

## ***Cochlear Implant***

**Effective:** January 1, 2019

**Next Review:** March 2019

**Last Review:** December 2018

### **IMPORTANT REMINDER**

Medical Policies are developed to provide guidance for members and providers regarding coverage in accordance with contract terms. Benefit determinations are based in all cases on the applicable contract language. To the extent there may be any conflict between the Medical Policy and contract language, the contract language takes precedence.

PLEASE NOTE: Contracts exclude from coverage, among other things, services or procedures that are considered investigational or cosmetic. Providers may bill members for services or procedures that are considered investigational or cosmetic. Providers are encouraged to inform members before rendering such services that the members are likely to be financially responsible for the cost of these services.

### **DESCRIPTION**

A cochlear implant is a device for treatment of severe-to-profound hearing loss in individuals who only receive limited benefit from amplification with hearing aids.

### **MEDICAL POLICY CRITERIA**

#### **Notes:**

- This policy does not apply to surgically anchored bone-conduction hearing aids or externally worn air-conduction hearing aids. Cochlear implants are not hearing aids. While hearing aids function by amplifying sound, cochlear implants replace the functions of an absent or nonfunctioning cochlea.
- This policy does not address the use of the Nucleus® 24 Auditory Brain Stem Implant, which is designed to restore hearing in patients with neurofibromatosis who are deaf secondary to removal of bilateral acoustic neuromas.
- Hybrid cochlear implant/hearing aid systems are devices that include a hearing aid integrated into the external sound processor of the cochlear implant. If hearing aid components of such systems are billed separately, there may be specific member benefit language addressing coverage of hearing aids that would be applicable. Contract language takes precedence over medical policy.

- Repeat hearing tests or trials of hearing aids are not necessary for patients who have previously met criteria I. and II. as it is unlikely that natural hearing or the benefit from hearing aids will improve significantly over time.

I. **Unilateral or bilateral implantation of FDA approved (i.e., PMA or 510k only) cochlear implants, *other than* cochlear implant/hearing aid *hybrid* devices, and associated aural rehabilitation may be considered **medically necessary** when both of the following criteria (A and B) are met:**

A. Patients 12 months or older who meet either of the following criteria:

1. Patients diagnosed with enlarged vestibular aqueduct (EVA) (greater than 1mm at the midpoint), as evidenced by MRI or CT imaging; or
2. Patients with both of the following (a and b):
  - a. Bilateral severe to profound pre- or postlingual (sensorineural) hearing loss, defined as a pure-tone average of 70 decibels (dB) hearing threshold or greater at 500 Hz (hertz), 1000 Hz and 2000 Hz; and
  - b. Limited or no benefit from hearing aids (defined below) unless hearing aids are unreasonable.
    - i. Adults: Scores less than or equal to 50 percent correct on tape recorded sets of open-set sentence recognition in the ear to be implanted
    - ii. Children: Failure to develop basic auditory skills, and in older children, less than or equal to 30 percent correct on open-set tests

B. Patients do not have any of the following contraindications:

1. Deafness due to lesions of the acoustic nerve (eighth cranial nerve), central auditory pathways, or brain stem in the implanted ear
2. Active or chronic infections of the external or middle ear and mastoid cavity in the implanted ear, including but not limited to otitis media.
3. Tympanic membrane perforation
4. Radiographic evidence of absent cochlear development in the implanted ear
5. Inability or lack of willingness to participate in post-implantation aural rehabilitation.

II. **Unilateral implantation of FDA approved (i.e., PMA or 510k only) *hybrid* cochlear implant/hearing aid systems that include the hearing aid integrated into the external sound processor of the cochlear implant, may be considered **medically necessary** when all of the following criteria are met (A – E):**

- A. Age 18 years or older; and
- B. Bilateral severe to profound pre- or postlingual (sensorineural) hearing loss, defined as a pure-tone average of 70 decibels (dB) hearing threshold or greater at 500 Hz (hertz), 1000 Hz and 2000 Hz; and

- C. Limited or no benefit from hearing aids unless hearing aids are unreasonable, defined as scores less than 50 percent correct on tape recorded sets of open-set sentence recognition in the ear selected for implantation; and
- D. Meets all of the following (1 and 2):
  - 1. All of the following in the ear selected for implantation (a – c):
    - a. Low frequency hearing thresholds no poorer than 60 dB hearing level up to and including 500 Hz (averaged over 125, 250, and 500 Hz; i.e., threshold average of 125, 250, and 500 Hz less than or equal to 60 dB hearing level); and
    - b. Severe to profound mid-to-high frequency hearing loss (threshold average of 2000, 3000, and 4000 Hz greater than or equal to 75 dB hearing level); and
    - c. Aided consonant-nucleus-consonant word recognition score from 10 percent to 60 percent in the preoperative aided condition
  - 2. All of the following for the contralateral ear (a and b):
    - a. Moderately severe to profound mid-to-high frequency hearing loss (threshold average of 2000, 3000, and 4000 Hz greater than or equal to 60 dB hearing level); and
    - b. Aided consonant-nucleus-consonant word recognition score equal to or better than that of the ear selected for implantation but not more than 80 percent correct; and
- E. Does not have any of the following contraindications:
  - 1. Deafness due to lesions of the acoustic nerve (eighth cranial nerve), central auditory pathways, or brain stem in the implanted ear
  - 2. Active or chronic infections of the external or middle ear and mastoid cavity in the implanted ear, including but not limited to otitis media
  - 3. Tympanic membrane perforation
  - 4. Radiographic evidence of absent cochlear development in the implanted ear
  - 5. Inability or lack of willingness to participate in post-implantation aural rehabilitation.
  - 6. A duration of severe to profound hearing loss of 30 years or greater.
- III. Implant replacement with a *next-generation* device may be considered **medically necessary** only in the small subset of patients whose response to existing components is inadequate to the point of interfering with activities of daily living, which would include school and work.
- IV. Implant replacement with a *next-generation* device is considered **not medically necessary** when criterion III. is not met.
- V. Implantation of cochlear implants is considered **not medically necessary** when neither criterion I. nor II. above is met.
- VI. Upgrades of an existing, functioning external system to achieve aesthetic improvement, such as smaller profile components, or a switch from a body-worn

external sound processor to a behind-the-ear (BTE) model are considered **not medically necessary**.

*NOTE: A summary of the supporting rationale for the policy criteria is at the end of the policy.*

## POLICY GUIDELINES

### REQUIRED DOCUMENTATION:

It is critical that the list of information below is submitted for review to determine if the policy criteria are met. If any of these items are not submitted, it could impact our review and decision outcome.

- History and Physical/Chart Notes
- Manufacturer and Model Name of Cochlear Implant being requested
- Audiology test results

## CROSS REFERENCES

1. [Transcutaneous Bone-Conduction and Bone-Anchored Hearing Aids](#), Surgery, Policy No. 121

## BACKGROUND

A cochlear implant provides direct electrical stimulation to the auditory nerve, bypassing the usual transducer cells that are absent or nonfunctional in deaf cochlea. The basic components of a cochlear implant include both external and internal components. The external components include a microphone, an external sound processor, and an external transmitter. The internal components are implanted surgically and include an internal receiver implanted within the temporal bone, and an electrode array that extends from the receiver into the cochlea through a surgically created opening in the round window of the middle ear.

