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Background

The **11th European Symposium on Paediatric Cochlear Implantation (ESPCI)** took place in Istanbul, Turkey, on 23–26 May 2013, presided over by Prof. Dr Caglar Batman from Marmara University in Istanbul. Around 1800 scientists from 85 countries attended, representing otorhinolaryngology, audiology, biomedical engineering, radiology, genetics, psychology, and speech therapy. ESPCI symposia have been held every 2–3 years since 1992. Over the four days of the conference there were four satellite symposia (including invited lectures), 16 seminar lectures, 4 plenary lectures, 28 discussion panels/round tables, 12 debates, and around 400 free paper presentations. In addition, almost 700 posters were presented.

Eleven staff members of the World Hearing Center of the Institute of Physiology and Pathology of Hearing (WHC IPPH) in Warsaw participated in ESPCI 2013, sharing 27 oral presentations and 9 posters (In 2009, the 9th ESPCI was organized by WHC IPPH). The work involved almost all aspects of diagnostic procedures and therapy for patients with hearing impairments, surgical procedures, and devices used to enhance or substitute hearing; in addition there were outcomes of neuroimaging studies presented, performed at WHC IPPH to evaluate the structure and the function of the auditory system.

Oral Presentations

On the first day of the conference, four leading manufacturers of hearing implants – Advanced Bionics, Neurelec, Cochlear, and Med-El – held plenary symposia to present their new products and developments. Among others, the following products were discussed: a) Nucleus 6, a new cochlear implant by Cochlear, which, with the magnet removed, is MRI-compatible and is equipped with a new automatic sound-regulating system; b) the RONDO wireless speech-processor by Med-El, equipped with novel sound-coding strategies, FP and FS4, that enable transmission of fine structure information; c) EVO, a new flexible electrode array by Neurelec for cochlear implantation in partial deafness.

Oral presentations shown at ESPCI 2013 covered several themes that are all briefly presented in the following paragraphs. Particular attention here is given to presentations delivered by specialists from WHC IPPH, Poland.

Genetics

Over 50% of hearing losses are genetically determined. Mutations and deletions in about 100 genes appear to be the underlying cause. Inheritance can be either autosomal (primary recessive) or related to modifications in the sex-determining *X* chromosome. In rare cases these are mitochondrial mutations that lead to a hearing impairment. Genetically determined hearing loss is also present in 100 syndromes, such as Usher, Pendred, Jervell and Lange-Nielsen, Waardenburg, and Stickler, which involve various complex developmental impairments (eye, lung, kidney). Finally, there are also congenital defects in ear structures that might underlie hearing defects, such as Mondini aplasia, Scheibe dysplasia, and enlarged vestibular aqueduct syndrome (EVAS).

At ESPCI 2013 oral presentations were delivered by Prof. Guy van Camp from the University in Antwerp, Prof. Mustafa Tekin from the University in Miami, and Prof. Shinichi Usami from the Shinshu University School of Medicine. All specialists emphasized that finding time- and cost-effective methods for auditory genetic screening remains a challenge. Such methods might allow effective prophylactic measures to be introduced.

Genetic research at the WHC IPPH focuses on mutations in mitochondrial DNA in isolated hearing impairment, as well as mutations in the GJB2 gene in isolated autosomal hearing loss. The prevalence and the mechanisms of these genetic phenomena have been explored and assessed in the Polish population [1,2].

Cochlear Implantation

Partial deafness

Results of studies done at WHC IPPH in assessing aspects of cochlear implantation in partial deafness were covered in the following oral presentations: *Long Term Results of Partial Deafness Treatment (*Prof. Henryk Skarzynski*)*; *Hearing Preservation Classification* (Prof. Henryk Skarzynski); *Hearing Preservation Surgery* (Piotr Skarzynski); *Electrode Designs for Optimal Stimulation* (Piotr Skarzynski); *Audiological Results Of Electroacoustic Stimulation* (Anna Piotrowska); *Outcomes Of Delayed CI In Prelingual Hearing Loss* (Anita Obrycka); *Academic Achievements Of Cochlear Implantees* (Adam Walkowiak).

