1 History of Auditory Implantation

Studying the history of auditory implantation and following the developments that have taken place in only about 50 years is exciting and teaches us about the courage, vision and endurance of some special individuals located on different parts of the globe. It also makes us realize that the cochlear implant has been developed with multidisciplinary efforts and would not have existed if other developments had not paved the way; without the experience with silicone covered leads in pacemakers, biocompatibility studies and the presence of antibiotics this development had not been possible. The reaction of disbelieve and scepsis in the community of the auditory professionals, and later the reaction of anxiety and anger in the deaf community to these new developments, that felt like a threat and offence to their culture and way of living also shows the sociological impact that the CI has had and sometimes still has. Finally this chain of development could not have taken place without serendipity lending a hand, and without some very courageous patients who decided in close dialogue with their doctors to become an object of research for this possible new treatment.

Five episodes in the development of auditory implants can be distinguished:

- Forerunners
- Pioneering & Experimentation 1957-1960s
- Feasibility studies, safety studies, evaluation of auditory gain 1970s
- Development of commercial multi-electrode cochlear implant 1980s
- Development of auditory brainstem implant 1990s

I. Forerunners

Alessandro Volta (1745 – 1827)

The interest in stimulating hearing by use of electricity starting in 1790 when Alessandro Volta, an Italian physicist and count of the region of Lombardia in Northern Italy, stimulated his own auditory system by connecting a battery of about 50 Volt to two metal rods that were inserted into his ears. Apparently he heard a 'boom within his head' and then a hissing sound as if 'soup was boiling'; he found the experience quite uncomfortable and moreover it lacked tonal quality!

Volta had had an interest in electricity from a very young age onwards and already at the age of 18 years was corresponding with different professors and scientists on the subject. He invented the electrical battery, the Voltarian cell (1800), and also developed an interest in chemistry. He was also the person who discovered methane in a nearby swamp as a gas that could be used for fueling (1778). As the son of a family of 9, who was expected to become a priest, just like 5 of his siblings, Alessandro Volta has contributed greatly as a scientist and became professor in physics at the University of Pavia in 1779 and professor in philosophy in Padova in 1815. As recognition the Volt (entity of current) is named after him (1881).

Some more experiments with electrical stimulation of the auditory system were described in these years all without tonal quality of sound. In 1855 Duchenne of Boulogne (1806-1875), based in Paris, stimulated the ear with alternating current instead of direct current leading to a sensation of 'the beating of a fly's wings'; still an unsatisfactory outcome.

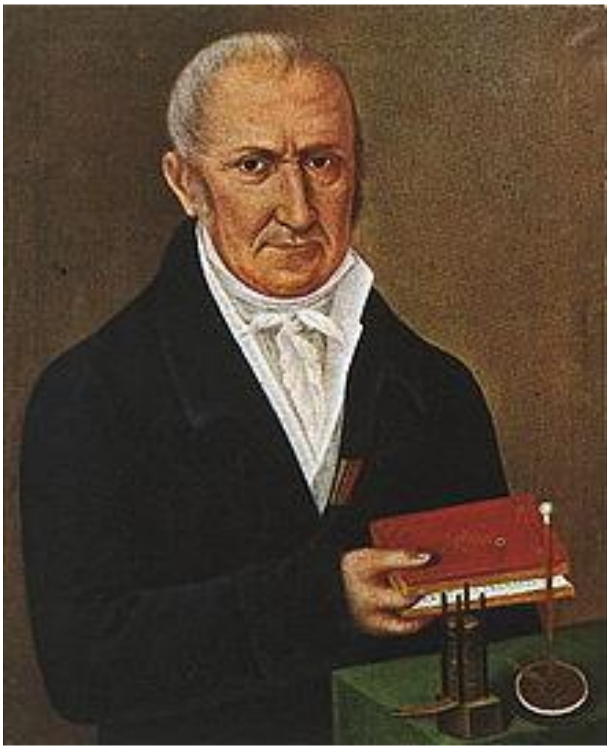

Fig 1. Alessandro Volta with his Voltarian cell.

Of influence on the final development of the auditory implant were several discoveries in the beginning of the 20th century, around the 1930s, the era of the development of the telephone.

