REVIEW ARTICLE

Organisation of a Cochlear Implant Programme

Manuel Manrique Rodríguez, Alicia Huarte Irujo

Departamento de Otorrinolaringología, Clínica Universidad de Navarra, Pamplona, Navarra, Spain

Received 12 August 2011; accepted 12 September 2011

Abstract A cochlear implant (CI) programme brings together a number of professionals who, during the stages of selection, surgery, programming, rehabilitation, and monitoring, develop a series of tasks aimed at promoting comprehensive attention to the implanted patient.

The aim of this paper was to describe in detail the tasks in each of the phases described in a programme of CI, materials and necessary equipment and the role of the professionals involved. It also raised a number of recommendations on how to develop a CI programme gradually to facilitate the progression from the simplest to the most complex cases.

© 2011 Elsevier España, S.L. All rights reserved.

PALABRAS CLAVE

Implantes cocleares; Hipoacusia; Atención integral

KEYWORDS

Cochlear implants; Hearing loss; Comprehensive attention

Organización de un programa de implantes cocleares

Resumen Un programa de implantes cocleares (IC) reúne a una serie de profesionales, que durante las fases de selección, cirugía, programación, rehabilitación y seguimiento, desarrollan una serie de tareas enfocadas a promover una atención integral al paciente implantado.

El objetivo de esta publicación es describir con detalle cuáles son las tareas a realizar en cada una de las fases descritas en un programa de IC, los materiales y equipos necesarios, y el papel que juegan los profesionales implicados. Así mismo, se plantearán una serie de recomendaciones sobre cómo desarrollar de forma paulatina un programa de IC, con el fin de facilitar su progresión desde los casos más sencillos a los más complejos.

© 2011 Elsevier España, S.L. Todos los derechos reservados.

Introduction

Teamwork represents a challenge which must be faced by all those professionals who are involved in a cochlear implant (CI) programme. We must consider that the results obtained by a CI are conditioned by biological factors inherent to each patient, the technical characteristics of the CI and also by the correct organisation and operation of the team comprising the CI programme. Therefore, we believe that this
publication may help to improve the quality of our work, become helpful for professionals who are initiating the creation of a CI programme and perhaps serve as a reference for institutions or health authorities which support the development of this activity.

The technique of CI does not simply consist in performing surgery. Its implementation requires the organisation of a programme which ensures it: selecting the right candidates, effectively executing both implantation surgery and programming of the device, providing adequate and sufficient rehabilitation, closely coordinating those specialists involved in the programme and appropriately monitoring implanted patients, as well as with maintaining equipment. Furthermore, we must add the motivation of candidates and their families, as these agents should always be considered in a CI programme.

In order to address all these aspects, it is necessary to have a multidisciplinary team which is able to cover every stage comprising a CI programme in a coordinated manner: selection, surgery, programming, rehabilitation and follow-up. Taking into account the recommendations on disability of the Agency for Health Technology Assessment of Instituto Carlos III and the Expert Committee on Disability of the Royal Board, such teams should be integrated by the following professionals or units: ENT specialist with experience in otological surgery, oto-neuroradiologist, Audiology Unit, audio-prosthesis technician, psychiatrist, psychologist, speech therapist, phoniatrician, Programming Unit, and technical support unit for CI maintenance. In the case of CI programmes aimed at paediatric populations, the various specialists and units mentioned previously should have extensive professional experience in the care of children with hearing loss. These cases must have the cooperation of teachers with language and hearing experience who deal with the children at school. Other professionals including paediatric neurologists, social workers, neurophysiologists, etc. may be able to offer an invaluable help in certain situations, so it is advisable to work in an environment which favours their collaboration.

At least one member of the team should assume the role of coordinator. This person should not only coordinate the work of all specialists, but also ensure that candidates receive comprehensive and appropriate information about the CI programme, while ensuring proper compliance by patients after implantation.

The programme, and therefore the specialists integrating it, must have the appropriate means to carry out their intended mission. Consequently, they must be willing to conduct those explorations and actions which will be examined in this text forthwith.

**General Structure of a Cochlear Implant Programme and Action Algorithm**

As previously noted, the stages comprising a CI programme are: selection, surgery, rehabilitation, and follow-up. Although these stages will be subsequently examined in detail, the algorithm shown in Table 1 provides a chronological overview of the sequence of actions which make up this CI programme.

### Table 1  General Structure of a Cochlear Implant Programme. Action Algorithm.

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
</table>
| I. Selection | Initial consultation  
  - Anamnesis and ENT exploration  
  - Categorisation of hypoacusis (hearing loss)  
  - Specific consultation as candidate for CI  
    - Auditory evaluation  
    - Radiological evaluation  
    - Psychosocial evaluation  
    - Evaluation of speech and language  
    - Other evaluations: genetic, neurological, ophthalmological, etc.  
  - Consultation for indication of CI  
    - Interview for orientation and analysis of expectations  
    - Preoperative tests |
| II. Surgery | Surgical intervention  
  - Intraoperative telemetry  
  - Intraoperative radiological controls  
  - Postoperative monitoring |
| III. Programming of CI | Verification of CI operation  
  - Determination of auditory and comfort thresholds  
  - Selection of stimulation strategy  
  - Evaluation of the initial results and reprogramming |
| IV. Rehabilitation | Design and execution of an individualised rehabilitation programme |
| V. Monitoring | Clinical and radiological  
  - Evaluation of results  
  - Verification of CI operation  
  - Adjustments in programming  
  - Technical maintenance of CI components  
  - Adjustments in the rehabilitation model  
  - Information for families |

**Selection Phase**

The selection phase must be aimed at categorising hearing loss, eliminating certain contraindications and analysing a number of prognostic factors which will influence, to a greater or lesser extent, the post-implantation results. This selection process will have different characteristics depending on whether it is aimed at adults or children, prelingual or postlingual hearing loss, and patients with hearing losses which are associated with other disabilities or isolated.

