivers for children. Another observation to note is the relatively shy, withdrawn and introverted personalities of these bilateral atretic children who present for the first time to us in the teens – perhaps years of not being able to fully interact with family and friends and to be fully involved may have been a contributing cause.

Conventional Bone-conduction Hearing Aid

The default hearing aids of choice to prescribe are the conventional bone-conduction hearing aids (Figure 13). Sound picked up by the microphone is translated to the bony skull via a vibrator held pressed onto the surface of the skin usually over the mastoid region by a spring headband. There remains little discrepancy in the sound heard when properly applied other than slight reduction in the low frequency sounds and overall loudness intensity due to the intervening soft tissue. These aids remain relatively inexpensive in comparison to the BAHAs.

There are however several disadvantages. The whole hearing aid system is very visible. This can be a visible identifier of a hearing disability like the "white cane" for the partially sighted but most users find them too conspicuous and use them only out of necessity to hear. Firm pressure at the vibrator-skin interface is important for good sound conduction and is achieved by the spring headband. This poses two problems; firstly the pressure on the skin becomes painful with use over time e.g. 30 minutes to 2 hours and local skin pigmentation and pressure necrosis have been reported. Secondly pressure can be easily lost with movements of the head so physical participation in sports or a more active life-style whilst using the aid simultaneously can be impeded.

Surgical Reconstruction of the Ear Canal

Conventional surgical reconstruction of the ear canal has long been practiced to reconstruct the ear canal, the tympanic membrane and the ossicles. Reconstruction is the ideal and aspired choice but there are several points to consider.

In a congenitally malformed ear, the facial nerve, ossicles and cochlea are potentially abnormal in form and anatomy may vary. Preoperative CT scanning is mandatory to delineate these structures clearly. Nonetheless surgery carries a potential risk to these vital structures. The facial nerve may be injured and a perilymph leak at the cochlea can result in a "dead" cochlea, and hearing is irreversibly lost. Reconstruction of the ossicles may also be required as they may be congenitally fixed and the otological surgeon would be doing very well to achieve a closure of the conduction hearing difference to 10-20 dB HL from the preexisting 60 dB HL.

Another problem is maintaining the neo-external canal size – these are very proned to restenosis after surgery and re-drilling and re-grafting may be required. A postoperative preventative measure may be to prescribe an in-the-canal hearing aid which stents open the ear canal and doubles up as a hearing aid to maximise the final hearing gain. Even though this does work, otologists must surely question their rationale for surgery in the first place.

Because of the potential risks of the surgery and the relatively average results in hearing gain by most clinicians, it is a held view amongst some otologists that perhaps reconstruction should not be performed. Their argument lie in the fact that the BAHA (which is described below) is a simple one-off procedure to undertake, without risks and has a consistent aided hearing gain of 50 dB HL.

Bone-anchored Hearing Aid (BAHA) – The Extraoral Osseointegrated Solution

The bone-anchored hearing aid is fast becoming established as the option of choice (Figure 14). Anchorage is fixed and secure without discomfort (Figure 15). Sound conduction is not affected by vigorous head movements during sports unless the hearing aid is accidentally knocked off its abutment receptacle. The sound heard is clear and not attenuated by any intermediary soft tissue. In fact, new BAHA users have consistently expressed their satisfaction with the sound heard and their preference for the BAHA system when compared to their previous conventional bone-conduction hearing aids. Another significant advantage is its size – the BAHA is a smaller and less conspicuous device. It is easier to be concealed by the hair at its recommended site just behind the ear.

The drawbacks of the BAHA system are the relatively higher one-off costs for the titanium implantation and the unit cost of the hearing aid. The average life of the hearing aid has been approximated to be three years depending on its use and care by the user. In children, the life expectancy may be anticipated to be shorter due to their more active and care-free play. Like the implants for the prostheses, daily attention of the implant site is also required and often can be cleansed during showers.