Homer Dudley – the Vocoder

Working as a researcher at the Bell Telephone Laboratories in New York, Dudley described and designed in 1939 a real-time voice synthesizer that produced intelligible speech. Fundamental frequency of speech, the intensity of its spectral components and its overall power could be extracted using a special designed circuit. This synthesizer was named the 'vocoder' (coding the voice) and its operating principles have formed the basis for the early speech processing schemes in auditory implants.

Wever & Bray – the cochlear microphonic

In 1930 Ernest Glen Wever and Charles Bray recorded electrical potentials in the cochlea that reproduced the sound stimulus and they described this phenomenon, that was later called the Wever-Bray effect. These experiments were performed in a cat, with an electrode introduced into the auditory nerve. While they thought to record the discharges of the auditory nerve, following the telephone theory (voice carried along the cable of the ear, i.e. auditory nerve) in fact it was the cochlear microphonic that they recorded, produced by the outer hair cells of the cochlea. It was only later that the telephone theory was dismissed, but Wever and Bray did inspire several CI pioneers.

S.S. Stevens – electrophonic hearing

In the 1930s Stevens and his colleagues described 'electrophonic hearing', thought to be the mechanism by which cochlear structures respond to electrical stimulation to produce hearing and therefore only present in intact cochleae. It is now known that electrophonic hearing is a result of the mechanical oscillation of the basilar membrane responding to voltage changes. Before 1957 efforts to stimulate hearing electrically were performed on patients with at least a partial functioning cochlea. Therefore the results could be based on electrophonic hearing instead of on direct stimulation of the auditory nerve. The early pioneers had to prove the effect of their auditory implant as being a result of stimulation of the auditory nerve and not electrophonic hearing.

II. Pioneers and Experimentation

In France: Andre Djourno & Charles Eyries (1957-1973)

The first direct electrical stimulation of the auditory nerve was performed in the 1950s by the french-algerian surgeons Andre Djourno (1904-1996) and Charles Eyries (1908-1996). They both had a different interest and background. Whereas Djourno as a scientist, who also had studied medicine, had been interested in medical applications of electricity and nerve stimulation for a long time, Eyries was a trained otolaryngologist and was more of a clinician. He had more interest in the facial nerve embryology and function and ways to restore this function.

Before working together with Eyries, Djourno had already produced a device to continuously measure pulse, had used EEG to study narcolepsy and invented the use of electricity for removal of metal pieces from bones. He also invented some sort of artificial respiration by direct stimulation of the phrenic nerve. With these inventions he showed his deep interest in neural stimulation by the use of prostheses. His next project of interest was the making and testing of implantable induction coils (he called them microbobinages), which he made himself, to use for 'telestimulation'. He tested these in rabbits; the induction coil was placed under the skin and the stimulation was transcutaneously; subsequently the rabbit jumped after stimulation of the sciatic nerve. He studied several aspects of telestimulation amongst which electrode biocompatibility, effect of long-term telestimulation of a nerve and stimulus frequency. Because with higher frequency the muscle did not contract and with lower frequency the contraction was painful he ended up with the perfect stimulus frequency being around 450 Hz; finally using his own voice as the telestimulating stimulus because this was of the right frequency. This finding might have prepared him for the idea of stimulating the auditory nerve to restore hearing.

A 57 year old male patient that presented postoperatively after resection of large bilateral cholesteatomas with both bilateral loss of hearing and loss of facial mobility brought Djourne and Eyries together; in quest for a possible nerve graft Eyries met Djourno at the laboratories of the medical school in Paris and they decided together with the patient on a surgical procedure with the purpose of restoring facial as well as acoustic nerve function.
This procedure was carried out on February 25, 1957 by Eyries during which the induction coil was placed under the temporal muscle and the active electrode was placed in the stump of the auditory nerve, while at the same time the facial nerve graft was applied. The procedure gave a restoration of facial nerve function by the graft. The reports on the auditory outcome, also partly tested intra-operatively, showed eventually after

extensive rehabilitation with a speech therapist auditory sensations, discrimination between lower and higher frequencies, but no speech perception. Unfortunately after some weeks the implanted electrode broke down, a subsequently implanted second implant also broke down. Eyries held Djourne responsible for the break-down of the electrodes and refused to perform a third implantation; this marked the end of their working partnership and communication.
Djourne however went on and was approached by a colleague who proposed to organize funding and engineering support for further development of the implant by collaboration with industry, in exchange for exclusivity. Djourne, a true academian refused, was not interested in profiting from his inventions and detested industry. Out of principle he implanted one more patient together with a different, third surgeon. This implantation was not successful and because of lack of funding Djourne finally stopped working in the field of auditory prostheses.