In recent years indications for cochlear implantation (CI) have been extended to include sensorineural deafness with some natural hearing preservation (typically at high frequencies). This change followed long-term observations indicating considerable benefits for these patients, as well as the emergence of new methods of preserving ear structures during and after surgery. The recommended treatment for such impairments (partial deafness) is now a combination of electric stimulation (cochlear implant) and acoustic stimulation. If the latter is provided by a hearing aid, the system is termed electro-acoustic stimulation (EAS). If there is no acoustic amplification required for natural hearing, then it is possible to introduce the CI array only partially into scala tympani, limiting stimulation to high-frequency regions (EC, electric complement) [3].

A program of partial deafness cochlear implantation (PDCI) was introduced at WHC IPPH some 16 years ago. First results in adults (*n*=16) were presented in 2000 at the European Federation of Oto-Rhino-Laryngological Societies conference [4] The same year, the first findings in children (*n*=52) were shown at ESPCI in Antwerp [5,6]. In 2009, at the 9th ESPCI in Warsaw, Prof. Henryk Skarzynski presented a classification system of partial deafness treatment based on tone audiometry testing. In addition, in 2010 he suggested a new classification scheme for describing the extent of hearing impairment based on the frequency bands 125, 250, 500, 1000, 1500, and 2000 Hz [3,7,].

At the WHC IPPH, cochlear implantation is performed using the round window approach. Surgical techniques include a 6-step procedure, described in [8,9]. Implantation via the round window can be safely done using flexible 20–28 mm electrode arrays and new 2 mm diameter electrodes [10]. Extreme caution is recommended during cochlear implantation, since any damage to the fragile cochlear structures might result in degeneration of neural cells (spiral ganglion) whose proper function is required for CI benefits to occur.

At the WHC IPPH, hearing preservation has been achieved in 70–90% of patients [3]. This measure is based on the difference between tone audiometry prior to and after cochlear implantation. A decrease of 0–10 dB is interpreted as full hearing preservation, with 10–30 dB considered partial hearing preservation. These criteria are only broad indications, as the results are strongly affected by the patient's original hearing levels. However, specialists from the Hearring association (*URL:http://www.hear-ring.com/*) all now agree that a common classification of CI results is crucial. At ESPCI 2013, WHC IPPH presented a new method of assessing the degree of hearing preservation, to be published this year.

Results for three groups of WHC IPPH patients after PDCI were shown at ESPCI 2013. These were based on 1562 cochlear implant users with partial deafness. In one study, Prof. Skarzynski presented results in 29 patients with postlingual deafness after 8–10 years of using the electro-acoustic system. To assess their performance, a test of monosyllable word recognition in quiet and in noise was used. In quiet, an improvement was seen of 40–90%, as soon as 6 months post-implantation. After this time, a plateau effect was found. In some patients, however, there was a learning effect seen up to 5 years post-CI (from 10 to 70%). Average deterioration in tonal audiometry in the implanted ear amounted to about 12 dB (9 years post-CI). In the non-implanted ear, there was about 20 dB deterioration.

In another group of patients, some 25 prelingually deaf children recommended for EC or EAS treatment, implantation was done at an age of 4.2–16.9 years. Monosyllable word recognition in quiet and in noise was evaluated 1, 3, 6, and 12 months following activation of the speech processor [11]. Improvement was found in speech understanding, which however did not correlate with age at implantation. There was an additional correlation between tone audiometry at 125, 250, and 500 Hz prior to CI and speech improvement post-CI.

Some 18 other children were recommended for electro-acoustic and electric complement treatment and received their cochlear implants at an average age of 9.9 years (4.1–15 years). At the time of the study, they had been using the device for 5.9 years (5.1–7.4 years). Results for monosyllable recognition tests improved in quiet from 30 to 70% and in noise SNR +10 dB from 5% to 45%,a year after CI [12].