In conclusion, its advantages probably outweigh its disadvantages. The clarity of sound heard, a more active lifestyle with simultaneous unimpeded audio reception and easily hidden hearing aids were preferred by converts to the BAHA. Recent studies have also shown a significant improvement in sound localisation and speech recognition when binaural (bilateral) BAHAs are implemented.

Figure 14 14 years old boy with left BAHA.

Figure 15 BAHA abutment in continuity with an osseointegrated titanium implant in bone (not visible).

Further Considerations of the BAHA in Children

Speech and language development occurs early in our life, and in children with a hearing loss, efforts are taken to document the hearing loss type and degree early so that hearing can be appropriately optimised. The experience with the cochlea implants for deaf children is a good example; when it was first introduced, surgery was performed on the adult deaf population. With time, experience showed that the best cochlea implantees were the children and the younger they were implanted, the better were the results. This has been related to the auditory plasticity of the auditory cortex and supports the notion that hearing rehabilitation should begin as early as possible.

The BAHA is usually recommended to be implanted at age 5 years and beyond, again to account for the relatively softer and thinner skull bones of children who require it. Certainly otologists realise that inserting the BAHA younger could be more beneficial, and to date, the youngest BAHA recipient was implanted at age 6 months with some modification to the technique to account for the thinner bone. In the author's own series of 10 paediatric BAHA implantees in Hong Kong Chinese children with bilateral ear canal atresia aged between 5 years and 15 years at implant, only one child required a second but successful revision BAHA due to his soft and thinner bone (he was the youngest of the group). All the children (and their parents) preferred the BAHA to their previous conventional bone conduction hearing aid claiming clarity of sound, comfort of use and inconspicuousness as their reasons. Interestingly two from this BAHA converted group would not use their conventional bone-conduction hearing aids when their BAHAs were sent away for repair.

The remaining issues relating to BAHA in children are bilateral BAHAs and paediatric BAHA for unilateral total hearing loss. Bilateral BAHAs in patients with bilateral microtia and ear canal atresia has been shown to improve speech recognition and sound localisation by 10%. A problem here is the added cost of implanting and maintenance.

The use of the BAHA for unilateral total hearing loss, irrespective of aetiology, will surely become an option for children in the foreseeable future. Known as BAHA for single sided deafness (SSD), this is currently undergoing investigation in adult populations. The logic behind it is simple – the BAHA is implanted on the side of the "dead" ear; it processes the sound from the deaf side and conducts it through the bony cranium to the good cochlea on the contralateral side which is stimulated. Adult recruits in SSD trials worldwide, including the author's, have been very excited with being able to "hear" again. If this proves to be as good as it sounds, it would only be a matter of time for our children with SSD to benefit from the extra-osseointegrated BAHA.

Conclusion

The extraorally osseointegrated titanium implant is very welcomed addition to solving some of the problems we faced in prosthetic retention and audiological rehabilitation in general. Children have softer and thinner bone and so the implant success rate is only marginally lower. Nevertheless its benefits are proven, the surgery simple and relatively complication free when compared to other available options. Perhaps it will be these essential points that will prove themselves over time to be the crucial factors in deciding for an osseointegrated solution for our children in need.

Further Reading

1. A Matter of Balance. Williams, E. Akademiforlaget, 1992.
2. Craniofacial Prostheses - Anaplastology and Osseointegration. P-I Branemark, MF de Oliviera. Quintessence Books 1997.
3. The Birmingham bone anchored hearing aid programme 1988 - 1995. J Laryngol Otol 1996;110 (BAHA Suppl 21):7-12.
4. It works – the patient say so: The evidence base for aural rehabilitation with bone anchored hearing aids. J Laryngol Otol 2002;116(Suppl 28):1-47.
5. Gordon Soo. Osseointegration: Applications in cranio-maxillofacial rehabilitation and otology. Medical Progress 2000; 27;19-26.