The activities of Djourne and Eyries were followed up in Paris by Chouard, a student in Eyries lab. He became instrumental in de development of one of the first functional multichannel implants (Chorimac, Paris). He considered Charles Eyries as his major source of inspiration. Because of the work and implantation of Djourne and Eyries in 1957, this year is seen as the year in which the development of the auditory implants started.

Fig 2. Andre Djourne and Charles Eyries

Early American years

The discoveries of Djourne and Eyries did not reach the outside world and the USA quickly: they published their findings in a french medical journal and the connections of Djourne, the scientist rather than the surgeon, with the American otolaryngologists were not close. Eyries, the clinician, on the other hand did not show much enthusiasm for the project and only briefly. Via a patient William House in California serendipitously was brought a translated English summary of the French manuscript around 1959; the manuscript was very positive on the findings and House became inspired.

*William House

At that time House (1923 - 2012) was a young dentist-turned-otologist who had completed his residency in 1956 and had just started working in Los Angeles at the Otologic Medical Group, with his half-brother Howard House. Although early in his career he had already made some significant contributions to the field of otology/neurootology by developing the facial recess approach and later on he also developed the middle fossa approach. Bill's bar at the fundus of the internal auditory canal, a landmark for the identification of the labyrinthine segment of the facial nerve, carries his name.

When the manuscript from Paris reached him he was working with John Doyle, neurosurgeon on the middle fossa approach. They were working on recording the cochlear nerve response to sound, associated with tinnitus. James Doyle, brother of John Doyle, an electrical engineer took care of the electrical recordings during surgery. Having found successful recordings of sound induced potentials from the cochlear nerve, they planned on stimulating the nerve to restore hearing.
They first experimented with electrical stimulation to restore hearing during stapes surgery, using promontory or opened oval window stimulation. This was successful: these patients reported to be able to hear the stimuli. This stimulated them to implant a patient with a device.

The first patient who consented in being implanted was a 40-year old man with severe deafness due to otosclerosis. Promontory stimulation of the right ear showed responses on January 5, 1961 and 4 days later a gold wire electrode was inserted under local anaesthesia via retroauricular approach through the round window into the cochlea. The electrode left the ear via the retroauricular skin. The patient heard electrical stimuli but had poor tolerance of loud noise. After several weeks the implant was removed. The second patient, suffering from congenital syphilis, followed during the same month: this lady also heard the stimulus. Eventually the wire was removed because of fear of infection. Hoping to be able to study and produce discrimination of the higher frequencies, the first patient was implanted again, this time with a five wire electrode: the results were not that encouraging and this device also needed to be removed because of risk of infection. This problem with biocompatibility of the materials presented a big worry for the follow up of these experimental procedures.

The thought to implant a five-wire electrode was to be able to spread the high frequency stimuli along spatially separated electrodes, subpopulations of nerve fibers would thus be stimulated, summating into a high frequency response along the whole nerve. Early patent application for this multi-electrode implant was submitted by James Doyle and Earle Ballentyne in 1961. The patent was only accepted in 1969. The supporting theory however was proven to be wrong because the same signal was applied to all electrodes.

In the mean time the press got hold on the story of these two patients: over enthusiastic articles were printed, leading to deaf patients calling dr. House and dr. Doyle for ‘this cure for their deafness’. At the same time investors became interested also to earn money on this new medical device. House was worried about these developments that were far too optimistic, certainly in the light of the struggles with the biocompatibility. Differences in opinion on how to proceed and handle this situation lead to a separation between House and the Doyle brothers. The development of the implant became less of a priority to House, who also was running a busy otologic practice, while the Doyle brothers continued with experimenting and implanting, helped by a otologist from Los Angeles, Frederick Turnbull. Although they presented their results optimistically, no systematic analysis was performed. In 1968 James and John Doyle quitted their research activities due to lack of funding.