Sounds that are picked up by the microphone are carried to the external signal processor, which transforms sound into coded signals that are then transmitted transcutaneously to the implanted internal receiver. The receiver converts the incoming signals to electrical impulses that are then conveyed to the electrode array, ultimately resulting in stimulation of the auditory nerve.

Hearing loss is rated on a scale based on the threshold of hearing. Severe hearing loss is defined as a bilateral hearing threshold of 70-90 decibels (dB) and profound hearing loss is defined as a hearing threshold of 90 dB and above.

A post-cochlear implant rehabilitation program is necessary to achieve benefit from the cochlear implant. The rehabilitation program includes development of skills in understanding running speech, recognition of consonants and vowels, and tests of speech perception ability.

### REGULATORY STATUS

Note: Full FDA approval includes only Premarket Approval (PMA) and 510k approval. Devices with Investigational Device Exemption (IDE) or Humanitarian Device Exemption (HDE) are not considered fully FDA approved.

Several cochlear implants are commercially available in the United States. The FDA-labeled indications for currently marketed electrode arrays are summarized in the table below. Over the years, subsequent generations of the various components of the devices have been FDA approved, focusing on improved electrode design and speech-processing capabilities. Furthermore, smaller devices and the accumulating experience in children have resulted in broadening of the selection criteria to include children as young as 12 months.

Manufacturer and FDA approved Cochlear Implants	Indications for Adults or Children
<b>CONVENTIONAL COCHLEAR IMPLANTS</b>	
<p><b>Advanced Bionics®</b></p> <ul style="list-style-type: none"> <li>• HiResolution Bionic Ear System (HiRes 90K*)</li> <li>• Predecessors:               <ul style="list-style-type: none"> <li>○ Clarion Multi-Strategy</li> <li>○ HiFocus CII Bionic Ear</li> </ul> </li> </ul>	<p style="text-align: center;"><u>Adults:</u></p> <ul style="list-style-type: none"> <li>• ≥ 18 years of age</li> <li>• Post-lingual onset of severe to profound bilateral sensorineural hearing loss [≥70 decibels (dBs)]</li> <li>• Limited benefit from appropriately fitted hearing aids, defined as scoring ≤ 50% on a test of open-set Hearing in Noise Test (HINT) sentence recognition</li> </ul> <p style="text-align: center;"><u>Children:</u></p> <ul style="list-style-type: none"> <li>• 12 months to 17 years of age</li> <li>• Profound bilateral sensorineural deafness (&gt;90dB)</li> <li>• Use of appropriately fitted hearing aids for at least 6 months in children 2 to 17 years of age or at least 3 months in children 12 to 23 months of age.</li> <li>• Lack of benefit in children &lt;4 years of age is defined as a failure to reach developmentally-appropriate auditory milestones (e.g., spontaneous response to name in quiet or to environmental sounds) measured using the Infant-Toddler Meaningful Auditory Integration Scale or Meaningful Auditory Integration Scale or &lt; 20% correct on a simple open-set word recognition test (Multisyllabic Lexical Neighborhood Test) administered using monitored live voice [70 dB SPL (sound pressure level)]</li> <li>• Lack of hearing aid benefit in children &gt;4 years of age is defined as scoring &lt; 12% on a difficult open-set word recognition test (Phonetically Balanced-Kindergarten Test) or &lt; 30% on an open-set sentence test (HINT for Children) administered using recorded materials in the soundfield (70 dB SPL)</li> </ul>
<p><b>Cochlear®</b></p> <ul style="list-style-type: none"> <li>• Kanso™</li> <li>• Nucleus® 6</li> <li>• Nucleus® 5*</li> <li>• Nucleus Freedom</li> <li>• Predecessors:               <ul style="list-style-type: none"> <li>○ Nucleus 22, 24</li> </ul> </li> </ul>	<p style="text-align: center;"><u>Adults:</u></p> <ul style="list-style-type: none"> <li>• ≥ 18 years old</li> <li>• Pre- or post-lingual onset of moderate to profound bilateral sensorineural hearing loss</li> <li>• ≤50% sentence recognition in the ear to be implanted</li> <li>• ≤60% sentence recognition in the opposite ear or binaurally</li> </ul> <p style="text-align: center;"><u>Children 12 months to 24 months:</u></p> <ul style="list-style-type: none"> <li>• Profound sensorineural hearing loss bilaterally</li> <li>• Limited benefit from appropriate binaural hearing aids</li> <li>• Lack of progress in the development of auditory skills</li> </ul> <p style="text-align: center;"><u>Children 25 months to 17 years 11 months:</u></p>

Manufacturer and FDA approved Cochlear Implants	Indications for Adults or Children
	<ul style="list-style-type: none"> <li>• Severe to profound bilateral sensorineural hearing loss</li> <li>• Multi-syllabic Lexical Neighborhood Test (MLNT) scores of ≤30% in best-aided condition in children 25 months to 4 years 11 months</li> <li>• Lexical Neighborhood Test (LNT) scores of ≤30% in best-aided condition in children 5 years to 17 years and 11 months</li> <li>• Lack of progress in the development of auditory skills</li> </ul>
<p><b>Med EI®</b></p> <ul style="list-style-type: none"> <li>• Maestro (Concerto, Sonata or Pulsar)</li> <li>• Predecessor: <ul style="list-style-type: none"> <li>○ Combi 40+</li> </ul> </li> </ul>	<p style="text-align: center;"><u>Adults:</u></p> <ul style="list-style-type: none"> <li>• ≥ 18 years old</li> <li>• Severe to profound bilateral sensorineural hearing loss (≥70dB)</li> <li>• ≤40% correct Hearing in Noise test (HINT) sentences with best-sided listening condition</li> </ul> <p style="text-align: center;"><u>Children:</u></p> <ul style="list-style-type: none"> <li>• 12 months to 18 years with profound sensorineural hearing loss (≥90dB)</li> <li>• In younger children, little or no benefit is defined by lack of progress in the development of simple auditory skills with hearing aids over a 3-6 month period</li> <li>• In older children, lack of aided benefit is defined as &lt;20% correct on the MLNT or LNT depending upon the child's cognitive ability and linguistic skills</li> <li>• A 3-6 month trial with hearing aids is required if not previously experienced</li> </ul>
<b>HYBRID COCHLEAR IMPLANTS</b>	
<p><b>Cochlear®</b></p> <ul style="list-style-type: none"> <li>• Nucleus® Hybrid™ L24 Cochlear Implant (Nucleus 6)</li> </ul>	<p style="text-align: center;"><u>Adults:</u></p> <ul style="list-style-type: none"> <li>• ≥ 18 years old</li> <li>• Residual low-frequency hearing sensitivity</li> <li>• Severe to profound high-frequency sensorineural hearing loss</li> <li>• Limited benefit from appropriately fit bilateral hearing aids</li> </ul>
<p><b>Med EI®</b></p> <ul style="list-style-type: none"> <li>• Med EL EAS™</li> </ul>	<p style="text-align: center;"><u>Adults:</u></p> <ul style="list-style-type: none"> <li>• ≥ 18 years old</li> <li>• Residual low-frequency hearing sensitivity</li> <li>• Severe to profound high-frequency sensorineural hearing loss</li> <li>• Candidates should go through a suitable hearing aid trial, unless already appropriately fit with hearing aids</li> </ul>
<b>RECENTLY FDA-APPROVED DEVICES</b>	
<ul style="list-style-type: none"> <li>• <u>New devices that come onto the market are added to the policy at policy updates. In the interim, new devices may be approved for coverage for FDA-approved indications when applicable criteria are met.</u></li> </ul>	