Despite the high effectiveness of cochlear implants, patients find it hard to communicate in noise and in competing sounds, as well as report difficulty in hearing prosodic cues and appreciating music. The experience of the WHC IPPH is that the optimal solution is often a combination of electric and acoustic amplification in one ear. This is probably due to the acoustic stimulation providing high-frequency resolution and fine structure of the sound, maintaining original fundamental frequencies.

The results presented at ESPCI 2013 by international medical centres, including universities in Hannover (Prof. Thomas Lenarz) and in Freiburg (Prof. Roland Laszig), indicate high hearing preservation levels when using both deep and partial implantation of flexible cochlear implant arrays. Saving ear structures, even if the residual hearing is non-functional, is crucial. In the future, a method might be developed for regenerating hearing cells and the spiral ganglion. Both centres believe that high-frequency partial deafness is best treated with the EAS system.

Single-sided deafness

Professor Angel Ramos from Gran Canaria emphasized in his lecture the need to distinguish between asymmetric deafness, with different levels of hearing impairment in both ears, and single-sided deafness in which one ear retains normal hearing. Recently, an increasing number of medical centres worldwide have suggested cochlear implantation as a treatment method to their patients who have postlingual single-sided deafness. The treatment was awarded the European CE certificate in May 2013 (*http://ec.europa.eu/enterprise/policies/single-market-goods/cemarking/*).

As Prof. Paul van de Heyning showed during ESPCI 2013, there have already been several cochlear implantations performed in patients with single-sided deafness at the Antwerp University Hospital. When speech and a competing sound were presented in various combinations, patients showed consistent benefits in speech comprehension across all conditions. Best performance was found for sound-coding strategies that provide fine structure information. He suggested that by evaluating the single-sided deafness patient's performance after CI, new insights can be gleaned concerning auditory processing in various frequency bands.

At the WHC IPPH, cochlear implantation in single-sided hearing impairment has been recently done in several patients. The outcomes are promising.

Bilateral stimulation

Two presentations delivered by WHC IPPH personnel focused on bilateral cochlear implantation: *Bilateral hearing in pre-school children with cochlear implants* (Anita Obrycka) and *Fitting for Bilateral CI* (Artur Lorens).

Bilateral auditory stimulation affords more efficient sound localization and better speech recognition in quiet and in noise. However, programming of the two devices is demanding. Studies are being performed worldwide to compare auditory performance in patients with bilateral cochlear implants and in those using a bimodal set combining a cochlear implant in one ear and a hearing aid in the second ear. It appears that the CI/CI and CI/HA combinations provide similar results in intonation perception, syllabic accent recognition, and understanding of syntax. Bilateral cochlear implantation, however, seems to have the advantage in terms of binaural functions, such as loudness summation and the effect of redundancy. Key lectures covering bilateral auditory stimulation were provided by Prof. Paul Govaerts from the University of Antwerp, Prof. Susan Waltzman from the University of New York, Prof. Stefan Brill from the University in Innsbruck, Prof. Domenico Cuda from the University of Piacenza, and Prof. Michal Luntz from the University of Haifa.

Outcomes from 31 children, patients of WHC IPPH, with sequentially implanted bilateral CIs were presented at the symposium. In this group, the first implantation was done at an average age of 1.9 years, the second at an average age of 5.9 years, and at the time of the study the average age was 7.9 years. To assess language functions (speech recognition threshold in free field) the Polish adaptation of the Adaptive Auditory Speech Test for children older than 3–4 years (by Prof. Fransa Coninxa from the University of Koeln) was performed. Both in quiet and in noise, patients with two functioning implants obtained significantly better speech understanding compared to those that had only one CI turned on. There was a significant correlation between the time interval between the two implants and the difference in results obtained with a single functioning implant.

Another study compared 59 users of unilateral cochlear implants and 60 children with normal hearing. Both groups were matched for age, including age at the first and second cochlear implantation (average age at first CI was 2 years). Age at the time of analysis was 6.2–7.6 years. Speech recognition in users of two cochlear implants was statistically higher, when compared to patients with one-sided devices [13].