Fig. 3 William House

*F. Blair Simmons at Stanford University

F. Blair Simmons (1930-1998) was the first who stimulated the cochlear nerve in the USA; this was in 1962.

During medical school at Harvard Simmons worked in the lab of S.S. Stevens as a research associate and later also in the Walter Reed Institute before starting his residency in otolaryngology at Stanford University. He became an assistant professor at Stanford in 1962 and within a month was presented with the chance to stimulate the cochlear nerve during a surgical procedure in an 18 year old man with a cerebellar ependymoma. This recurrence of tumor had presented with a mild hearing loss. An exploratory craniotomy was planned under local anesthesia, giving opportunity for cochlear nerve stimulating and for receiving feedback from the patient. After explaining the patient agreed with the intraoperative stimulation and received a preoperative training. During the procedure the patient described the bipolar square wave stimulation directly on the auditory nerve as auditory sensations and was able to discriminate frequencies of stimulation up to 1 kHz. Simmons first implantation then followed in 1964; this 60 year old male had been deaf on one side and was now losing the hearing in the better hearing ear, but also suffered from severe loss of sight due to retinitis pigmentosum. He agreed with the procedure wholeheartedly. A six-channel percutaneous device, developed by Simmons was implanted via combined retroauricular and transmeatal approach under local anesthesia. A 2 mm cochleostomy and then a 0.1 mm hole in the modiolus gave access to the cochlea and auditory nerve. Testing was performed at Stanford and at Bell Laboratories. The testing however was very difficult due to the combination of disabilities of the patient, but Simmons proved that stimulation of the six different parts of the cochlea, by stimulating each electrode separately, lead to different frequencies/pitch perceptions. His implant was a percutaneous device to be able to stimulate all 6 electrodes separately, different than the five-wire electrode of House in which all electrodes received the same signal at the same time.

After these experiments and results Simmons was pessimistic about possibilities to reach speech perception and thought that biocompatibility studied first had to be performed before further work on a cochlear implant would be worthwhile.

Fig. 4. Blair Simmons with his invention the crib-o-gram, ancestor of the neonatal hearing screening.

Later American years

*William House re-engages

Where House had left the field of auditory implant development frustrated and focused more on the clinic in 1960s, with the development of pacemakers and ventriculoperitoneal shunts he senses that return to the field of cochlear implantation might be possible as the issue of biocompatibility seemed to be solved. In the 70s he developed a single channel device together with the engineer Jack Urban. Eventually this lead in 1972 to the House/3M single channel device, approved of by the FDA in 1984. This was the first implant worldwide that has been implanted in a larger group of patients.

*Robert Michelson

The third implanting surgeon in the field of auditory implants in the USA was Robert Michelson, working in Los Angeles. His preliminary report on cochlear implantation using gold wire electrodes in 3 patients to the American Academy of Otolaryngology brought a storm of protest; the old school auditory theories could not explain how electrical stimulation of neural tissue could create a cortical auditory percept. The fact that he did not first perform his experiments on animals, but directly on humans added to the critic.
Part of his experiments was performed in the Coleman laboratoria at the University of California, where he met Francis Sooy.

*Implant team University of California

Around that time in San Francisco Francis Sooy, the newly appointed head of department of ENT of the University hospital of California was building his own cochlear implant team. His vision was to gather strong individuals of different, multidisciplinary backgrounds and he found and hired Robin Michelson, Robert Petit and Michael Merzenich, a neurophysiologist, to work together.
At that time and age in the audiological and ENT society there was a great scepsis and disbelieve in the success of these implants. The lay press had mainly been writing on the miracle, but no analyses were presented for publication in the scientific journals. Robert Petit, a student assistant joined in after meeting Michelson in his lab and telling him about his believe in and dream of a multichannel electrode. However Michelson did not believe that multiple channels were necessary: they teamed up though, and worked with a two channel implant now imbedded in silicone. Merzenich performed neurophysiological tests on the cats implanted by Michelson and Petit, one side with normal hearing, the other side with a cochlear implant. Merzenich, at first a cynic, was convinced the auditory input by the implant reached the brain of the cat, but understanding what exactly humans heard remained difficult. A search for new tests was performed by Petit; he hired a music professor to create simple tunes, with different sound envelopes and different pitches and loudness levels. One of the newly implanted and tested patients in carefully controlled and filmed laboratory conditions was presented a song through the implant: it was recorded on film how the patient hummed the melody and tapped the rhythm of the song with a pencil. This movie convinced Francis Sooy to support the cochlear implant team even more and was shown at a meeting of otologists in 1972. It finally convinced the professional field that it was indeed possible to stimulate a cochlear nerve to reach auditory cortical perception, although concerns and doubts still remained.