\*Note: Cochlear, Ltd. voluntarily recalled the Nucleus CI500 range in September 2011 for device malfunction in the CI512 implant. The external Nucleus 5 sound processor is not a part of the recall. Advanced Bionics HiRes90K was voluntarily recalled in November 2010 and given FDA-approval for re-entry to market the device in September 2011.

While cochlear implants have typically been used mono laterally, in recent years, interest in bilateral cochlear implantation has arisen. The proposed benefits of bilateral cochlear implants are to improve understanding of speech in noise and localization of sounds. Improvements in speech intelligibility may occur with bilateral cochlear implants through binaural summation; i.e., signal processing of sound input from two sides may provide a better representation of sound and allow one to separate out noise from speech. Speech intelligibility and localization of sound or spatial hearing may also be improved with head shadow and squelch effects, i.e., the ear that is closest to the noise will be received at a different frequency and with different intensity, allowing one to sort out noise and identify the direction of sound. Bilateral cochlear implantation may be performed independently with separate implants and speech processors in each ear or with a single processor. However, no single processor for bilateral cochlear implantation has been FDA approved for use in the United States. In addition, single processors do not provide binaural benefit and may impair localization and increase the signal to noise ratio received by the cochlear implant.

In March 2014, FDA approved the Nucleus® Hybrid™ L24 Cochlear Implant System (Cochlear Corporation) through the premarket approval process.<sup>[1]</sup> This system is a hybrid cochlear implant and hearing aid, with the hearing aid integrated into the external sound processor of the cochlear implant. It is indicated for unilateral use in patients aged 18 years and older who have residual low-frequency hearing sensitivity and severe to profound high-frequency sensorineural hearing loss, and who obtain limited benefit from appropriately fit bilateral hearing aid. The electrode array inserted into the cochlea is shorter than conventional cochlear implants. According to the FDA's premarket approval notification, labeled indications for the device include:

- Preoperative hearing in the range from normal to moderate hearing loss (HL) in the low frequencies (thresholds no poorer than 60 dB HL up to and including 500 Hz).
- Preoperative hearing with severe to profound mid- to high-frequency hearing loss (threshold average of 2000, 3000, and 4000 Hz  $\geq 75$  dB HL) in the ear to be implanted.
- Preoperative hearing with moderately severe to profound mid- to high-frequency hearing loss (threshold average of 2000, 3000, and 4000 Hz  $\geq 60$  dB HL) in the contralateral ear.
- Consonant-Nucleus-Consonant (CNC) word recognition score between 10% to 60% (inclusively) in the ear to be implanted in the preoperative aided condition and in the contralateral ear equal to or better than that of the ear to be implanted but not more than 80% correct.

In September 2016, FDA approved the Med EL EAS™ (Electric Acoustic Stimulation) Hearing Implant System (Med EL Corp.).<sup>[2]</sup> This system is a hybrid cochlear implant and hearing aid, with the hearing aid integrated into the external sound processor of the cochlear implant. It is the combination of the SYNCHRONY cochlear implant and the SONNET EAS audio processor. According to the FDA's premarket approval notification:<sup>[3]</sup>

The MED-EL EAS System is indicated for partially deaf individuals aged 18 years and older who have residual hearing sensitivity in the low frequencies sloping to a severe/profound sensorineural hearing loss in the mid to high frequencies, and who obtain minimal benefit from conventional acoustic amplification. Typical preoperative hearing of candidates ranges from normal hearing to moderate sensorineural hearing loss in the low frequencies (thresholds no poorer than 65 dB HL up to and including 500 Hz) with severe to profound mid- to high-frequency hearing loss (no better than 70 dB HL at 2000 Hz and above) in the ear to be implanted. For the non-implanted ear,

thresholds may be worse than the criteria for the implanted ear, but may not be better. The CNC word recognition score in quiet in the best-aided condition will be 60% or less, in the ear to be implanted and in the contralateral ear. Prospective candidates should go through a suitable hearing aid trial, unless already appropriately fit with hearing aids.

## EVIDENCE SUMMARY

Cochlear implants (CI) are recognized effective treatment of sensorineural deafness in select patient, as noted in a 1995 National Institutes of Health Consensus Development conference, which offered the following conclusions:<sup>[4]</sup>

- Cochlear implantation has a profound impact on hearing and speech reception in postlingually deafened adults with positive impacts on psychological and social functioning.
- The results are more variable in children. Benefits are not realized immediately but rather are manifested over time, with some children continuing to show improvement over several years.
- Prelingually deafened adults may also benefit, although to a lesser extent than postlingually deafened adults. These individuals achieve minimal improvement in speech recognition skills. However, other basic benefits, such as improved sound awareness, may meet safety needs.
- Training and educational intervention are fundamental for optimal post implant benefit.
- Cochlear implants in children under two years old are complicated by the inability to perform detailed assessment of hearing and functional communication. However, a younger age of implantation may limit the negative consequences of auditory deprivation and may allow more efficient acquisition of speech and language. Some children with post-meningitis hearing loss have been implanted under the age of two years due to the risk of new bone formation associated with meningitis, which may preclude a cochlear implant at a later date.

### ENLARGED VESTIBULAR AQUEDUCTS (EVA)

Enlarged vestibular aqueduct (also known as enlarged vestibular aqueduct syndrome (EVAS), large vestibular aqueduct, large vestibular aqueduct syndrome (LVAS), or dilated vestibular aqueduct) is a condition which is associated with childhood hearing loss. According to the NIH National Institute on Deafness and other Communication Disorders (NIDCD):<sup>[5]</sup> most children with enlarged vestibular aqueducts (EVA) will develop some amount of hearing loss, and approximately 5-15% of children with sensorineural hearing loss (hearing loss caused by damage to sensory cells inside the cochlea) have EVA.

### Systematic Reviews

In 2014, Xu conducted a systematic review in Chinese to assess the efficacy and safety of cochlear implantation in deaf patients with inner ear malformations compared to deaf patients with normal inner ear structure, including 11 RTCs (N=655 patients).<sup>[6]</sup> In terms of postoperative complications, electrode impedance, behavior T-level, hearing abilities and speech discrimination; patients with mixed inner ear malformations, Mondini syndrome or EVA were not significantly different than controls. However, the reviewers concluded that additional larger controlled studies with longer follow-up may help to evaluate the efficacy of cochlear implantation for deaf patients with inner ear malformation more reliably.



