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Otolaryngology Current Trends

Research Article

Behr R, et al. Otolaryngol Curr Trends: JOCT-111.

DOI: 10.29011/ JOCT-111. 000011

Single Implant Bilateral Auditory Brainstem Implantation (SIBIL-ABI): A New Surgical Approach

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Citation: Behr R, Polak M, Brill S (2018) Single Implant Bilateral Auditory Brainstem Implantation (SIBIL-ABI): A New Surgical Approach. Otolaryngol Curr Trends: JOCT-111. DOI: 10.29011/ JOCT-111. 000011

Received Date: 04 December , 2017; **Accepted Date:** 08 February, 2018; **Published Date:** 13 February, 2018

Introduction

Auditory brainstem implantation is a well-established method for the restoration of hearing in patients with anatomical or functional defects of the cochlear nerve. Initially, it was developed for Neuro- Fibromatosis Type-2 (NF-2) patients in whom the cochlear nerve was destroyed by the tumor or the nerve could not be preserved during surgery. Usually, the Auditory Brainstem Implant (ABI) is implanted in the same surgery as tumor removal, and on the same side with unilateral stimulation of the cochlear nucleus. Over the last few years ABI has proven to be beneficial in several other indications. For example, in adults with complete deafness after head trauma and bilateral fracture of the temporal bone, in cases of meningitis with cochlear ossification where there is no possibility of cochlear implantation, or in prelingually deaf children with nonfunctional bilateral cochlear nerve.

In NF-2 patients the results after auditory brainstem implantation are often not good enough to reach open-set speech understanding. Although recently, there are much more promising results after ABI [1,2]. In order to improve hearing results in tumor patients, several new approaches were tested. Penetrating electrodes in the cochlear nucleus did not show a real improvement in hearing outcomes [3,4]. Therefore, this approach is not used anymore. A second idea was to implant electrodes into the colliculus inferior; another relay station of the hearing pathway. However, this option shows relatively poor results with limited open-set hearing [5-7].

From Cochlear Implant (CI) candidates, it is known that bilateral CI are beneficial in terms of hearing restoration and performance [8]. Therefore, bilateral ABI is another option to improve hearing in deaf patients. To achieve this goal, two independent ABI electrode arrays can be inserted into both foraminae of Luschkae in two operative sessions. However, this solution may be more expensive and not always possible [9]. Another option is to use one implant with a split electrode array and implant them on both cochlear nuclei in one operation. The objective behind this is to stimulate both pathways of the central hearing system and get as much information as possible into this biological system using the central pathway, from its beginning at the cochlear nucleus.

Methods

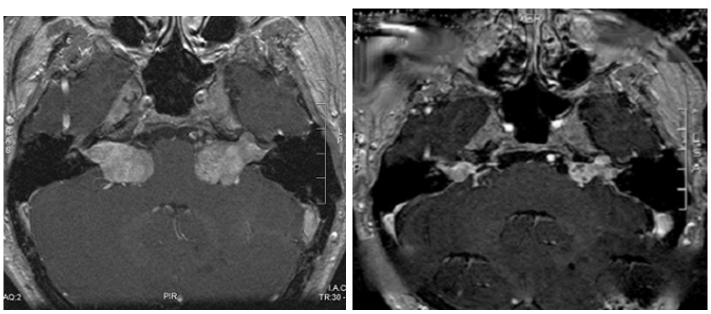
The surgical approach for bilateral implantation using one implant differs from the common ABI surgical approaches. The single sided surgical approach includes either a retrosigmoid or translabyrinthine approach. The proposed bilateral ABI surgical approach is via the midline with the patient in prone or semi-sitting position. This approach is not intended to remove tumors in the cerebello pontine angle. Tumors have to be removed in a prior operation. However, if tumors are already removed, the midline approach facilitates an easier way to the cochlear nucleus. One of the advantages is no need for the dissection of scarring, which is usually very difficult and dangerous. Secondly, after radiation therapy with deafness and tumor control, this approach is a new and good option for surgical restoration of hearing.