The selection of candidates must be addressed by a multidisciplinary team which analyses the following areas: otolaryngological–medical, audiological, phoniatric–speech therapy, and psychological–psychiatric. Furthermore, in the case of children, it should explore other areas which will require further professionals with specialisations related to infant stages, such as paediatricians and paediatric neurologists. Moreover, it is essential to integrate those speech therapists and educators who regularly manage the
rehabilitation and education of children into the selection phase. Their opinion, based on their prior knowledge of candidates, will be important in establishing the indication for implantation and to decide subsequent actions in the rehabilitation programme.

Otolaryngological – Medical Considerations
At this stage of selection, the otolaryngologist has to, at least, conduct an anamnesis and basic ENT examination, as well as request a high-resolution computed tomography (CT) scan in order to study the both temporal bones and/or magnetic resonance imaging (MRI) scan which studies the labyrinth, the cochlear nerve and the condition of the brain parenchyma. The results of these explorations will enable a series of key anatomical aspects to be defined, in order to conduct or contraindicate the surgical process of cochlear implantation.

This assessment may be complemented by genetic studies of hearing loss and the implementation of any necessary specialised interconsultations, according to the characteristics of each patient.

Audiological – Audio-prosthetic Considerations
The audiologist, in collaboration with the audio-prosthetic specialist, must evaluate that patients meet the required audiometric criteria for the indication of a cochlear implant. These criteria have varied over time, so that today we can speak of established and emerging audiometric criteria.4

Established Audiometric Criteria. According to the FDA (USA Federal Food and Drug Administration), when considering the population of postlingual adult candidates, CI is indicated for bilateral sensorineural hearing losses with hearing thresholds above 70 dB for mean frequencies of 500, 1000, 2000, and 4000 Hz, with free field audiometry with hearing aids above 55 dB in the same frequencies and with less than 40% discrimination using open lists of words and appropriate audio-prosthetic equipment at a stimulation intensity of 65 dB HL.5

According to the same agency, in the case of children, the audiometric criteria should be more restrictive than in adults. CI are indicated in bilateral sensorineural hearing losses with mean losses exceeding 90 dB HL (500, 1000, 2000, 4000 Hz).4 The FDA recommends conducting implantations after the age of 12 months. The reasons for this include difficulty in conducting behavioural hearing tests, lack of objective evidence to assess hearing thresholds throughout the entire frequency range, short test time with hearing aids and coexistence of middle ear disease, which may hinder diagnosis of the degree of hearing loss at ages under 18 months. However, this age has shown a clearly decreasing trend, as experience with the use of CI has increased and diagnostic techniques have improved. This is an important determinant of post-implantation results, since there is a critical period for language acquisition which includes the early years of life. Therefore, the lower age limit is currently marked by diagnostic safety in determining the degree of hearing loss.6

Emerging Audiometric Criteria.
Bimodal Stimulation. Following a series of clinical trials, there has been a tendency to perform implants in patients with severe sensorineural hearing loss in one ear and profound hearing loss in the other. Clinical experience has shown that these patients simultaneously use a CI in the ear with lower levels of hearing and a hearing aid in the contralateral ear. This stimulation paradigm is known as bimodal strategy. It was found that these patients achieved better sound location and improved their speech discrimination levels, in both noisy and silent environments, compared to those who only used hearing aids or CI.7,8

The audiometric criteria employed would be the following: profound sensorineural hearing loss in one ear and severe (between 71 dB and 90 dB) in the contralateral ear. Placement of the cochlear implant would take place in the ear with worse hearing (Fig. 1).

Implantation in Patients With Residual Hearing. There are some patients with good levels of residual hearing at low frequencies and sharp drops in hearing at middle and high frequencies. This group of patients usually presents poor levels of speech discrimination which do not improve substantially with the use of hearing aids. In such cases, the use of special electrode guides and a refined surgical technique known as atraumatic, may preserve the remnants of hearing in the implanted ear. This circumstance enables an electrical stimulation with the CI and an acoustic stimulation with the hearing aid (hybrid stimulation) to be performed simultaneously in the same ear. The results obtained with this stimulation paradigm suggest that patients are able to hear significantly better, especially in noisy environments, and achieve a satisfactory perception of music.9

While this treatment approach is still experimental and there are no unified criteria, we could consider this technique for patients who met the following criteria: 1) 18 years of age or older; 2) severe to profound postlingual sensorineural hearing loss at frequencies >1500 Hz and mild to moderate postlingual sensorineural hearing loss at frequencies >500 Hz, with no audiometric restrictions for the contralateral ear (Fig. 2); 3) duration of hearing loss <30 years; and 4) recognition of disyllabic words with aids (correctly adjusted prosthesis) in the ear to be implanted between 10% and 50%, in silence and at 65 dB SSPL (saturated sound pressure level).

Bilateral Cochlear Implants. Various studies have shown clear benefits among patients undergoing bilateral implantation, including being able to locate sounds, obtaining a summation effect, avoiding the “head shadow” effect and improving speech discrimination in noisy environments.10 The most widespread audiometric criterion for a simultaneous or sequential indication of bilateral CI is the existence of a profound sensorineural hearing loss in both ears, with limited levels of disyllabic word discrimination below 40% whilst using properly adjusted hearing aids.