In 2012, Pakdaman conducted a systematic review to determine if abnormal cochleovestibular anatomy influences surgical and audiologic outcomes following cochlear implant (CI) surgery in children, including 22 studies.<sup>[7]</sup> Out of the 311 children included, 89 (29%) were diagnosed with EVA, considered to be a mild/moderate anomaly. Outcomes of CI surgery were analyzed based on the severity of the ear malformation (mild/moderate anomaly versus severe), and subgroup analyses were not performed based on the different malformations observed. The reviewers reported that severe inner ear dysplasia was associated with increased surgical difficulty and lower speech perception.

### **Nonrandomized Studies**

There have been a number of case series and retrospective analyses published on the efficacy of cochlear implants in patients with EVA, all generally reporting an improvement of outcomes including various clinical scores for hearing improvement and scores measuring quality of life. These studies range in size from three to 47 cases.<sup>[8-18]</sup> Some of these studies have focused on pediatric patients, while others have included mixed patient populations and have not analyzed pediatric patients from adults in terms of outcomes. Overall, these studies report that outcomes in EVA patients are comparable to cochlear implant patients with no malformations, including similar risk of cerebrospinal fluid (CSF) gusher during cochlear implantation.

There is research indicating that the age of cochlear implantation for patients with EVA affects health outcomes. In 2013, Ko conducted a study (1) to assess health outcomes of Mandarin-speaking patients with EVA after cochlear implantation (CI); (2) to compare their performance with a group of CI users without EVA; (3) to understand the effects of age at implantation and duration of implant use on the CI outcomes.<sup>[19]</sup> Forty-two patients with EVA participating in this study were divided into two groups: the early group received CI before five years of age and the late group after five years of age. The patients with EVA with more than five years of implant use (18 cases) achieved a mean score higher than 80% on the most recent speech perception tests and reached the highest level on the CAP/SIR scales. The early group developed speech perception and intelligibility steadily over time, while the late group had a rapid improvement during the first year after implantation. The two groups, regardless of their age at implantation, reached a similar performance level. These patients do not necessarily need to wait until their hearing thresholds are higher than 90 dB HL or PB word score lower than 40% to receive CI. Similar results have been reported in small pediatric case series, indicating that if patients receive cochlear implants prior to becoming severely to profoundly deaf, that residual hearing is preserved.<sup>[8,20]</sup>

In contrast to studies reporting favorable outcomes, one small retrospective study performed by Bichy in 2002 that reported better hearing outcomes in patients with EVA using hearing aid than those who had undergone cochlear implantation.<sup>[21]</sup> The analysis in this study included 16 children and adults with EVA that had undergone cochlear implantation and 10 children and adults undergoing treatment of progressive or fluctuant sensorineural hearing loss with the use of a hearing aid alone. Although the hearing aid group had a better mean pure-tone average (70.8 dB; SD 24.4) versus (107.0 dB; SD 21.7) for the cochlear implant group, the use of health utility indexes determined that greater net health benefit (including quality of life) was derived from cochlear implantation over hearing aids.

### **INFANTS UNDER AGE 12 MONTHS**

Note: FDA approval of cochlear implants (CI) includes patients over 12 months of age; therefore, implantation in infants who are under the age of 12 months is an off-label use of these devices.

The literature review focused on studies comparing the impact on hearing, speech development and recognition, and complication rates of implantation in infants younger than 12 months with those of older age groups. This includes the question of whether any early benefits that may occur in these very young patients later converge with those in older patients.

## **Systematic Reviews**

Two systematic reviews were identified that addressed CI in children under 12 months of age. The reviews, summarized below, reported few studies of CI in this age group compared with CI in children over one year of age. Both systematic reviews ranked the available studies as poor to fair due to heterogeneity in study participants and study designs, and high risk for potential bias. In addition, differences in outcomes between the age groups did not reach statistical significance. Therefore, it remains unclear whether the benefits of early cochlear implantation outweigh the risk of surgery and anesthesia in these very young patients.

In 2011 Forli reported similar findings in seven studies comparing CI implanted prior to one year of age with implantations performed after one year of age.<sup>[22]</sup> The studies precluded meta-analysis due to heterogeneity of age ranges analyzed and outcomes evaluated. While studies suggested improvements in hearing and communicative outcomes in children receiving implants prior to one year of age, between-group differences did not reach statistical significance. In addition, it is not certain whether any improvements were related to duration of cochlear implant usage rather than age of implantation. Nor is it clear whether any advantages of early implantation are retained over time.

In 2010, Vlastarakos conducted a systematic review of studies on bilateral cochlear implants in a total of 125 children implanted before one year of age.<sup>[23]</sup> The authors noted that follow-up times ranged from a median duration of 6 to 12 months and, while results seemed to indicate accelerated rates of improvement in implanted infants, the evidence available was limited and of lower quality. Additionally, the lack of reliable outcome measures for infants demonstrated the need for further research before cochlear implantation prior to one year of age becomes widespread.

## **Nonrandomized Studies**

A 2017 retrospective study by Kalejaiye assessed surgical complications, operative times, and reoperation rates in 73 patients under one year of age.<sup>[24]</sup> They compared these patients, identified from the American College of Surgeons National Surgical Quality Improvement Program Pediatric database (2012-2013), with pediatric patients in the database above the age of one. They found that the patients under one year had higher readmission rates (6.9% vs. 2.7%) and longer mean operative times (191 minutes vs. 160 minutes), but no significant differences were noted in complication rate, postoperative length of stay, or reoperation rate.

In 2015, Guerzoni conducted a prospective study of 28 children with profound sensorineural hearing loss who were implanted early with cochlear implants (mean age at device activation: 13.3 months).<sup>[25]</sup> The investigators reported that at one-year follow-up, assertiveness and responsiveness scores were within the normal range of normal-hearing age-matched peers.

Age at cochlear implant activation exerted a significant impact, with the highest scores associated to the youngest patients.

In 2011, Colletti reported on the 10-year results comparing 19 children with cochlear implants received between the ages of 2 to 11 months to 21 children implanted between 12-23 months and 33 children implanted between 24-35 months.<sup>[26]</sup> Within the first six months post-implantation, there was no significant difference among groups in Category of Auditory Performance testing but differences became significantly better in the infant group (early implantation) at the 12 and 36 month testing. Previously, Colletti reported on findings from 13 infants who had implants placed before 12 months.<sup>[27]</sup> The procedures were performed between 1998 and 2004. In this small study, the rate of receptive language growth for these early implant infants overlapped scores of normal-hearing children. This overlap was not detected for those implanted at 12–23 or 24–36 months.

In 2009 Ching published an interim report on early language outcomes of children with cochlear implants.<sup>[28]</sup> This study evaluated 16 children who had implants before 12 months of age compared to 23 who had implants after 12 months (specific time of implantation was not provided). The preliminary results demonstrated that children who received an implant before 12 months of age developed normal language skills at a rate comparable to normal-hearing children, while those with later implants performed at two standard deviations below normal. The authors noted that these results are preliminary, as there is a need to examine the effect of multiple factors on language outcomes and the rate of language development.