After osteoplastic trepanation in the midline, the dura is opened in a Y-shape and the arachnoid membrane is dissected. The cerebellar tonsils are elevated [10,11] and the cochlear nucleus is reached from below and from the midline. After electrically evoked Auditory Brainstem Responses (eABR) are recorded, a bone well is drilled and the housing of the implant is fixed with non-resorbable sutures. Both electrode arrays, each with six electrodes, are then positioned over the spot with the best eABR recordings and fixed, typically with fibrin glue, Surgicel^R, and TachoSil^R. The cerebellar tonsils are laid over the electrode arrays for additional fixation.

After reinserting the bone flap, the skin is closed in layers.

1. Patients

After studying the technical feasibility and stimulability in patients suffering from tumors in the midline of the posterior fossa [12], a 21-year-old male NF-2 patient was selected for bilateral implantation. The patient was already operated on several times intracranially and intraspinally due to his severe tumor load (Figure 1A). At the time of auditory brainstem implantation, 24.11.2009, both vestibular schwannomas were partially resected via a retrosigmoid approach (Figure 1B). Prior to the ABI implantation the patient was completely deaf. The patient suffered from a bilateral incomplete facial palsy, House-Brackmann II [13], and an oculomotor palsy left sided with no lower cranial nerve deficits. The patient had no oculomotor deficit on the right side. The situation was discussed intensively with the patient and his relatives. The patient gave informed consent for the procedure.



A B

Figure 1: A CT scan taken A) on February 22, 2009, prior to bilateral tumor removal; B) on November 18, 2009, prior to bilateral ABI implantation**.**

A custom made two branch bilateral PULSAR Med-El ABI was used. Both branches contained six electrodes. Electrodes 1-6 were placed on the left cochlear nucleus and electrodes 7-12 were placed on right cochlear nucleus (Figure 2 and 3).

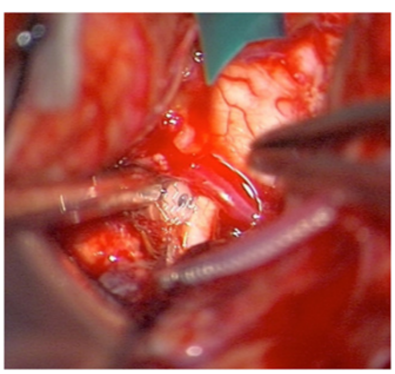


Figure 2: Split electrode array (placing electrode) on the right cochlear nucleus.

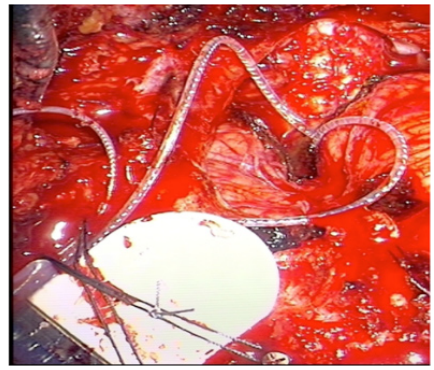
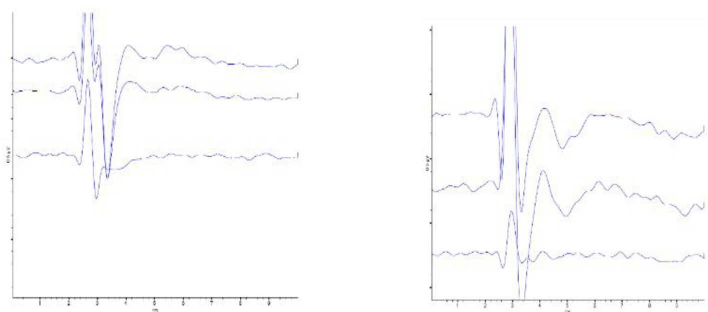


Figure 3: A custom made bilateral PULSAR Med-El ABI.

Results

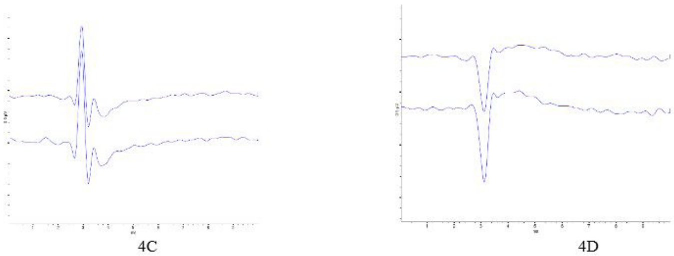
The operation was performed in prone position as described previously. Positive eABR responses were obtained (Figure 4), and both electrodes were successfully implanted. A placing electrode was used to find the most responsive area for both the left and right side (Figure 2). For each side, the placing electrode was repositioned twice. We were able to record responses for each electrode contact. An example of eABR recordings is shown in (Figures 4A and B). For each graph the amplitude stimulating current increases so that the bottom line is the recording for the lowest current amplitude and the upper trace are the response to the higher current amplitude.