Explorations. For cooperating candidates who have acquired some experience in oral communication, hearing assessment includes the following battery of tests:

1. Pure tone audiometry with earphones.
2. Free field audiometry with hearing aids.
3. Verbal audiometry with earphones.
4. Free field speech audiometry with hearing aids.*
5. Audiometry with auditory brainstem evoked potentials.

Although the aim is to explore adult candidates, it is desirable to have the results of an objective auditory
6. Promontorial test, only required in cases of total cochlear ossification, congenital otic malformation and previous surgery on the eighth cranial nerve.

*A wide variety of materials can be used to conduct the speech audiometry. We recommend using a basic evaluation protocol which includes at least the following lists: vowels, everyday words, disyllabic words, and phrases. Moreover, it is of great interest to know the extent to which the results obtained in these tests improve with the support of lip reading and vary in noisy environments.

Given the difficulty of obtaining an audiometric diagnosis in children with prelingual hearing loss, especially those younger than 5 years, it is necessary to include the following evaluations within the battery of tests:

1. Behavioural pure tone audiometry with earphones.
2. Behavioural pure tone audiometry in free field, with and without hearing aids.
3. Impedanciometry.
4. Otoacoustic emissions.
5. Brainstem auditory evoked potentials.
7. Middle latency evoked potentials after promontorial electrical stimulation, compulsory in at least the following cases: total cochlear ossification, congenital otic malformation (stenotic internal auditory canal, cochlear hypoplasia, and common cavity) and history of pathology or surgery on the auditory pathway.
8. Verbal audiometry adapted to each case by age and cognitive development, in free field, with and without hearing aids.

Tests should be performed at least 3 times and as often as necessary to verify that the results obtained are consistent. It is necessary to have an experienced team of audiologists, specialising in child audiology, who are able to implement these hearing assessment protocols, specifically created for a CI programme.

The collaboration of an audio-prosthetic specialist is necessary in order to verify that the adapted hearing aids meet the required technical specifications and provide optimal results according to the characteristics of each hearing loss. Once this has been verified and, where appropriate, timely corrections have been made, it will be possible to conduct
audiometric examinations requiring the use of hearing aids. If the child does not have hearing aids, then their use is normally imposed for 3/6 months, under speech therapy treatment, in order to carry out a subsequent audiometric assessment.

Phoniatric – Speech Therapy Considerations
In the case of postlingual patients, the assessment of subjects pursues 2 basic objectives:

- To evaluate the reception and understanding of spoken language, with and without lip reading, in order to determine the baseline and compare it a posteriori with the subsequent evolution of the patient.
- To collect the necessary data to programme the content of rehabilitation sessions, in order to adapt the materials to the socio-linguistic level of each patient.

The most commonly used instruments are:

- Lip reading test (this aspect has been described previously in the section on audiological – audio-prosthetic assessment).
- Samples of spontaneous speech, reading, and writing (application of the Manchester scale).
- A “cloze-type” test may be interesting to assess the mental substitution capacity of patients, which is very important to discriminate incomplete information like that provided by both lip reading and implants.
- If voice and articulation are already impaired due to hearing loss, it is important to record the vocal level objectively (voice analyser).

In the case of children with prelingual hearing loss, explorations aim to obtain information on their language proficiency:

- Capacity for understanding, recognition and expression of sounds, words, and phrases.
- Current intelligibility of speech.
- Extension of lexicon and command of morphosyntactic structures.
- Prevalence of aural-or oral or gestural communication in everyday life.
- Willingness to learn and work.

The following tests can be used to evaluate these aspects:

- Induced phonological registry.
- Peabody or Carrow vocabulary test.
- ITPA (Illinois test of psycholinguistic abilities).
- PLON (oral language test of Navarra).
- Reynell scales.
- GAEL-P
- Functional voice exploration.

It will always be necessary to supplement the information provided by these tests with a qualitative assessment of spontaneous communication by an experienced examiner specialising in deaf patients.

Psychological – Psychiatric Considerations
The contribution of psychiatry and psychology in regard to treatment by cochlear implant should be twofold:

- During the first phase, collaborating in the selection of candidates by detecting possible psychopathological alterations which could represent an obstacle to the achievement of treatment results.
- During the second phase, after surgery and once the patient is in the rehabilitation period, monitoring the adaptation of patients to their new situation.

When conducting patient selection in both adults and children, it is not only important to detect psychopathological issues which may contraindicate treatment temporarily or permanently, but it is also of special interest to assess the level of expectations and the degree of motivation of each patient. Virtually all authors consulted agree on this point. The suggested tests to be conducted during psychopathological assessment include the following:

- Psychiatric interview: this is intended to investigate the existence of severe disorders which could represent an obstacle to the result of the implantation.
- Assessment of the intellectual level through the Weschler intelligence scale (WAIS for adults).
- Likewise, the existence of neuropsychological disorders should also be examined, especially in the area of speech and language.
- Assessment of personality. Although the existence of a personality disorder does not imply an absolute contraindication for treatment, it may represent an obstacle for the development of postoperative rehabilitation and for the adaptation of patients after implantation. Most authors employ the Minnesota Multifactorial Personality Inventory (MMPI) for this purpose.

From the psychological point of view, we consider it essential that patients are fully aware of both the characteristics of the treatment (what it consists in, its phases, its approximate duration including the rehabilitation period, etc.) and their expected condition after implantation, in order not to create false expectations which could be a deterrent for their subsequent adaptation.

Special Populations
Cochlear implants always require an individualised indication. This rule is even more relevant when applied to different population groups other than those defined above, such as prelingual adolescents–adults, individuals with a sensorineural deficit or suffering systemic disease associated with deafness, etc.