III. Feasibility, safety and evaluation studies

*The Bilger Report

Francis Sooy was responsible for arranging a meeting in 1974 sponsored by the National Institutes of Health (NIH): it was decided that at this stage cochlear implantation surgery was still experimental, that inclusion criteria needed to be formulated and it was decided upon to stop all further implantation, until a strict and scientific evaluation was performed on hearing outcome and success of the procedure in the already implanted patients.
In 1975 the National Institutes of Health (NIH) organized this thorough evaluation of the patients that had been implanted thus far in the USA: 13 in total were implanted with single channel devices by either Robin Michelson (2) or William House (11). The contract to perform this assessment was awarded to a team from the University of Pittsburgh, directed by Robert Bilger. The patients were sent to Pittsburgh for a week for extensive evaluation: psychoacoustic, audiological and vestibular tests were performed..
On studying these 13 patients three conclusions were drawn: a cochlear implant does give support in lip reading skills, improves the quality of life and surprisingly patients also improve in their own speech production after implantation. Overall, the Bilger report concluded that a single channel device helped deaf people, with minimal risks. This opened finances and funding for research to develop mutually a multichannel device. Also, for the time being, the single channel implant was officially allowed.

IV. Development of a multichannel device

Development of a Multichannel Device

After the Bilger report and its conclusions, cochlear implant research became more legitimate as did the funding. Questions on safety and feasibility of electrical stimulation of the auditory nerve in the long run needed to be answered and also the best material for electrical biostimulation needed to be found. Two groups started working on the development of a multi-electrode cochlear implant: the UCSF group led by Francis Sooy, including Merzenich, Michelson and Robert Schindler, and the Melbourne group led by Graeme Clark. Helped by the technological advancements in the computer and aerospace industry (Adam Kissiah, 1974) they worked on minimizing the receiver device and improving the safety and durability of the electrode array. The physicist Adam Kissiah working for the NASA/Kennedy Space Center played an important role: he patented an electronic digital hearing aid in 1977. His design is currently still used.

Around the same time, during the 70s also in Vienna, Austria, work on a multichannel implant was conducted, leading to the implantation of a multichannel device ('3M Vienna') in 1977 by Kurt Burian. The implant was developed by Ingeborg and Erwin Hochmair; the later founders of Med-el in 1989. Also in France Claude-Henri Chouard together with Patrick MacLeod worked on a multichannel implant. In 1976 a French paper was published by Pialoux, Chouard and MacLeod detailing on the experiences with an 8 channel device, the Chouard-Bertin device.

William House, however, kept working on his, now approved, single channel device and refined together with Jack Urban, the House 3M single-channel implant, which was the first FDA approved implant. More than 1000 were implanted from 1972 – 1985, after which the age criteria of the FDA started lowering (see table)

The separate activities of the UCSF and Melbourne group led eventually to the introduction of the Advanced Bionics Clarion device, respectively the Cochlear Nucleus device. They were introduced in 1984 and overtook the single channel devices because of better spectral perception and speech recognition abilities as proven in large, clinical studies with adults. In 1985 FDA approval was granted for adults, in 1990 for children from the age of 2 years onwards.

USA FDA approval in historical perspective:

- 1984: single-channel electrode array in adults (House/3M)
- 1985: multi-channel electrode array in adults (Cochlear)
- 1985: first implantation in children (5 and 10 years)
- 1990: multi-channel implantation from 2 years onwards (Cochlear)
- 1998: multi-channel implantation from 18 months onwards
- 2000: multi-channel implantation from 12 months onwards
- 2000: multichannel ABI approval (Cochlear)

Whereas now with the FDA approvals safety was not so much of a research question any longer, attention was pointed at other questions: speech processing was one of these items, earlier implantation in congenitally deaf children was another.
Combined work in universal neonatal hearing screening programs, earlier diagnosis of deafness and a team approach, education and rehabilitation of implantees and a growing acceptance of the deaf community followed.