4A 4B

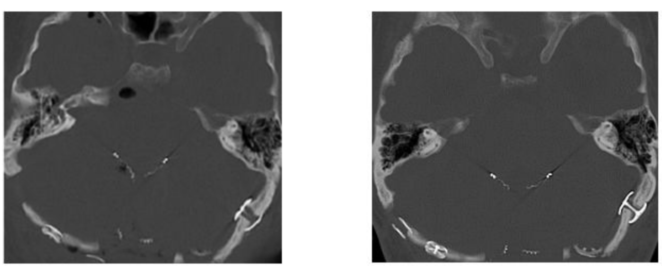
Figures 4(A-B): Example of eABR responses. 4A (top left) Recordings from position 2-3 placing electrode, right side; 4B (top right) Recordings from position 2-3 placing electrode; left side.

After finding the best responsive area, both implant electrode paddles were placed on that spot of the brainstem. We were able to get responses from electrodes 2-12. The response for electrode 1 (right side) was questionable. The surgeon decided to keep the position of both right-side and left-side electrodes without further repositioning. For every electrode the eABR consisted either of 2 or 3 waves. An example of the recording with the implant electrodes is shown in (Figures 4C and D).



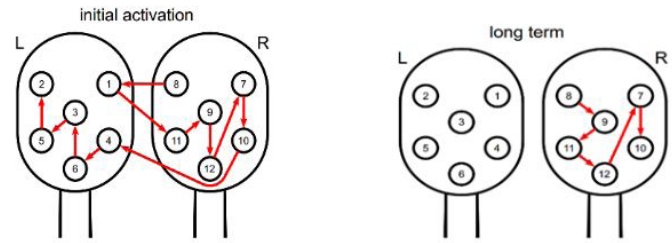
Figures 4(C-D): 4C (bottom left) Recordings from electrode 6 of the ABI implant; right side; 4D) Recordings from electrode 9 of the ABI implant; left side.

The electrode impedances were within normal limits (3.6-7.4kOhms). The intraoperative and postoperative period was uneventful and the patient recovered quickly. The postoperative CT scans showed correct bilateral implantation (Figures 5A and B). The initial stimulation of the patient's ABI TEMPO + audio processor occurred on March 16, 2010. The fitting occurred in the intensive care unit. The patient was monitored for respiratory and heart function. No non-auditory side effects were observed on any of the electrode contacts. All 12 electrodes were activated.



Figures 5(A-B): Postoperative CT scans performed on Nov 25 2009 (5A, left), Dec. 23 2009 (5B, right). The CT scans were taken one day, one month and three months after the surgical intervention, respectively. The CT scans confirmed correct electrode paddle placements.

The current charges varied from 19.8 to 40nC for thresholds and 53 to 200nC for the most comfortable levels. (Figures 6A and B) depicts the tonotopic orientation of both the right-side and left-side electrode arrays. The patient was able to distinguish 11 electrodes. The patient could not distinguish the difference in pitch between electrodes 1 and 8. One month later a second fitting occurred. During this session the patient's perception had changed. While electrodes 7-12 were clearly distinguishable, and the threshold and most comfortable levels for electrodes 7-12 did not increase for more than 10% from the initial stimulation, the patient did not show any auditory sensation for electrodes 1-6. There were no non-auditory side effects on any of the electrodes.



Figures 6(A-B): Tonotopic orientation after the initial stimulation (6A, left side) and the later fitting sessions (6B). Arrows point from lower to higher perceived distinct electrode pitch.

After the failed stimulation of the left side, which showed good responsiveness during the first fitting, new CT scans were performed. These scans showed that the left-side electrode had twisted, and was no longer in contact with the cochlear nucleus (Figure 7). This displacement can clearly be seen by comparing (Figures 5 and 7).