In the case of adolescent-adult patients with prelingual hearing loss, considering the information obtained through the same screening tests used in children, the indication for cochlear implants must be limited to highly motivated subjects with well-developed oral language living in an environment with essentially oral communication. Although the percentage of candidates who meet these conditions is low, the satisfactory results associated with them justify the
indication of cochlear implantation in this small population group.12

In general, deaf and blind patients can be excellent candidates.13,14 In these cases, the programme must become specialised and develop specific contents for the selection and rehabilitation phases. The programme should also include professionals who can manage the visual deficit and offer psychological support to candidates.

These and other special cases must always be addressed by teams with extensive experience in postlingual and paediatric cases, considering in detail every aspect concerning each candidate in any of the 3 stages of a cochlear implant programme.

Advice Prior to Cochlear Implantation

During and after the conclusion of the selection stage, patients and their families will be informed about the stages and processes comprising the cochlear implant programme and the possibilities in their specific case.

Candidates and families should be given a simple questionnaire so as to ensure that the information has been properly understood. This will help the CI team to assess whether there were any doubtful or misunderstood points which should be reviewed. Regardless, it is important to provide written material in order to reinforce oral information. It is also useful to have the collaboration of subjects who have already undergone implantation and their families, as long as they present similar clinical characteristics to those of the candidate.

Contraindications for Cochlear Implantation

At present, the following situations are considered as temporary or permanent contraindications:

- Congenital malformations manifesting with bilateral aghenesis of the cochlea.
- Lack of functionality of the auditory pathway or presence of diseases causing central type hearing loss.
- Severe psychiatric disorders.
- Diseases that contraindicate surgery under general anaesthesia.
- Lack of motivation towards implantation.
- Non-compliance with audiometric criteria.

Surgical Stage

The surgical procedure is conducted under general anaesthesia and aims to achieve the following objectives:

- Implantation of the internal components of the CI.
- Verification of the correct position and functionality of the implanted system.
- Obtention of responses which indicate stimulation of the auditory pathway and which may be subsequently used for the activation and programming of the CI.

The intervention has a variable duration, ranging between 1 and 3 h depending on whether implantation is unilateral or bilateral. Hospitalisation usually lasts around 2 days, with scarce complications or discomfort being reported in this postoperative period.15

The correct position and condition of the electrode guide are verified perioperatively through a simple radiological study. In addition, this radiograph will serve as a reference to analyse a potential migration of the electrodes outside the cochlea. It is possible to verify the correct operation of the CI through telemetry procedures. Registration of impedances from each of the electrodes will determine their functionality. A study of the stapedial reflex and neural response tests will provide information on the condition of neural afferents and offer useful data for programming the CI.

Cochlear Implant Programming Stage

This is performed after the fourth week following the completion of surgery, in order not to interfere with the process of wound healing and also to ensure a stable thickness of the cutaneous cover which does not obstruct the communication between the transmitter and CI antenna. It is at this point that the external elements of the implant are placed. These consist mainly of the microphone, processor, and transmitter.

Before the CI is activated, the otolaryngologist must verify that the condition of the ear is normal and that the surgical wounds have healed correctly. It is also important to verify that there are no space conflicts in the retroauricular region between the implanted components and the external processor.

The Programming Unit must be directly linked to the implant centre. Only in this way will it be possible to achieve optimal results and prevent the occurrence of severe complications derived from poor coordination and information transfer problems.

Although there are differences between various implant models, the processor must be programmed or activated according to the characteristics of the implanted person. This process must have adequate computer equipment and specialised personnel for the selected implant. In uncooperative patients, the use of telemetry techniques that report on neural responses obtained from stimulation of the implanted electrodes is useful to determine the auditory map during cochlear implant programming. Proper operation of the CI should be verified prior to its activation. While this should have already been done at the end of surgery, changes occurring in the postoperative period may make this review advisable. Programming of the CI should be conducted by seeking the maximum comfort and sound perception thresholds. This allows a map of the auditory characteristics of the patient to be outlined. The area defined by the aforementioned thresholds is known as the dynamic range. Moreover, the stimulation strategy (monopolar, bipolar, etc.), coding strategy (CIS, HR, etc.), stimulation rate and number of channels to be activated will be selected at this time. Adaptation of the external components should also be planned at this time. Thus, a coshareal or retroauricular processor, along with those complements which ensure optimal stability, will be selected by careful consideration of the characteristics of each patient.

In the case of bimodal stimulation (CI+hearing aid in the contralateral ear) or bilateral stimulation with 2 CIs, programming and activation of these devices should take into
account the information received by the patient through both ears, optimising each stimulation level to attain a comfortable and symmetrical listening experience.

In the case of children it is crucial to be extremely careful during the first programming. It is a priority not to induce unpleasant experiences which may lead to rejection of the CI. The results of telemetry tests performed during surgery will be useful in the initial programming, in order to guide the development of the auditory map. In addition, the collaboration of the usual speech therapist may also be helpful in order to reassure the child and also to aid in assessing reactions to sound. Therefore, it is desirable to establish this cooperation before starting programming, so as to obtain a good sound conditioning and training to respond to the presence-absence of sound, as well as the different intensities thereof.

The initial programming process may extend over 1 or 2 weeks. This allows for a gradual exposure to sound whilst making the necessary adjustments in programming to achieve optimal stimulation. Various different objective and subjective audiometric evaluations will be conducted during this period in order to obtain information about the quality of the stimulation delivered via the CI. Similarly, the work of a speech therapist forming part of the implantation centre will be of great interest when evaluating the first responses to auditory stimulation by the CI. This “feedback” will be highly relevant for the Programming Unit when establishing the final activation parameters of the CI.