Therapy, evaluation of benefits, prognostic factors

In the field of rehabilitation after cochlear implantation and the evaluation of benefits, there were two oral presentations from WHC IPPH: *Assessment of quality of life after CI* (Anita Obrycka); *Factors influencing the auditory development in cochlear implanted children* (Anita Obrycka); *Academic Achievements Of Cochlear Implantees* (Adam Walkowiak). Details are given below.

Research done in other international medical centres, such as the University of Edinburgh (Prof. Sue Archbold), shows that in older children, as in adults, the real benefits from CI become apparent from subjective assessments of the initial impairment and its treatment outcomes, particularly the quality of life after the implantation. Implanted children appreciate the ability to actively engage in sport, to recognize environmental sounds, and to better understand and produce speech. Parents (or caretakers) consider collaboration between the hospital (were the diagnostic work-up is done) and the school as critical. As Professor Archbald indicated, a new direction in this field of research is to collect opinions from patient's siblings who are of similar age [14,15].

When assessing post-operative outcomes, the view of specialists from WHC IPPH, as presented at ESPCI 2013, is to take into account the relationships between hearing performance and numerous psycho-social environmental factors. The standard tool to assess the performance in children who receive cochlear implants before the age of 2 years is the LittleEars questionnaire, which is completed by children. The questionnaire contains 35 questions, and requires simple *yes* or *no* answers. Studies done in 123 patients from WHC IPPH show a positive correlation between auditory development, as measured with LittleEars, with the duration of CI use. In the first post-operative months, the outcomes seem affected by the hearing preservation levels (the higher they are, the better the auditory outcomes), as well as the patient's experience with hearing aids. The best results were achieved by patients 16 months post-CI, which indicates that the adaptation of the auditory system is dynamic and prolonged. In addition, parents report improvements in their children's environmental sound detection, speech

understanding, articulation, lexicon development, quantity and quality of social interactions, and self-esteem [16].

In older CI-users, language development is also assessed. It relates to learning abilities and emotional development (self, emotion regulation, identity), and finally determines a person's social involvement. In several presentations at ESPCI 2013, three fundamental aspects of language were emphasized which should be longitudinally followed after cochlear implantation. These were phonological awareness, lexicon size, and language experience (Dr Urlika Loefkvist from the Karolinska University, Dr Cecilia Nakeva von Mentzer from the University in Linköping, Dr Francois Bergeron from the University of Quebec). It was also shown that the number and the quality of spoken messages directed at the child are vital, as passive and active language abilities are strongly related.

At ESPCI 2013 patient's results were measured using language tests. These involved auditory analysis and synthesis, recognition and production of rhyme, picture naming (e.g. Peabody test), and a test for reception of grammar, reflecting verbal intelligence and vocabulary. It was also shown that cognitive functions, such as memory, attention, and drawing non-verbal conclusions might be affected by exposure to CI stimulation; development of these functions might determine benefits from an implant.

As regards forecasting cochlear implantation outcomes, several specialists suggested that later diagnosis, later age of cochlear implantation, shorter experience with the device, and lower levels of hearing preservation lead to more limited benefits. Patients who receive implants at an age younger than 1 year often develop language abilities comparable to children with normal hearing. In addition, it has been shown that auditory and verbal abilities develop during the first two years after CI, with audio-visual skills improving up to three years post-operatively.

As regards rehabilitation, the most often presented approach was 'auditory verbal training' (AVT), which is offered in clinical centres in numerous countries (e.g. Great Britain, USA, Canada, Australia, Russia). AVT is based on collaboration between specialists, parents, and teachers of the patient. Each patient is approached individually. It is strongly recommended to create natural everyday situations when the child is exposed to auditory stimulation, and to provide it in combination with other modalities. It is important that the child should use their natural preserved hearing as much as possible. Specialists from WHC IPPH have attended special training and are certified experts in AVT.