*Graeme Clark, Melbourne University Australia (1935 – now)

On the other side of the globe, Graeme Clark an otolaryngologist, grew up with a deaf father being a farmacist. From a very young age he witnessed the difficulties his father was having with communication and this energized him in his future goals. As a medical student he read the work of Blair Simmons and his discovery of the tonotopy of the cochlea and was impressed. In 1969 he studied single and multichannel devices in experimental animal studies at the University of Sydney and documented in his thesis that single channel devices had limited utility. He searched for a systemic scientific approach to develop a multichannel device, looking at speech processing strategies, electrode array design and development of a reliable implantable receiver. His efforts lead to the first multichannel device, implanted in 1978 and funded by the later to become Cochlear Company, the University of Melbourne and the Australian Government.
Some of the importants findings of Clark and his group were the round window insertion resulting in less trauma and the use of platinum electrodes for safest long term stimulation. In 1981 he showed that without use of lip reading some open set speech understanding with the multichannel implant was possible.

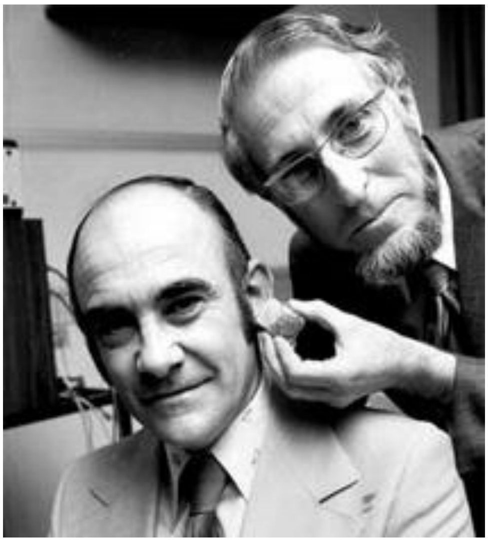

Fig. 5. Graeme Clark with the first multichannel cochlear implant patient, Rob Saunders.

Anxiety and anger in deaf communities

Where at the start and during the earlier development of cochlear implants the professionals were the resistant group, who, limited at that time by their concept and knowledge of the auditory system, did not believe in the reports that were being put forward, in a later stage it was the Deaf community itself that started fighting. At conferences and meetings in the late 80s and early 90's concerning cochlear implantation protest actions were organized and the professionals at that time working on cochlear implants found a very strong and active negative force standing up against them. Especially the choice to implant congenitally deafened children at a very young age without their own consent, viewed with the concept of disability was affronting. The term 'cultural genocide' was even used to express the threatening feeling within the Deaf community, that mainly consisted of prelingually deafened people using sign language. Deaf culture critics argued that because of the cochlear implant and the rehabilitation the identity and focus of the child on mastery of hearing and speech production will lead to a poor self-image; being a disabled person instead of being a proud deaf person using sign language. Especially in New York and England these revolts turned into battles.

Nowadays cochlear implants are more mainstream and many congenitally deafened, early implanted children attend main stream education instead of deaf schools or schools for the hearing deprived.

V. Development of auditory brainstem implant

Auditory Brainstem Implant

Whereas during the pioneering years several surgeons stimulated the cochlear nerve already directly at the modiolus or at the cerebellopontine angle, the development of the ABI started in 1979 when a female patient with NF2 asked for placement of a single-channel electrode on her brain in quest for hearing restoration. Although the outcome was thought to be very doubtful, her perseverance led to the first auditory brainstem implantation in 1979 by William House and the neurosurgeon William Hitselberger at the House Ear Institute. A single ball-type electrode was placed within the cochlear nucleus complex and led to hearing sensations, however probably due to a shift of the electrode these effects were lost and a new design electrode, better situated to the anatomy, was developed, resulting in a dacron mesh/platinum ribbon two electrode array (in collaboration with the Huntington Medical Research Institute). Around 25 patients were implanted with this system and their outcomes proved to be comparable to the results of the single channel cochlear implant (sound awareness and support of lip reading skills). When the amount of electrodes in the ABI was increased to 3 it became clear that the auditory outcome and especially pitch might vary according to electrode location, showing tonotopy to be present in the cochlear nucleus. The initial patient was implanted with a 8 multichannel ABI developed in collaboration between Cochlear, House Ear Institute and the Huntington Institute) in 1992 proving this theory: better speech perception performance and sound quality were achieved. This led to clinical multicenter trials in 1994 with a multichannel brainstem implant (Nucleus Multichannel ABI, Cochlear, approved of by the FDA as an investigational device in June 1994) and eventually to a hearing solution for NF2 patients.