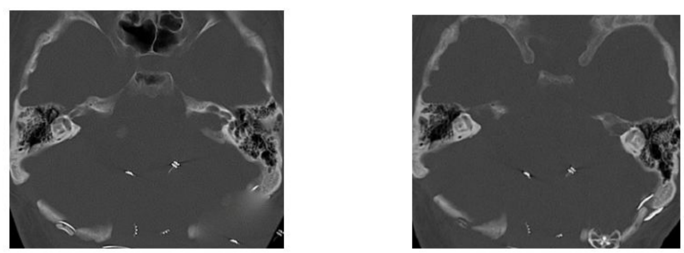


Figure 7: Postoperative CT scan performed on August 2, 2010 (7A) and August 25, 2010 (7B), after the second fitting session. The CT scans confirmed the correct placement of the electrode paddle on the right side but the electrode paddle displacement on the left side.

Revision surgery was an option, but the patient refused another surgical procedure because his mobility was deteriorating and a spinal operation was necessary, in the near future. Thus, the patient was fitted with the right sided electrode and has continued with this map until now. He uses the implant the whole day and is able to communicate well with his relatives. Despite migration of the left-side electrode array as described earlier, the tonotopic order on the right-side remained similar to its initial state. Repeated checking in follow-up sessions showed unchanged relative pitches since the one-year post-surgery fitting session (Figure 6B).

The patient uses his ABI system regularly and is able to communicate well with speakers with familiar voices, however he relies also on lip-reading. He reports to be able to distinguish and recognize most of the environmental sounds he is exposed to in everyday life. (Figure 8) shows his performance over time in the closed set Monosyllable-Trochee-Polysyllable (MTP) test. In this test, the patient is offered 12 different words twice and in randomized order. The patient knows about possible responses beforehand from a printed list. Thus, the subject's task in this test is to perform 24 one out of twelve selection tasks for a single test run. Of the twelve words, 4 are monosyllables, 4 have two and 4 have three syllables, so the results can be analyzed not only for word recognition, but also for detection of the number of syllables presented.

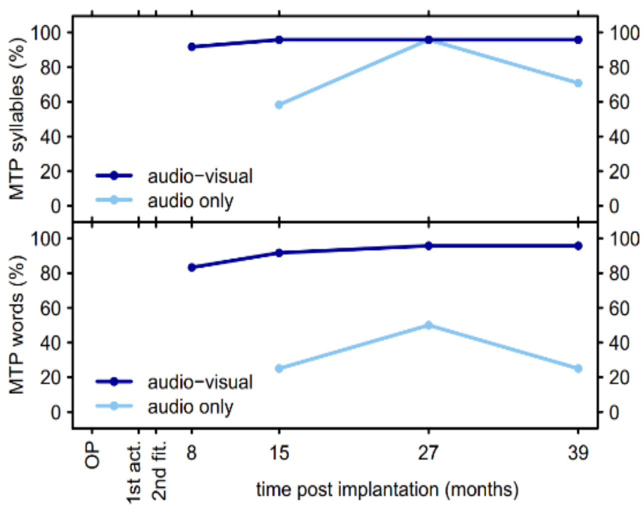


Figure 8: Speech understanding (MTP test) over time after ABI implantation. The upper panel shows recognition of the number of syllables, the lower panel shows word recognition scores in the closed set MTP test. Results for both audio only and combined audio-visual condition (i.e. with lip-reading) are shown.

Obviously, these two results are highly correlated. The upper panel of Figure 8 shows number of syllables recognition in both with and without lip-reading conditions. The lower panel shows word recognition scores. The results at month 39 post-surgery seem to exhibit a decrease in performance. However, this appears to have been caused by a time-span of non-use immediately before the session due to a technical problem with the processor. In this situation, the patient decided to wait until the soon upcoming appointment to get his processor checked and not use it until then.

Discussion

Since the first auditory brain stem implantation, by House and Hitselberger in 1979 [14], many new surgical and technological advancements were achieved. The main input came from new technologies in cochlear implantation, which were transformed to ABI. The initial candidates for auditory brainstem implantation were patients suffering from NF-2. In the beginning the results were more-or-less poor in terms of open-set speech understanding [15]. However, with the improvement of implants and elaborated surgical techniques true open-set hearing can also be achieved in NF-2 patients [1,2,9]. Although, in NF-2 the tumor load, revision surgeries, tumor regrowth and post-therapeutic scarring, also after radiation therapy, still remain a problem. To overcome these problems and improve hearing in NF-2 patients some new strategies were developed. Penetrating electrodes, inserted into the cochlear nucleus (PABI), did not prove to be as beneficial as thought initially [3,4]. The midbrain implant, which was inserted into the inferior colliculus, showed relatively poor results with limited open-set hearing [5-7].