The information gathered during this process will help to develop a unified strategy for rehabilitation and long-term monitoring in coordination with the team of speech therapists and educators who will support patients at their residences.

As noted below, this programming should be reviewed periodically, especially in children, since the thresholds and dynamic range may change over time. This will help to obtain better hearing levels and will also be useful to verify that the system is working as expected.

Implanted patients and their families should be instructed on the management of CI external components during this CI programming phase. They should also receive information about potential problems arising from the use thereof and what actions to take to resolve them.

Rehabilitation Phase

Rehabilitation should target the patient as a whole. In this sense, it should not be limited to a mere mechanical training procedure, instead covering different aspects such as:

- Providing more information on the management and care of the implant.
- Adjusting expectations to the real possibilities of each patient, clearly stating the objectives of each stage of the programme.
- Providing adequate support to patients and their families in times of doubt or disappointment.
- Influencing the environment so as to apply the necessary adjustments in their oral communication.

Regarding the content, duration, and time of application of the programme, it is possible to distinguish 3 main groups of implanted patients: postlingual patients, prelingual patients older than 6 years, including adolescents and adults, and prelingual patients younger than 6 years.\textsuperscript{16–18}

Postlingual Patients

These patients were able to hear at some point and thus stored a considerable number of auditory patterns in their memory which could support rehabilitation. However, if the period of deafness has been long, it is possible that these patterns have deteriorated considerably.

In some cases, hearing recovery is extremely fast and the content of the programme focuses rapidly on functional training (directed conversation, followed by open conversation). However, most patients require a longer period to pass through the different stages which should be addressed progressively, so as to prevent initial rejection reactions due to lack of achievement of the performance levels they had expected from the onset. In this sense, the information process initiated during the pre-implantation phase should be maintained and expanded, in order to allow patients to better interpret their progress and maintain their motivation, which will be pivotal to the success of any rehabilitation treatment.

The rehabilitation programme usually contains analytical exercises (focused on perception of discrete elements, such as a particular phoneme) and more global comprehension exercises in which mental substitution plays a big role. The relative proportion of these 2 approaches varies with each patient (according to perceptual responses, as well as learning styles) and should, therefore, be adapted individually.

Most programmes agree on a separation into 5 stages:

- **Detection**: patients are trained to detect the presence or absence of a sound (using sound sources from daily life and voice).
- **Discrimination**: patients must recognise whether 2 items are equal or not; their progression will go from very different items, to increasingly similar items, to minimal pairs (2 words which differ in only 1 phoneme).
- **Identification**: patients are trained to recognise a sound, a word or a phrase in a closed set situation. Progression will be based on the total number of items for each exercise and their similarity. As for words, the first level of differentiation tends to focus on the relative size (number of syllables) and then goes through frequency contrasts, maximum phonetic opposition and pitch differences, finishing with minimal phonetic oppositions. Once patients reach an advanced stage of identification, they can start to use the telephone.
- **Recognition**: at this level, patients must repeat a word or phrase in an open set situation. Since for many patients this level represents a very significant step which is sometimes difficult to achieve, they may be prepared with semi-open situations, that is, with certain contextual aids (including the word to be recognised within a written sentence, placing words and phrases within a referential context from a theme, a picture, etc.). Patients may start listening to television.
- **Understanding**: patients are trained in semi-open dialogue situations (based on a theme or a specific reference) and, finally, reach open dialogue.
We must bear in mind that the exercises will be conducted with and/or without lip reading, depending on the base level of each patient. For example, for a person with little initial understanding with lip reading, the first objective of the programme will be to improve it through information from the implant. However, if the patient already has excellent lip reading abilities, the exercises will focus more directly on auditory discrimination.

The overall duration of rehabilitation can be highly variable: in general, a period between 6 months and 1 year is indicated, with an initial intensive frequency which is progressively reduced as the patient progresses, and also depending on the possibility that the family can take part in training. As previously mentioned, some cases may require far less time, but it is also important to note that long-term improvements also take place, even 2 or 3 years after implantation.

It is recommended that the contents of training are adapted to the cultural and social circumstances of each patient insofar as possible, and also that the family is involved, both from the point of view of their own training and of psychological support.

Pre-lingual Patients Older Than 6 Years, Adolescents and Adults

These patients lack preestablished auditory patterns or only have very basic schemes about the nature of sounds. In most cases, their language and speech present significant distortions and limitations. Neither the results nor the pace of progress will be similar to those of postlingual subjects.

Prior to the placement of the CI, these patients usually employed complementary and/or alternative modes to oral communication. Following the activation of the CI, they should continue with these modes of communication, so that the visual component will be progressively reduced as auditory information beings to cover the communication needs of the subject.

The structure of the rehabilitation programme is no different from the previous case, but the time required for each stage will be considerably longer. In general, a rehabilitation covering 2–5 years of relatively intensive work is to be expected. In the case of children or adolescents of school age who receive specialised help, either at special or inclusive schools, it is advisable that this training is incorporated into the auditory and verbal stimulation programme and continued for the entire school term.

The technical monitoring of the implant in such cases should be done more frequently since, at least initially, it is likely that these patients may not notice small differences in the performance of their implants and, therefore, will not indicate so spontaneously.

Pre-lingual Patients Younger than 6 Years

In these cases, implantation takes place as the global process of voice, speech, and language rehabilitation is starting. In such cases, the programme is no longer specific for the cochlear implant; instead the implant becomes an aid for a more effective use of stimulation provided by the specialised educational team and the family, precisely during the years when the auditory capacity of the brain is at its optimum stage for such learning.