Johr (2008) highlighted the surgical and anesthetic considerations when performing cochlear implant surgery in very young infants.<sup>[29]</sup> This was an observational study and literature review by pediatricians at a tertiary children’s hospital in Switzerland. Surgical techniques and anesthetic management aspects of elective surgeries in small infants were analyzed in patients younger than one year of age undergoing cochlear implant surgeries. The results demonstrated that the age of the patient and the pediatric experience of the anesthesiologist, but not the duration of the surgery, are relevant risk factors. The authors concluded, “Further research is needed to provide more conclusive evidence that the performance outcome for children implanted before 12 months of age does not converge with the results of children implanted between 12 and 18 months.”

## **ADULTS AND CHILDREN OVER AGE 12 MONTHS**

Since there is sufficient evidence that bilateral and unilateral cochlear implants are safe and lead to improvements in health outcomes in adults and children over the age of twelve months with bilateral severe to profound pre- or postlingual (sensorineural) hearing loss, the evidence reviewed below will be focused on systematic reviews and randomized studies. Nonrandomized studies will not be described in detail.

### **Systematic Reviews**

The following is a summary of the most recent systematic reviews related to CI. These reviews included a critical analysis of the quality of the included studies. While noting the heterogeneity of the studies, and the potential for bias, these reviews found that the studies consistently reported beneficial outcomes for both bilateral and unilateral CI in select children and adults compared with no hearing devices or with conventional hearing aids.

#### **Adults**

In 2013, the authors of the 2011 AHRQ technology assessment reported the following findings of an updated systematic review of studies published through May 2012:<sup>[30]</sup>

- Unilateral cochlear implants

Sixteen (of 42) studies were of unilateral cochlear implants. Most unilateral implant studies showed a statistically significant improvement in mean speech scores as measured by open-set sentence or multi-syllable word tests. A meta-analysis of four studies revealed a significant improvement in cochlear-implant relevant quality of life (QOL) after unilateral implantation. However, these studies varied in design and there was considerable heterogeneity observed across studies, making it difficult to compare outcomes across studies.

- Bilateral cochlear implants

Thirteen studies reported improvement in communication-related outcomes with bilateral implantation compared with unilateral implantation and additional improvements in sound localization compared with unilateral device use or implantation only. The risk of bias varied from medium to high across studies. Based on results from at least two studies, the QOL outcomes varied across tests after bilateral implantation. A meta-analysis was not performed because of heterogeneity in design between the studies.

In 2012 and 2013 Crathorne and van Schoonhoven, respectively, published updated systematic reviews for the National Institute for Health and Care Excellence (NICE). Included studies were from the U.S. and Europe and compared bilateral with unilateral cochlear implants. In two studies the unilateral implant group also had an acoustic hearing aid for the contralateral ear. Neither systematic review was able to conduct a meta-analysis due to the heterogeneity of the studies and the level of evidence of the studies which was rated as moderate-to-poor.

In October 2011, Berrettini published results of a systematic review of unilateral and bilateral cochlear implant effectiveness in adults.<sup>[31]</sup>

- Unilateral cochlear implants

Eight articles on unilateral cochlear implants in advanced age patients were included. All of the studies reported benefits with cochlear implantation despite advanced age at time of implant (age 70 years or older). In six studies, results were not significantly different between younger and older patients. However, two studies reported statistically significant inferior perceptive results (e.g., hearing in noise test and consonant nucleus consonant test) in older patients. This systematic review also examined three studies totaling 56 adults with pre-lingual deafness who received unilateral cochlear implants. The authors concluded unilateral cochlear implants provided hearing and quality-of-life benefits in prelingually deaf patients, but results were variable.

- Bilateral cochlear implants

Thirteen articles on bilateral cochlear implants were reviewed. Sound localization improved with bilateral cochlear implants compared with monaural hearing in six studies. Significant improvements in hearing in noise and in quiet environments with bilateral implants

compared with unilateral implants were reported in ten studies and seven studies, respectively. Five of the studies reviewed addressed simultaneous implantation, five studies reviewed sequential implantation, and three studies included a mix of simultaneous and sequential implantation. However, no studies compared simultaneous to sequential bilateral implantation results, and no conclusions could be made on the timing of bilateral cochlear implantation.

In June 2011 the most recent technology assessment, by the Tufts Evidence-based Practice Center for the Agency for Health Care Research and Quality (AHRQ), reported the following findings on the effectiveness of unilateral and bilateral cochlear implants (CIs) in adults:<sup>[32]</sup>

- Unilateral cochlear implants

The assessment examined 22 studies with 30 or more patients and concluded that, while the studies reviewed were rated as poor to fair quality, unilateral cochlear implants are effective in adults with sensorineural hearing loss. Pre- and post-cochlear implant scores on multi-syllable tests and open-set sentence tests demonstrated significant gains in speech perception regardless of whether a contralateral hearing aid was used along with the cochlear implant. Additionally, the assessment found generic and disease-specific health-related quality of life improved with unilateral cochlear implants. However, the available evidence was insufficient to draw conclusions on improvements in open-set sentence test scores (i.e., >40% and ≤50% or >50% and ≤60%), and any relationship between pre-implantation patient characteristics and outcomes [e.g., age, duration of hearing impairment, Hearing in Noise Test (HINT) scores and pre- or post-linguistic deafness.]

- Bilateral cochlear implants

The technology assessment examined 16 studies published since 2004 which were determined to be of fair to moderate quality. The assessment concluded that bilateral cochlear implants provided greater benefits in speech perception test scores, especially in noise, when compared with unilateral cochlear implants with or without contralateral hearing aids. Significant binaural head shadow benefits were noted along with some benefit in binaural summation, binaural squelch effects, and sound localization with bilateral cochlear implants. However, it was unclear if these benefits were experienced under quiet conditions, although benefits increased with longer bilateral cochlear implant usage indicating a need for longer term studies. Hearing-specific quality of life could not be assessed because only one study evaluated this outcome. Additionally, although gains were experienced in speech perception using open-set sentences or multi-syllable tests compared with unilateral cochlear implants or unilateral listening conditions, the evidence available on simultaneous bilateral implantation was found to be insufficient. The assessment noted longer term studies are needed to further understand the benefits with bilateral cochlear implantation and identify candidacy criteria given the risks of a second surgery and the destruction of the cochlea preventing future medical intervention.

## Children

In a 2015 systematic review, Fernandes evaluated 18 published studies and two dissertations that reported hearing performance outcomes for children with ANSD and cochlear implants.<sup>[33]</sup> Studies included four nonrandomized controlled studies considered high quality, five RCTs

considered low quality, and 10 clinical outcome studies. Most studies (n=14) compared the speech perception in children with ANSD and cochlear implants with the speech perception in children with sensorineural hearing loss and cochlear implants. Most of these studies concluded that children with ANSD and cochlear implants developed hearing skills similar to those with sensorineural hearing loss and cochlear implants; however, these types of studies do not allow comparisons of outcomes between ANSD patients treated with cochlear implants and those treated with usual care.