This may be due to problems with implantation; or because an important central integrating part of the hearing pathway, from the cochlear nucleus to the inferior colliculus, is not activated using this implant. The advantage of having bilateral cochlear implants in comparison to a unilateral cochlear implant is the improvement in speech performance and spatial hearing, and hearing is reached with less effort [8]. Recently, bilateral cochlear implantation became a standard procedure in prelingually deaf children [16]. The idea to implant two separate ABI systems is not new, and has already been realized in selected patients with success [9].

However, such a solution may be relatively expensive and not covered by insurance providers. The approach in the aforementioned cases was a standard retrosigmoid approach, just after tumor resection in two operations. The subtonsillar approach was described by Samejima and his colleagues in 2003 as an option in ABI implantation. The latest idea, however, is to use the midline approach, which has been used for decades in neurosurgery to access tumors e.g. in the 4th ventricle. From the midline it is possible to reach the cochlear nucleus either from the 4th ventricle or from the subtonsillar, which is a little more lateral. In both instances the way through the Cerebello Pontine Angle (CPA) is bypassed. That means that this approach is not endangered by post-therapeutic scarring after surgery or radiation. Important nerves, like the facial nerve, are not endangered as much as by the classical approach via the CPA. Furthermore, it means that tumor patients who became deaf after treatment either by operation or radiation and do not need tumor resection, due to tumor control, have the benefit of safer auditory brainstem implantation; avoiding the cranial nerves, vessels and scaring. In addition, using this approach both cochlear nuclei can be accessed and implanted in one single operation, using a new auditory brainstem implant with two leads and two electrode arrays.

Another advantage is in terms of tumor regrowth. In this case, a revision surgery can be performed more easily, as the lead of the implant and the array are not in the line of either the retrosigmoid or translabyrinthine approach of the tumor removal. Moreover, non-tumor patients and children may benefit from bilateral simultaneous ABI because with bilateral stimulation more fibers of the central auditory system are likely to be stimulated.

One disadvantage, however, is that the number of electrodes is reduced for each side. However, the average number of activated electrodes is in most cases 8 in total. This means the implantation must be very accurate with good intraoperative eABR recordings to achieve as many electrode distinct pitches as possible.

In our first patient with the single implant bilateral ABI we demonstrated that this procedure is possible and safe for the patient; who had no additional cranial nerve deficit and already reduced facial nerve function. The first CT after implantation showed a proper and exact implantation. The first fitting was very promising as all 12 channels were activated with a high number of different pitches and without any non-auditory side effects. For at least three months after the bilateral ABI surgery the electrode array was stable and remained in place. Afterwards, for some unknown reason, there was a displacement of the left-side electrode. This was discovered with a CT scan 6 month after surgery, which was performed because the patient's performance decreased and missing responsiveness during fitting procedure. The postoperative movement of the electrode arrays is not a frequent problem and it occurs mostly during the first three months after implantation. In our own series of more than 50 NF-2 patient's electrode displacement occurred three times, giving the rate approximately 6%.

The positive, despite this misfortune, was, that the patient still had one functioning implanted side which he could continue to use. In the case of a monolateral implantation the patient would have lost his hearing completely. In such an instance a revision surgery would have been necessary. In this case the reimplantation to reposition the left-side electrode was discussed. However, the patient did not agree due to upcoming spinal surgery and because he could still use the intact right side. In summary, we could show that the midline transventricular or subtonsillar approach with bilateral ABI implantation, which we called SIBIL-ABI, is a good new option and alternative in ABI surgery, especially in NF-2 patients, but also for other indications. After the tumor treatment simultaneous bilateral implantation offers a less scarred track to the cochlear nucleus with the additional option of stimulating the central auditory system bilaterally for improved results.

Acknowledgement

This work is dedicated to beloved "One Eyed Joe", forever in the skies.

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