Dr Deborah James presented the 'Video Interaction Guide', a program used routinely at Nottingham University Hospital. The program provides feedback to the caretaker about their own voice, gestures, and initiatives taken in communicating with their hearing-impaired child. This information is useful to the parent (or caretaker), as the literature shows that non-verbal communication and the caretaker's sensitivity to it shapes the child's expressive language development. Studies by James done in the British population suggest that best CI-outcomes are due to optimal parental engagement. This is even when the parents' intellectual abilities are below the normal range and they are of low socio-economic status.

In a number of presentations (e.g. by Adam Walkowiak from WHC IPPH) it was further emphasized that the school environment should be sensitive to the patient's special needs, providing auditory stimulation and exposing the child to social interactions. Nowadays there is a tendency, as in Poland, to place hearing-impaired children in general schools. It has been suggested that in special schools children with hearing loss can behave hyperactively and obtain lower grades [17].

Telefitting

A Polish scheme for remote programming of cochlear implants and for rehabilitating users was first implemented in 2000. The WHC IPPH established the Internet program „Slysze, Mowie, Widze" (I hear/I speak/I see) which can be used to efficiently and reliably assess individual abilities. In the years 2004–07 the scheme was further enhanced by offering remote rehabilitation and telefitting. From 2008 the system has been refined and implemented as the National Telerehabilitation and Teleaudiology Network. There are 16 Polish clinics involved now, as well as a centre in Odessa, Ukraine. The WHC IPPH received financial support from the Norwegian Mechanisms Programme to continue development of the telefitting network.

A standard remote consultation involves an interview, tone audiometry, free-field speech audiometry, and objective auditory tests such as evoked cortical auditory potentials (ECAP), electrically elicited stapedial reflex (ESR), telemetry, and psychoacoustic measurements (e.g. loudness growth functions). In 2007 the system was assessed in a multicentre study involving medical units from Warsaw, Freiburg, Las Palmas, Thessaloniki, and Mechelen in which parents of the children that participated in the teleconsultations were interviewed. The caretakers expressed satisfaction with the service, emphasizing that it was cost- and time-efficient. The absence of travel over long distances means that the tiredness of the child can be excluded as a factor. Teenage and adult users of cochlear implants (n=94, av. age 34.5 years, CI-use 5 months) rated the method to be as effective as an individual consultation and said they would attend another remote session. Potential funding sources to cover the costs of the network were evaluated, as well as potential channels to promote the method.

Arkadiusz Wasowski of WHC IPPH delivered two presentations about the network: *National Network of Teleaudiology for Pediatric Cochlear Implant Recipients* and *Expert telefitting mode for cochlear implant recipients,* both of which were well received by the international audience.

Other Auditory Implants

Bone-anchored implants

New strategies are constantly being developed in the field of bone conduction implants. Noteworthy are ways of enhancing the transmission of high frequency sounds and the implementation of directional microphones, the aim being to improve speech recognition. The main problem with bone-anchored aids is that patients do not use their devices regularly, as they feel socially stigmatized. Moreover, bone-anchored implants provide limited benefits for spatial hearing and in noisy situations (from presentations by Prof. Joachim Mueller from the University of Wuerzburg and Prof. Rolanda Laszig from the University of Freiburg).

During ESPCI 2013, several centres (WHC IPPH, Poland, and Prof. Klaus Boeheim from Landesklinikum, St Poelten, Austria) showed the first satisfactory results of patients using a new bone-anchored system, Bonebridge (Med-El, 2012), that is indicated for adult patients with conductive or mixed hearing impairments or single-sided deafness, with or without associated malformations of the outer and middle ear. Aesthetics is the main advantage of the system, with the inner portion totally implanted. The system can be relatively quickly activated post-operatively. Bonebridge has already been used in centres in Germany, Great Britain, Canada, and Australia.