In a 2014 systematic review, Lammers summarized the evidence on the effectiveness of bilateral cochlear implantation compared with unilateral implantation among children with sensorineural hearing loss.<sup>[34]</sup> The authors identified 21 studies that evaluated bilateral cochlear implantation in children, with no RCTs identified. Due to the limited number of studies, heterogeneity in outcomes and comparison groups, and high risk for bias in the studies, the authors were unable to perform pooled statistical analyses, so a best-evidence synthesis was performed. The best-evidence synthesis demonstrated that there was consistent evidence indicating the benefit of bilateral implantation for sound localization. One study demonstrated improvements in language development, although other studies found no significant improvements. The authors noted that the currently available evidence consisted solely of cohort studies that compared a bilaterally implanted group with a unilaterally implanted control group, with only one study providing a clear description of matching techniques to reduce bias.

In 2013, Eze published a systematic review comparing outcomes for cochlear implantation for children with developmental disability with those without developmental disability.<sup>[35]</sup> The authors noted that while approximately 30% to 40% of children who receive cochlear implants have developmental disability and that evidence about outcomes in this group was limited. Their review included 13 studies that compared receptive or expressive language outcomes in children with cochlear implants with and without developmental disability. The included studies were heterogeneous in terms of comparator groups and outcome measures, precluding data pooling and meta-analysis. In a structured systematic review, the authors reported that seven of the eligible studies demonstrated a significantly poor cochlear implant outcome in children with developmental disability, while the remaining studies reported no significant difference in outcomes between the groups.

Humphriss (2013) published a systematic review evaluating outcomes after cochlear implantation among pediatric patients with auditory neuropathy spectrum disorder (ANSD), a sensorineural hearing disorder characterized by abnormal auditory brainstem response with preserved cochlear hair cell function as measured by otoacoustic emissions testing.<sup>[36]</sup> The authors identified 27 studies that included an evaluation of cochlear implantation in patients with ANSD, including 15 noncomparative studies, one that compared children with ANSD who received a cochlear implant with children with ANSD with hearing aids, and 12 that compared children with ANSD who received a cochlear implant with children with severe sensorineural hearing loss who received a cochlear implant. Noncomparative studies were limited in that most (11/15) did not include a measure of speech recognition before cochlear implantation. Among the comparative studies, those comparing cochlear implantation to “usual care”, typically a hearing aid, provided the most information about effectiveness of cochlear implantation among patients with ANSD; the one small study that used this design found no significant differences between the groups. Overall, the authors suggested that further RCT evidence is needed.

The 2011 Forli systematic review noted above also addressed the effect of bilateral versus unilateral cochlear implants on verbal perception in children. Bilateral CI improved verbal perception in noise, and sound localization compared with unilateral implants in 19 of 20 studies reviewed.<sup>[22]</sup> However, none of the studies compared learning development and language in bilateral versus unilateral cochlear implant recipients. Simultaneous versus sequential bilateral cochlear implantation results were not examined in any of the studies reviewed. Seven studies were reviewed that examined cochlear implant outcomes in children with associated disabilities. In this population, cochlear implant outcomes were inferior and occurred more slowly but were considered to be beneficial.

In a 2011 systematic review of 38 studies, Black sought to identify prognostic factors for cochlear implantation in pediatric patients.<sup>[37]</sup> A quantitative meta-analysis was not able to be performed due to study heterogeneity. However, four prognostic factors: age at implantation, inner ear malformations, meningitis, and Connexin 26 (a genetic cause of hearing loss), consistently influenced hearing outcomes.

Pakdaman conducted a systematic review of cochlear implants in children with cochleovestibular anomalies in 2011.<sup>[38]</sup> Anomalies included inner ear dysplasia such as large vestibular aqueduct and anomalous facial nerve anatomy. Twenty-two studies were reviewed totaling 311 patients. The authors found implantation surgery was more difficult and speech perception was lower in patients with severe inner ear dysplasia. However, heterogeneity in the studies limited interpretation of these findings.

In another 2011 systematic review, Roush examined the audiologic management of children with auditory neuropathy spectrum disorder.<sup>[39]</sup> The review included 15 studies that addressed cochlear implantation in these patients. All of the studies reported auditory benefit with cochlear implantation in children with auditory neuropathy spectrum disorder. However, the studies were noted to be limited methodologically and further research is needed in this population.

### Adults and Children

Smulders (2011) examined the timing of cochlear implantation in a systematic review of 11 studies; five studies addressed postlingually deafened adults and seven studies addressed prelingually deafened children (discussed below).<sup>[40]</sup> One study on adults showed a delay in the timing of the second implantation resulted in poorer outcomes in quiet environments. Nevertheless, all studies reported benefits with bilateral implants, but all studies were considered to be of poor quality and with a high risk of bias.

### **Randomized Trials**

In 2016, Smulder conducted a small prospective multi-center randomized trial to evaluate the benefits of bilateral implants compared to unilateral implants in adults with postlingual deafness, including 38 patients.<sup>[41]</sup> At one-year follow-up, there were no significant differences between groups on the speech-in-noise or the consonant-vowel-consonant test. The bilaterally implanted group performed significantly better when noise came from different directions ( $p < 0.001$ ) and was better able to localize sounds ( $p < 0.001$ ) compared to the unilaterally implanted group. These results were consistent with the patients' self-reported hearing capabilities. The results were consistent at a two year follow up, reported in 2017.<sup>[42]</sup>

### **Nonrandomized Studies**

## Adults

Numerous case series have been published on adult patients with bilateral cochlear implants.<sup>[43-51]</sup> Most but not all studies report slight to modest improvements in sound localization and speech intelligibility with bilateral cochlear implants especially with noisy backgrounds but not necessarily in quiet environments. In addition, depression scores improved in cochlear implant patients from pre-implantation to 12 months post-treatment (geriatric depression scale improvement: 31%, 95% CI 10% to 47%) in a prospective observational study including 113 patients with postlingual hearing loss, of whom 50 were treated with cochlear implants and 63 with hearing aids.<sup>[52]</sup>

When reported, the combined use of binaural stimulation improved hearing in the range of one to four decibels or 1%–2%. While this improvement seems slight, any improvement in hearing can be considered beneficial in the deaf. However, this improvement may not outweigh the significant risks of a second implantation. In addition, similar binaural results can be achieved with a contralateral hearing aid, assuming the contralateral ear has speech recognition ability. A number of studies have reported benefits for patients with a unilateral cochlear implant with hearing aid (HA) in the opposite ear.

## Children

Several recent publications have evaluated bilateral cochlear implants in children.<sup>[53-55]</sup> These studies, ranging in size from 91 to 961 patients, generally report improved speech outcomes with bilateral implantation, compared with unilateral implantation. In a retrospective case series of 73 children and adolescents who underwent sequential bilateral cochlear implantation with a long (>five year) interval between implants, performance on the second implanted side was worse than the primary implanted side, with outcomes significantly associated with the interimplant interval.<sup>[46,50,56-61]</sup>

## Adults and Children

Ching (2006) subsequently reported on 29 children and 21 adults with unilateral cochlear implant and a contralateral hearing aid.<sup>[44]</sup> They noted that both children and adults localized sound better with bilateral inputs.