Therefore, it is important that the teaching staff maintain close contact with the implant monitoring team.

The techniques employed will not differ from those commonly used in auditory, vocal, and early language education. They require a high level of preparation and intensity throughout the preschool stage. The methods used will be much more comprehensive and functional than in the case of older children and adults.

A cochlear implant in a young child will only be effective if the accompanying educational programme has a strong focus on the use and development of oral language. This does not exclude the use in parallel of other communication modes as a complement to oral communication.

Monitoring Phase

Obtaining optimal results in patients with a CI does not only depend on the satisfactory completion of the stages mentioned, but also on an adequate monitoring conducted throughout their lives. When analysing long-term evolution and considering that correct hearing directly depends on the flawless operation of every component of the CI under potentially changing biological conditions, it is clear that this stage is of great significance.

Accomplishing this task represents a challenge. Firstly, because it consists in providing long-term quality care, 365 days a year, and secondly, because the recipient population of this care experiences an exponentially cumulative increase. Therefore, developing a structure capable of covering these needs is a goal that must be addressed by the entire CI team.

The tasks to be considered during the monitoring phase are the following:

- Evaluation of the clinical status of the implanted patient.
- Comprehensive assessment of results achieved.
- Verification of the operation of the CI.
- Review of the programming of the CI.
- Technical maintenance of the CI devices.
- Adjustments in the rehabilitation model.
- Information for the family.

Evaluation of the Clinical Condition of Implanted Patients

In the review consultation, the otolaryngologist should verify the presence of medical complications related to implantation, as well as the appearance of new risks or conditions that could compromise the normal functioning of the implanted system.

ENT examination, with a special emphasis on otoscopy and inspection of the retroauricular region, should highlight the existence of local complications. A simple radiographic study is sufficient to determine the location and depth of insertion of the electrodes, in addition to being useful for monitoring the presence of certain types of damage to the electrode. Special attention should be paid to signs and symptoms of a neurological nature, a fact that should be evaluated in coordination with a specialist in neurology or paediatric neurology.
Comprehensive Evaluation of Results Obtained

The main reason for this assessment is not simply to monitor results, but rather to study measurements which help to establish the performance of each implant through time. In the event that development does not occur as expected, it will help to investigate the possible causes.

Benefit assessment is made by techniques which evaluate the changes obtained in sound perception and discrimination, as well as speech production and language development. Similarly, this assessment should be incorporated into other measurements which, together, help to provide a comprehensive understanding of the condition of an implanted patient. In this sense, the material collected in the "Guidelines for the global assessment of children with hearing impairment" and in the "Technical Manual for the use of the Guidelines for the global assessment of children with hearing impairment", developed by an Expert Committee from the Spanish Hearing Aid Committee, under the auspices of the Royal Board on Disability, may be of great interest for the paediatric population.

Verification of the Operation of the Cochlear Implant

The various internal and external components of a CI may suffer failures which directly affect performance. The incidence, classification and reporting method of such failures has been the subject of various publications.

It is very important to detect and correct any failures affecting any of the elements of a CI as soon as possible. This is especially relevant in young children with implants, who will not, by themselves, be able to express that something is not working correctly. Therefore, it is essential to elaborate a review schedule along with the implant team, and also to establish an education programme aimed at patients, families, speech therapists and educators, so that they may be able to detect warning signs that point to a malfunction of the CI.

Undoubtedly, failure of the implanted parts has major implications, since their resolution implies performing reimplantation surgery. Failure of the external CI components can easily be repaired. However, the detection of these faults must take place promptly, since their ultimate result is the absence of adequate stimulation, with subsequent clinical implications.

Review of the Programming of Cochlear Implants

Cochlear implant programming should be reviewed periodically since, during the evolution, there will be changes requiring further adjustments in the stimulation mode of the electrodes. These controls should also help to detect and diagnose equipment failures, thus facilitating prompt repair. A scheme to be followed in children could be: 1 month, 3 months, 6 months, every 6 months during the development and consolidation of language and annually thereafter. In adults, after the initial programming, these reviews take place at 1 month, 3 months, 6 months, 1 year, and annually thereafter.

These reviews are conducted by the Programming Unit and should coincide with those conducted by other members of the cochlear implant team. This will facilitate a comprehensive picture of evolution, allowing the team to take any necessary corrective actions.

Technical Maintenance of the Devices of the Cochlear Implant

Technical support and instructions on handling are very important in implanted patients. Malfunction of the CI generates great anxiety and restlessness in deaf patients, since it returns them to a soundless world. Therefore, as previously mentioned, CI failures should be considered as an emergency, especially in the case of children, in whom the hearing deprivation period should be minimised.

It is important to note that the members of the CI Programming Unit should be trained to diagnose most commonly occurring technical problems. Technical service departments of the CI manufacturing companies will complement this technical support work by collaborating with the implant centre and Programming Unit. Ideally, the latter should have various replacement parts available, including spare processors, in order to avoid technical failures of the CI diluting in time.

Adjustments to the Rehabilitation Model

The results obtained should be used to aid decision-making on the rehabilitation model to be followed with each implanted person. Maintaining a cohesive team, in which the communication between its members is fluid, is one of the keys to achieving this goal.

Information for the Family

Family members living daily with the implanted person will be aware of the difficulties in the daily management of the implanted system and will note the progress achieved by the subject. In the case of young implanted children, information provided by the family during reviews and through questionnaires will be essential in assessing progress in the areas of hearing and speech.

Requirements for the Implementation of a Cochlear Implant Programme

The implementation of a CI programme requires, as a previous and indispensable step, knowledge of the needs of the population. In addition, the appropriate healthcare requirements to meet expected demand must also be established. It is essential to have a multidisciplinary team of professionals with appropriate training and a level of demand which ensures a regular workload.