The presentations by the WHC IPPH were delivered by Maciej Mrowka: *Current Perspectives Of Bone Conduction Hearing Aids, Long term results in patients with hearing loss, using Bone Anchored Hearing Aids (BAHA); Hearing loss treatment in various acquired and congenital ear malformations with the use of Bone Anchored Hearing Aids (BAHA) in children*; *BAHA application in single sided deafness (SSD) in children*; *Application of Med-El Bonebridge in adult patients with congenital and acquired hearing loss – first experiences.*

Middle ear implants

Active middle ear implants (AMEIs) can be either fully or partially implanted. Those most commonly used are the Vibrant Soundbridge (VSB; Med-El), MET (Otologics), Carina (Otologics/Cochlear), Maxum (Ototronix), and Esteem (Envoy Med Corp). AMEIs are indicated when reconstruction surgeries are of no benefit to the patient with sensorineural deafness.

At ESPCI 2013, the WHC IPPH documented how VSB is its most commonly used AMEI (true also worldwide) [*Stimulation of the round window membrane by Vibrant Soundbridge without interposition of the fascia – surgical implications* (Prof. Henryk Skarzynski); *Audiological Aspects of Middle Ear Implants* (Lukasz Olszewski); *Outcomes of Implantable Hearing Aids* (Lukasz Olszewski)]. The system is indicated for adults with one-sided or binaural stable sensorineural hearing loss, with no benefit from standard hearing aids and 50% monosyllable word recognition (65 dB SPL). Other candidates are those with conductive or mixed hearing loss. Contraindications include infections, effusion, and anatomy that excludes implantation of an FMT transducer. VSB is substantially more effective than hearing aids if the patient is allergic to any aid elements and/or experiences an occlusion effect.

Findings of international medical centres indicate that VSB confers considerable benefits to children and to adults, even when there is microtia or chronic ear disease. Prof. John Martin Hempel from the Ludwig Maximilian University in Munich showed that using both VSB and surgical reconstruction is a good solution to atresia.

In Landesklinikum in St Poelten (Prof. Klaus Boeheim), 250 VSB surgeries have been performed for high-frequency sensorineural deafness, as well as for conditions with mixed aetiology, both unilateral and bilateral. The FMT transducer is placed in various middle ear structures, including the stapes, the incus, and the round window. Patients with sensorineural hearing impairment showed better results in tests involving monosyllable word recognition (65 dB and 80 dB) than with open-fit hearing aids. Six months post-op the average outcome was 65%. Prof. Ad Snik from Rodboud University in Nijmegen reported very similar findings.

In users with mixed or conductive hearing loss, the average gain was 15–20 dB for high frequencies (Prof. Vittorio Colletti, Verona University) and 20–45 dB when atresia was diagnosed (Prof. Henning Frenzel, University Hospital Schleswig-Holstein, Luebeck).

Out of 187 patients of the WHC IPPH, 182 use the Vibrant Soundbridge system. Preoperative assessment involves standard speech audiometry and standard tonal audiometry in free field. An additional test, TEN, can be performed to assess 'dead' cochlear regions. After implantation, a reverse transfer function is done, if possible, using a probe placed in the external auditory canal to assess reaction to sounds of various intensities.

In many cases at the WHC IPPH, the FMT transducer is attached to the incus, although in other patients it is either the stapes or the round window. Direct stimulation of the RW membrane was first implemented by Prof. Vittorio Colletti, who suggested that there should be a fascia (and if necessary a commercially available connector) between the transducer and the membrane. However, the experience of WHC IPPH, presented at ESPCI 2013, is that the fascia can considerably limit transmission of low-frequency sounds [18]. Based on WHC IPPH data from 21 adult users of the VSB system, the main side-effect is transient tinnitus. As measured 3 years post-op, bone-conduction thresholds, after an initial drop, remain stable at a level better than the initial threshold.

As regards the most recently developed implants, the WHC IPPH is one of few centres in the world who have implanted the CODACS system by Cochlear Ltd in patients with otosclerosis of the middle ear. The implant delivers mechanical stimulation directly to the intracochlear fluids, with satisfactory results.