## **UNILATERAL HEARING LOSS WITH OR WITHOUT TINNITUS**

The use of cochlear implants in patients with unilateral hearing loss is an off-label use of these devices. As noted in the 2011 AHRQ technology assessment, a number of narrative literature reviews<sup>[62-64]</sup> and small ( $n \leq 30$ ) observational studies (described below) conducted primarily in adult patients have been published. However, these studies have included small numbers of patients ( $n \leq 30$ ) and had risk of reporting bias.

## **Systematic Reviews**

In 2015, van Zon published a systematic review of studies evaluating cochlear implantation for single-sided deafness or asymmetric hearing loss.<sup>[65]</sup> The authors reviewed 15 studies, nine of which ( $n=112$  patients) were considered high enough quality to be included in data review. The authors identified no high-quality studies of cochlear implantation in this population. Data were not able to be pooled for metaanalysis due to high between-study heterogeneity, but the authors conclude that studies generally report improvements in sound localization, quality of



life scores, and tinnitus after cochlear implantation, with varying results for speech perception in noise.

In 2014, Vlastarakos published a systematic review of the evidence related to cochlear implantation for single-sided deafness.<sup>[66]</sup> The authors included 17 studies, including prospective and retrospective comparative studies, case series and case reports that included 108 patients. The authors report that sound localization is improved after cochlear implantation, although statistical analysis was not included in some of the relevant studies. In most patients (95%), unilateral tinnitus improved. The authors note that most of the studies included had short follow-up times, and evaluation protocols and outcome measurements were heterogeneous.

In 2014, Blasco and Redleaf published a systematic review and meta-analysis of studies evaluating cochlear implantation for unilateral sudden deafness.<sup>[67]</sup> The review included nine studies with a total of 36 patients. In pooled analysis, subjective improvement in tinnitus occurred in 96% of patients (of 27 assessed), subjective improvement in speech understanding occurred in 100% of patients (of 16 assessed), and subjective improvement in sound localization occurred in 87% of patients (of 16 assessed). However, the small number of patients in which each outcome was assessed limits any conclusions that may be drawn.

### **Nonrandomized Studies**

In a 2017 prospective study, Sladen examined speech recognition and self-perceived health-related quality of life in a cohort of 20 adults and children with unilateral hearing loss.<sup>[68]</sup> Improvements were observed in speech recognition, both in quiet and noise, and self-perceived benefit with disease-specific instruments. Pure tone audiometry improved with air conduction in the implanted ear. CNC scores in quiet improved from 4.8% (SD 9.0%) in the preoperative period to 42.3% (SD 14.8%) at the six-month post-activation check in the patients who reached that follow-up.

A 2016 study also from Sladen reported on a retrospective review of prospectively-collected data of short-term (six-month) follow-up for 23 adults and children with single-sided deafness from a variety of mechanisms who received a cochlear implant.<sup>[69]</sup> In the implanted ear, CNC word recognition improved significantly from pre-implantation to three months post-activation ( $P=0.001$ ). However, for AzBio sentence understanding in noise (+5 dB signal-to-noise [SNR]), there was no significant improvement from pre-implantation to six months post-activation.

Also in 2016, Rahne reported on a retrospective review of four children and 17 adults with single-sided deafness treated with cochlear implants and followed for 12 months.<sup>[70]</sup> Sound localization with aided hearing improved from pre-implantation to aided hearing for all individuals. The Speech recognition threshold in noise (signal-to-noise) ratio improved from -1.95 dB (CI off, SD: 2.7 dB) to -4.0 dB after three months (SD 1.3 dB,  $P<0.05$ ), with continued improvements through six months.

In 2016, Mertens reported a case series including 23 individuals who received cochlear implants for single-sided deafness with tinnitus.<sup>[71]</sup> Eligible patients had either single-sided deafness or asymmetric hearing loss and ipsilateral tinnitus. Subjects had a mean eight years of experience with their cochlear implant (range, 3 to 10 years). Patients demonstrated improvements in VAS from baseline (mean score, 8) to one month (mean score: 4;  $p<0.01$  vs baseline) and three months (mean score: 3;  $p<0.01$  vs baseline) after the first fitting. Tinnitus

scores improved from baseline to three months post fitting (55 vs 31,  $p < 0.05$ ) and were stable for the remainder of follow-up.

In 2015, Ramos Macias reported results of a prospective multicenter study with repeated measures related to tinnitus, hearing, and quality of life, among 16 individuals with unilateral hearing loss and severe tinnitus who underwent cochlear implantation.<sup>[72]</sup> All patients had a severe tinnitus handicap (THI score  $\geq 58\%$ ). Eight (62%) of the 13 patients who completed the six-month follow-up visit reported a lower tinnitus handicap on the THI score. Perceived loudness/annoyingness of the tinnitus was evaluated with a 10-point VAS. When the CI was on, tinnitus loudness decreased from 8.4 preoperatively to 2.6 at the six-month follow-up; 11 of 13 patients reported a change in score of three or more.

In 2015, Arndt reported outcomes for 20 children who underwent cochlear implantation for single-sided deafness, which represented a portion of their center's cohort of 32 pediatric patients with single-sided deafness who qualified for cochlear implants.<sup>[73]</sup> Repeated-measure analyses of hearing data sets were available for 13 implanted children, excluding five who had undergone surgery too recently to be evaluated and two children who were too young to be evaluated for binaural hearing benefit. There was variability in the change in localization ability across the tested children. Self- (or child-) reported hearing benefit was measured with the Speech, Spatial and Qualities of Hearing Scale (SSQ). Significant improvements were reported on the child and parent evaluations for the scale's three subcategories: speech hearing, spatial hearing, hearing quality, and total hearing.

In 2013, Hansen reported results of a prospective study of cochlear implantation for severe-to-profound single-sided sensorineural hearing loss in 29 patients, 10 of whom had single-sided deafness due to Meniere's disease.<sup>[74]</sup> Performance was compared pre- to post-implant within each subject; outcomes were measured at three-, six-, and 12-months postoperatively. Patients showed significant improvements in CNC word and AzBio sentence scores showed improvement in the implanted ear pre-and post-implant. For the 19 patients with pre- and post-operative data available, the average improvement on CNC word score was 28% (range: -26% to 64%). The average AzBio score improvement was 40% (range: -57% to 92%).

Tavora-Vieira (2013) reported results of a prospective case series that included nine post-lingually deaf subjects with unilateral hearing loss, with or without tinnitus in the ipsilateral ear, with functional hearing in the contralateral ear, who underwent cochlear implantation.<sup>[75]</sup> Speech perception was improved for all subjects in the "cochlear implant on" state compared with the "cochlear implant off" state, and subjects with tinnitus generally reported improvement.