Cochlear Implant Requirements from a Population Standpoint

In a study of the "National Cochlear Implant Programme" conducted in the UK between 1990 and 1994, Summerfeld et al. detected an annual demand of 4 new cases per million in children and 1 in adults. Moreover, profound sensorineural hearing loss in children is mostly manifested among newborns and has an incidence of 1 per 1000 newborns who would be susceptible to cochlear implantation. According to the current birth rate in Spain (1 annual birth per 1000 inhabitants), this offers a similar number of candidates for implantation among children as previously mentioned. In addition, there is a historical remnant of patients in whom a CI would be indicated, which has been calculated at around 10 cases per 500,000 inhabitants among
children under 6 years of age, and 14 cases among those aged over 7 years. Clearly, these figures may vary depending on the criteria established for the indication. For example, changes in audiometric criteria to include cases with severe, bordering on deep, sensorineural hearing loss, would dramatically increase the number of candidates for CI.

The number of implantations performed by a team should be sufficient and coordinated. Therefore, it is not advisable to establish a cochlear implant programme in order to treat a reduced number of patients per year. Neither would it be advisable to implant a large population within a short period of time, as it would subsequently become difficult to treat patients adequately. On the other hand, since cochlear implantation is a lifelong issue, the number of implanted subjects will increase with the passage of time and the resources dedicated to its follow-up will need to increase in the same proportion. This suggests the creation of experienced and highly qualified centres which constitute reference units for the care of candidates for or users of a cochlear implant.

Members of a Cochlear Implant Programme

Those professionals required for a CI programme have already been mentioned, considering the recommendations of the Agency for Health Technology Assessment of Instituto Carlos III and the Expert Committee on Disability of the Royal Board. The functions performed by each professional, as outlined in the guidelines of Morera et al., will be henceforth described. As we shall see, members of the CI programme have been grouped into those belonging to the implant centre, those attached to the hospital and those offering local support, located near the residences of implanted patients (Fig. 3).

Implantation Centre

Otolaryngologist. This specialist has a key role, as he will be responsible for surgery, as well as for the indication and monitoring of the CI. Therefore, the patient selection process, including medical, audiological, radiological evaluation, etc., should be carefully studied by the surgeon before determining surgical indication. Furthermore, in addition to surgical implantation, the specialist must be in charge of postoperative monitoring of the implant by assessing its results. All this makes him into the keystone of the CI programme. 

Oto-neuroradiologist. The contribution of this specialist is essential in the selection phase in order to assess the patency of the cochlear scalae, rule out inner ear malformations, including agenesis of the cochlear nerve and other anatomical data relevant to surgery, such as the degree of pneumatization of the middle ear and the location of the facial nerve and lateral sinus. Likewise, his expertise will be crucial when analysing the brain parenchyma.

His involvement may be useful to assess the level of insertion and position of the electrodes, thus establishing a reference for the postoperative monitoring of their location and the diagnosis of a possible migration out of the cochlea.

Generally, the techniques used for this purpose are CT and MRI scans, although the latter should be used with some restrictions regarding current devices once they have been implanted. Conventional and digital radiology are still useful in the preoperative and postoperative assessment of CI.

Audiologist. Since the objective is to treat hypoacusis patients, it is essential to conduct a proper assessment of hearing, mainly during the patient selection process. Therefore, it is indispensable to have an experienced audiology team, specialising in paediatric audiology in the case of children, which is able to enact hearing evaluation protocols created specifically for a CI programme.

Furthermore, activation and programming of the CI in the initial stages, periodic review of its performance, preoperative and postoperative telemetric evaluations, assessment of the results and performance of the CI are fundamental tasks conducted by an audiologist during patient monitoring. Given the aforementioned duties, audiologists represent the backbone of the Programming Unit. This Unit must be located within the implant centre. Only thus may a strong collaboration with other professionals be established during intraoperative telemetry tests, as well as the programming and monitoring phases.

Audio-Prosthetic Specialist. The work of this specialist will be essential in ensuring that the hearing aid employed is suitable, its operation is optimal and it provides the best possible performance. This verification is important during the selection phase, in order to establish whether there are audiometric criteria to support the indication for a CI.

In implanted patients undergoing bimodal or electro-acoustic stimulation, the collaboration of an audio-prosthetic technician will also be important to adjust the hearing aid to the stimulation delivered by the CI.

Speech Therapist. Although their role is crucial in the rehabilitation phase, as discussed below in the section on local support, the involvement of a speech therapist integrated within the implant centre is useful during the programming of the CI.

Psychologists and Psychiatrists. The main objective of these specialists is to rule out the existence of any psychiatric condition and to assess the expectations and psychological conditions of patients, as well as their family and social environment.

In children, it is important to study the development of cognitive functions in relation to their age, educational status and family environment. During follow-up, it may be...
useful to assess progress and act therapeutically when the case so requires.

Other Healthcare Professionals. Depending on the characteristics of each patient, the involvement of other health professionals such as neurologists, neuropaediatricians, paediatricians, internists or ophthalmologists, among others, may become necessary, as is normal in a hospital environment.  

The involvement of social workers may also become necessary. Their collaboration can be very helpful in certain cases of patients who are candidates for CI or already implemented.

Local Support
Phoniatricians and Speech Therapists. Their collaboration is essential for the development of a CI programme. Prior auditory training and early stimulation are aspects to be analysed, since they have a considerable influence on the correct development of deaf children. However, their work is primarily developed in the postoperative rehabilitation phase, especially in children with prelingual hearing loss, conducting an individualised assessment of each case, marking and executing treatment guidelines according to the circumstances of each case.