At ESPCI 2013, Prof. Maurizio Barbara shared the results obtained in 33 patients implanted at the University in Rome with the AMEI 'Esteem' system, a device they have used since 2007. Each patient is first equipped with standard hearing aids, and if there is no benefit, Esteem is recommended. Drawbacks of the system include a surgery of 3–9 h and the need to insert a new fully-implanted battery every 3–5 years. In Rome, Esteem has also been used experimentally in patients with profound deafness. Performance so far is promising.

Auditory brainstem implants

The WHC IPPH has been implanting auditory brainstem implants (ABIs) for almost 10 years. When fitting the system, the two basic considerations are a) signal detection threshold, comfortable sound levels, scaling, and equalizing loudness; and b) sound intensity scaling. Electrodes are selected whose stimulation elicits only auditory sensations. There have been five children implanted at ages of 1.6–16 years, with hearing impairments of various etiologies. The children were happy with the device, and their parents were also very positive (ESPCI 2013 oral presentation: Pitch perception and the number of electrodes *vs.* long-term development of speech perception ability in auditory brainstem implants; [19]).

Professor Vittorrio Colletti from the University of Roma is the world leader in treatment with auditory brainstem implants. At ESPCI 2013 he presented the results of 114 adults and 77 children aged 1–12 years. Patients with neurofibromatosis type II, as well as those with comorbid motor and sight impairments or cognitive deficits, showed considerably lower results in auditory and speech tests. In general, however, the outcomes of ABI have been satisfactory, especially when visual cues are available (speech reading, gestures). Furthermore, high intersubject variability has been seen in terms of nerve and vessel anatomy around the site of the implant. This means that radiological and electrophysiological assessments prior to surgery are indispensible.

Auditory midbrain implants

Auditory midbrain implants (AMIs) are an alternative system for patients with brainstem defects. The electrodes are implanted in the inferior colliculus, which is a multilayer structure, with each layer processing a different sound frequency band. Prof. Thomas Lenarz from the University in Hanover, who has pioneered this treatment method, presented the results of five AMI patients. In summary, a) each patient experienced sound sources differently, b) the sensation of loudness is inhibited, c) auditory outcomes improve with use (which reflects plastic functional changes in the inferior colliculus), d) low frequency sounds are recognized first, followed by high frequencies. In all patients who had an AMI prototype implanted, lip reading was improved and, in a limited way, so was speech.

Vestibular implants

The first vestibular implants have been tried in three patients with bilateral balance disorders. The devices are cochlear implants, supplemented with additional arrays inserted into the vestibule. According to Prof. Jay Rubinstein of the University of Washington, who is the head of the clinical trial, parameters of the vestibulo-visual reflex were found to be close to normal.

Neuroimaging

Auditory evoked potentials

There were more than a dozen oral presentations at the Symposium showing auditory evoked potential (AEP) results in patients and in subjects with normal hearing. General findings came from the University Medical Center Utrecht, NL (Dr Mic Lammers); Sunnybrook Health Sciences Centre, Toronto (Dr Lendra Friesen); and University of Texas, Dallas (Dr Anu Sharma). It remains to be seen whether AEPs could be used as pre- or post-operative measures of cochlear implant outcomes.

The standard cortical response to auditory stimulation involves the N1–P1 complex. As was shown at ESPCI 2013, in postlingual deafness the N1 potential has parameters close to normal, whereas in prelingual deafness it is often absent. A direct relationship has been found between the N1 responses and phoneme recognition. The latter is considerably lower in prelingual hearing impairment. The P1 potential in normal hearing shows decreasing latency with age. In cases of hearing impairment, the P1 latency gets shorter with acquiring auditory language experience and reflects speech recognition outcomes. In late cochlear implantation (in adult life), P1 latency does not get shorter with learning, regardless of the etiology and the education level of the patient. Studies by Dr Anu Sharma reveal that even when implantation is performed after the age of 7 years, P1 shows longer latencies that never get close to normal. At the same time, Dr Sharma emphasized that the parameters of cortical evoked potentials are strongly affected by attention and memory.