Nowadays around 1000 ABI's have been placed, amongst which around 100 in congenitally deafened children. Besides NF2 patients, also non NF2 patients with congenital cochlear malformations, cochlear nerve aplasia, cochlear aperture stenosis and extensive cochlear ossification have been implanted with an ABI. Final USA FDA approval was granted in 2000 for adults (18 years and older) and NF2 only, but is nowadays granted for NF2 patients of 12 years or older with 'reasonable expectations'. In Europe ABIs have been implanted in children and adults for other indications besides NF2. Whereas the ABI used in the USA started out with 2, 3 and later 8 electrodes, the current unified ABI of Cochlear is the former European ABI with 21 electrodes developed in 1992.
The Med-el company also developed an ABI, with a 12 electrode or 16 electrode array.

A remaining problem with the current ABI is the fact that the surface electrodes do not reach the cochlear nucleus and its tonotopy as adequately as the cochlear implant does; especially the higher frequencies located below the surface are difficult to reach. For this matter a Penetrating ABI (PABI) was designed (House Ear Institute, Cochlear and Huntington Institute, 2008), with a 10 microelectrode array to penetrate 1-2 mm into the cochlear nucleus (in itself 2 x 8 mm) in addition to the 12 surface electrodes on a separate array. Although lower thresholds, activation of higher pitches and more selective stimulation were reached, the overall speech understanding was not significantly better than with a normal ABI.

Additionally for patients with damage of the cochlear nucleus or brainstem (mostly due to NF2) the auditory midbrain implant (AMI) or inferior colliculus implant (ICI) was designed. Around six patients have been implanted and showed disappointing results, although sound awareness and limited support of lip reading skills is found, comparable to the early ABI results in NF2 patients.

Summary of discoveries & developments

As this chapter shows the development of auditory implants has truly been a multidisciplinary, international endeavor. Alongside the development of the auditory implant also the knowledge of the function and physiology of the cochlea and the auditory pathway grew; more knowledge of the process of speech perception and of material and electrical technology went hand in hand. A summary of the most important discoveries & professionals in the timeline:

1790 Volta
Electrical stimulation of auditory system creates perception of sound – direct current

1855 Duchenne du Boulogne
Electrical stimulation of auditory system creates perception of sound – alternating current

1930 Wever & Bray
Recording of cochlear microphonic – taken for discharges of auditory nerves, analog to telephone line

1930s Stevens
Concept of electrophonic hearing in intact cochleae – taken for direct auditory nerve stimulation

1939 Dudley
Development of the vocoder, principle of speech processing

1950s Djourne
Transcutaneous electrocoiling

1957 Djourne/Eyries
Direct stimulation of auditory nerve

1957 House
Development of facial recess approach

1961 House & Doyle
Five-wire electrode cochlear implant, principle of summating high frequencies, later proven wrong

1962 Simmons
Six channel cochlear implant - discovery of tonotopy cochlea – leading to concept of multichannel electrode

1960s Michelson
Two-channel electrode imbedded in silicone

1972 Petit, Michelson
Movie of patient tapping song shown to otologists

1975 Bilger report
Outcome of single channel cochlear implant positive (improvement of lip reading skills, quality of life and in patients speech production); decision on mutual development of multichannel cochlear implant

1972 House
Further development of single channel device

1978 Clark
First multichannel cochlear implantation in adult

1979 House, Hitselberger
First ABI implantation in NF 2 patient, single channel bal-type electrode

1981 Clark
Open set speech understanding without lip reading proven in multichannel CI

1985 Clark
First multichannel cochlear implantation in children

1994 House, Hitselberger
Clinical trials with Multichannel Brainstem implant

New developments & future

Of course the developments within auditory implants have not come to a stand-still. Next horizons would be the total implantable cochlear implant (TICA), currently worked on in Melbourne, experiences with Auditory Brainstem Implants in Non NF2 patients have been published and will be continued, the perception of music with cochlear implants still has to be worked on and the development of hearing preservation and electro-acoustical stimulation is already becoming mainstream.

Conclusions

Nowadays more than 300.000 cochlear implants have been inserted, around 1000 auditory brainstem implants have been surgically placed and in the Western world bilateral implantation in children becomes standard practice because better incidental learning conditions at school and better environmental hearing are proven. The development in the field of auditory implantation over the last 50 years have truly been remarkable and has lead to a profound change in the living conditions, working conditions and quality of life of the deaf or hearing deprived patient.

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