These specialists also assist in monitoring and evaluating changes in understanding and development of speech and language. Their postoperative relationship with educators and families will include information and advice on those therapeutic aspects to be developed and recommendations according to the evolution.

Educators. The relationship of implant team managers with educators is essential in a paediatric CI programme. Children must be regarded as a “whole” and since they are in a period of knowledge acquisition, there must be an exchange of information between the CI team and educators, to complement the findings observed by each party in the development of the child.

Their function is to help optimise the results related to the acquisition of language. Moreover, their opinion on learning development is highly valuable, due to their prolonged and direct connection with children, allowing them to notice alterations which could hardly be observable by other members of the CI programme.

Family. Family support, especially from the closest relatives is essential for success after placement of a CI. Their greater ease to communicate with their deaf relative should be used to help them understand the issues and alternatives raised by inclusion in a CI programme.

The role of parents is crucial in the case of young children, since their dependence will be greater at lower ages. They will be responsible for the decision to include their child in a CI programme, but should also be actively involved in the process of rehabilitation, monitoring and evaluation of the CI, helping to highlight any problems that may arise. Thus, they should be informed promptly by the various professionals involved in the programme.

Technical Support. It is the responsibility of the implant centre to conduct the diagnosis of complications, including technical failure of the implant. Companies which manufacture CI are responsible for managing the resolution of those problems, either by replacing or repairing damaged parts promptly.

### Table 2  Guide for the Stepwise Planning of Actions in a Cochlear Implant Programme, According to the Difficulty of the Procedures Conducted in the Surgical, Audiological Programming, and Rehabilitation Fields.

<table>
<thead>
<tr>
<th>Surgical activity</th>
<th>Adults:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normal anatomy.</td>
<td></td>
</tr>
<tr>
<td>2. Partial cochlear ossification, &lt;4 mm from round window.</td>
<td></td>
</tr>
<tr>
<td>3. Partial cochlear ossification, &lt;7 mm from round window.</td>
<td></td>
</tr>
<tr>
<td>4. History of mastoidectomy with open technique.</td>
<td></td>
</tr>
<tr>
<td>5. Total cochlear ossification.</td>
<td></td>
</tr>
<tr>
<td>Children:</td>
<td></td>
</tr>
<tr>
<td>1. Normal anatomy in children older than 3 years.</td>
<td></td>
</tr>
<tr>
<td>2. Normal anatomy in children between 1 and 3 years.</td>
<td></td>
</tr>
<tr>
<td>3. Incomplete cochlear ossification (Mondini malformation).</td>
<td></td>
</tr>
<tr>
<td>4. Partial cochlear ossification, &lt;4 mm from round window.</td>
<td></td>
</tr>
<tr>
<td>5. Partial cochlear ossification, &lt;7 mm from round window.</td>
<td></td>
</tr>
<tr>
<td>6. History of mastoidectomy with open technique.</td>
<td></td>
</tr>
<tr>
<td>7. Common cavity.</td>
<td></td>
</tr>
<tr>
<td>8. Cochlear hypoplasia.</td>
<td></td>
</tr>
<tr>
<td>10. Total cochlear ossification.</td>
<td></td>
</tr>
</tbody>
</table>

### Audiological evaluation
1. Adults and children with postlingual hypoacusis.
2. Children with prelingual hypoacusis older than 4 years of age.
3. Children with prelingual hypoacusis aged between 2 and 4 years.
4. Children with prelingual hypoacusis younger than 2 years of age.

### Programming of CI
1. Adults.
2. Children.
4. Bilateral CI.
5. Children with other disabilities associated to hypoacusis.

### Rehabilitation
1. Adults with postlingual hypoacusis.
2. Children with postlingual hypoacusis.
3. Children with prelingual hypoacusis older than 4 years of age.
4. Children with prelingual hypoacusis aged between 2 and 4 years.
5. Children with prelingual hypoacusis younger than 2 years of age.
6. Patients in general undergoing bimodal stimulation.
7. Patients in general with sequential bilateral implants.
8. Patients in general with other disabilities associated to hypoacusis.
In order to carry out the diagnosis of technical failures, manufacturing companies must make all the necessary equipment and training available to implant centres. Usually, this means maintaining a sustained effort, given the rapid technological evolution experienced by CI models.

Planning of Activities in a Cochlear Implant Programme
Each of the professionals involved in a CI programme must gain experience through candidates with simpler processes before tackling more complex cases. For example, it is important to obtain experience in postlingually implanted adults before initiating programmes for children. Not only are there marked differences in the selection phase, but also in programming, rehabilitation and monitoring.

As a guideline, Table 2 presents a programming guide that may be useful to plan the activity of a CI programme, going from simple to more complex situations. The difficulty of these situations has been classified according to the intervention of professionals.

Conclusions
A cochlear implant programme requires a multidisciplinary structure capable of selecting candidates, perform surgery for implantation of the internal elements of the implant, activate it and programme it according to the characteristics of each patient, as well as establishing guidelines for rehabilitation, education and monitoring which ensure satisfactory results. The professionals involved in this multidisciplinary structure must work in a closely coordinated manner. Only then will it be possible to offer comprehensive treatment to patients with hearing impairment who carry a cochlear implant.

Financing
This article has received unconditional funding from Advanced Bionics.

Conflict of Interests
The authors have no conflict of interests to declare.

Acknowledgements
We wish to thank Advanced Bionics for their contribution to continuing education in the field of cochlear implants by favouring the elaboration of teaching material.

References