Professor Andrej Kral from the University of Hamburg presented findings of local field potential measurements in cats with normal hearing and those with induced deafness, finding significant differences between the groups. As an example, in single-sided deafness there was ipsilateral dominance of auditory responses, in complete contrast to normal hearing. The longer the impairment, the larger differences were reported. Since brain activations were still bilateral in the deafened cats, Prof. Kral believes that the deafened ear remains represented in the cortex (in contrast to what happens with impairments to vision). Moreover, for bilaterally induced hearing impairment, one-ear training initially only improved the results obtained with the trained ear. Professor Kral therefore suggested that in cochlear implant users additional training should be done with the implant turned off, or the implanted ear exposed to noise -measures which should induce additional bilateral brain responses to auditory stimulation.

Specialists from the WHC IPPH shared their results in electrophysiological studies employing quantitative EEG analysis (*Patterns of bioelectrical resting brain activity in tinnitus: preliminary results*; Katarzyna Cieśla). It was revealed that resting brain responses in tinnitus were different compared to normal and involved the distribution of particular brain waves, as well as their power. The results further suggested that the frontal and temporal brain regions may act as generators of tinnitus. In the future such research may serve as a way of assessing the results of tinnitus treatment [20].

Functional magnetic resonance imaging and positron emission tomography

The most recent approaches to understanding auditory function involve neuroimaging methods, including fMRI and PET. At ESPCI 2013, Professor Lee from Ecole Normale Superieure in Paris presented a number of analyses of brain activation in patients before and after cochlear implantation. The research investigated phonological memory, auditory-visual processing, brain plasticity induced by auditory deprivation and rehabilitation, and typical patterns of prelingual and postlingual deafness. Differences were found in both the site and extent of brain responses, which correlated with the duration of deafness, experience with the implant, and communication mode (speech *vs.* sign language *vs.* lip reading).

Furthermore, Dr Dona Yayakody from the University of Canterbury stated that brain processing of prosody, melody, intonation, loudness, and emotion (typical right-hemisphere functions) should be thoroughly assessed in hearing impaired patients. The reasoning is that because these stimuli are difficult for patients, they might therefore be uniquely represented in the brain.

Potentially, neuroimaging techniques can be used to provide additional information which might help to predict the outcomes of various treatment methods. For example, such techniques could be used in therapies employing phonogestures (combined gesture and speech) to establish the fundamentals of phonological awareness. They could also be used in developing treatment models involving multisensory stimulation (Prof. Ranjith Rajeswaren).

At the WHC IPPH, fMRI research involves assessing brain response patterns to various auditory stimuli (FM tones, chirps, syllables, pseudo-words) in both normal hearing and hearing loss. The results showed at ESPCI 2013 indicate fMRI as an effective method to assess the tonotopic organization of the primary auditory cortex in candidates for cochlear implants, as well as to estimate the extent of auditory association regions (*Functional magnetic resonance imaging in children with partial deafness,* Katarzyna Ciesla; *Functional magnetic resonance imaging of tonotopic organization of the primary auditory cortex*, Katarzyna Ciesla) [21,22].

A completely new research direction is to assess structural parameters using MRI, such as decreased white matter density (due to deoxygenation, infections, metabolic impairments), enlarged ventricles, cysts, and the like, to see if these affect speech outcomes after cochlear implantation (Prof. E. N. Garabedian, University of Paris).

Regeneration of Ear Structures

Compared to natural hearing, electric stimulation via a cochlear implant has limited frequency resolution, and artificial stimulation requires comparatively large amounts of energy. New studies have pointed to ideas such as direct auditory nerve stimulation with neurotrophins, which elicit cell growth towards the cochlear implant electrodes. A European Union project (*www.nanoci.org*) aims to design a human–machine interface that might allow such techniques to be implemented. Dr Claude Jolly presented the first laboratory findings in this area.

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