Arndt published a pilot study in 2010 of 11 adult patients with unilateral hearing loss of various causes.<sup>[76]</sup> The aim was to evaluate the use of unilateral electrical stimulation with normal hearing on the contralateral side and after a period of six months compared with the preoperative unaided situation, conventional contralateral routing of signal or bone-anchored hearing aid hearing aids. Ten patients also suffered from tinnitus. Two tests were used to assess speech comprehension, localization was assessed using an array of multiple speakers, and QOL was evaluated using three questionnaires. The study results were presented as p-values without adjustment for multiple testing. The authors reported that cochlear implantation improved hearing abilities in these study patients and was superior to the above alternative treatment options. The use of the cochlear implant did not interfere with speech understanding in the normal-hearing ear.

The application of cochlear implants for tinnitus relief in patients with unilateral deafness has also been described in previous studies. For example, van de Heyning published a study in 2008 of 21 patients with unilateral hearing loss accompanied by severe tinnitus for at least two years who underwent cochlear implants at a university center in Belgium.<sup>[77]</sup> The majority of patients demonstrated a significant reduction in tinnitus loudness based on a visual analogue scale (two years after implantation,  $2.5 \pm 1.9$ ; before implantation,  $8.5 \pm 1.3$ ). Three patients showed complete tinnitus relief.

## **COCHLEAR RESTORATION**

The optimal timing of cochlear implantation in children is of particular interest given the strong associations between hearing and language development. While there is current research investigating the ability to restore hearing by stimulating cochlear hair cell regrowth, cochlear implantation damages the cochlea and eliminates the possibility of cochlear restoration. However, the potential to restore cochlear function is not foreseeable in the near future; therefore, if implantation of cochlear implants is felt to be most beneficial at a younger age when the nervous system is “plastic”, this potential development seems too far in the future to benefit young children who are current candidates for a cochlear implant.

## **HYBRID COCHLEAR IMPLANTATION**

### **Systematic Review**

Santa Maria (2014) conducted a systematic review and meta-analysis of hearing outcomes after various types of hearing-preservation cochlear implantation, including implantation hybrid devices, cochlear implantation with surgical techniques designed to preserve hearing, and the use of post-operative systemic steroids.<sup>[78]</sup> The study included 24 studies, but only two studies focused specifically on a hybrid cochlear implant system, and no specific benefit from a hybrid system was reported.

### **Nonrandomized Studies**

The pivotal trial for the Med-EL EAS system was a prospective, multi-center, non-randomized, non-blinded, repeated measures clinical study of 73 subjects at 14 U.S. sites, implanted with either SONATA FLEX24 or a PULSAR FLEX24.<sup>[3]</sup> The score was compared across two conditions: the acoustic-only condition (baseline) and the 12-month post-activation EAS condition (ipsilateral electric + ipsilateral acoustic). Performance was compared pre- to post-implant within each subject; outcomes were measured at three-, six-, and 12-months postoperatively. Patients’ hearing was evaluating in three states: preoperative acoustic-only (acoustic stimulation to the ear to be implanted), postoperative electric-only (electric stimulation to the ear to be implanted), and postoperative EAS (simultaneous electric and acoustic stimulation in the implanted ear via the MED-EL EAS system). The primary effectiveness endpoint of improvement of CUNY sentence-in-noise scores from baseline to 12-months post-implant was 42.4% (95% confidence interval [CI]: 33.6%, 51.2%) in 66 of the 73 total enrolled patients. CUNY sentence in noise scores between the postoperative EAS condition and the postoperative electric-only condition (CUNY post EAS – post E) showed a mean improvement of 18.4% (95% CI: -19%, 77%,  $p = 0.003$ ). Thirty-five adverse events were reported to be related to the device or procedure, eight of which (11%) were profound/total residual hearing loss. At 12-months post-insertion, two subjects had undergone device explantation, one due to migration of the electrode and one due to device failure.

The pivotal trial for the Nucleus® Hybrid™ L24 Cochlear Implant System, published by Roland in 2016, was a prospective, multi-center, one-arm, non-randomized, non-blinded, repeated-measures clinical study of 50 subjects at 10 U.S. sites.<sup>[79]</sup> Performance was compared pre- to post-implant within each subject; outcomes were measured at three-, six-, and 12-months postoperatively. Post-operatively, patients' hearing was evaluated in three states: Hybrid (simultaneous electric and acoustic stimulation in the implanted ear via the Hybrid L24 including the acoustic component), Bimodal (electric stimulation only using the Hybrid L24 minus the acoustic component with contralateral acoustic stimulation), and Combined (electric and acoustic stimulation via the Hybrid L24 and contralateral acoustic stimulation). Results from the Bimodal and Combined conditions were grouped into an "Everyday Listening" category, which was not prospectively defined by the manufacturer. All 50 subjects enrolled underwent device implantation and activation. One subject had the device explanted and replaced with a standard cochlear implant between the three- and six- month follow up visit due to profound loss of low frequency hearing; an additional subject was explanted before the 12-month follow up visit and two additional subjects were explanted after 12 months. For the two primary effectiveness endpoints, CNC word-recognition score and AzBio sentence-in-noise score, a measure of sentence understanding in noisy environments, there were significant within-subject improvements from baseline to six-month follow up. The mean improvement in CNC word score was 35.7% (95% confidence interval [CI] 27.8% to 43.6%); for AzBio score, the mean improvement was 32.0% (95% CI 23.6% to 40.4%) For safety outcomes, 71 adverse events were reported, most commonly profound/total loss of hearing (occurring in 44% of subjects) with at least one adverse event occurring in 34 subjects (68%).

In 2015, Friedmann conducted a retrospective review that included 22 subjects implanted with a cochlear implant with either a standard electrode (n=12) or the Nucleus Hybrid L24 electrode (n=10).<sup>[80]</sup> At one year post-implant, 30% patients with the Hybrid-L and 58% patients with the standard electrode lost residual acoustic hearing resulting in a profound hearing loss in the implanted ear. The authors reported that while hearing preservation rates with the hybrid electrode tended to be better, among recipients who lost residual hearing, speech perception was better in those with the longer standard electrode.

Lenarz (2013) reported results of a prospective multi-center European study evaluating the Nucleus Hybrid™ L24 system.<sup>[81]</sup> The study enrolled 66 adults with bilateral severe-to-profound high frequency hearing loss. At one year post-operatively, 65% of subjects had significant gains in speech recognition in quiet and 73% had significant gains in noisy environments. Compared with the cochlear implant hearing alone, residual hearing significantly increased speech recognition scores.

Gifford (2013) compared hearing outcomes pre- and post-implantation for 44 adult cochlear implant recipients with preserved low-frequency hearing in two test conditions: cochlear implant plus low-frequency hearing in the contralateral plus low-frequency hearing in the contralateral ear (bimodal condition) and cochlear implant plus low-frequency hearing in both ears (best-aided condition).<sup>[82]</sup> The authors reported that there were small but statistically significant differences in improvements in adaptive sentence recognition and speech recognition in a noisy "restaurant" environment, suggesting that the presence of residual hearing is beneficial.

A small number of studies in a small number of patients suggest that a hybrid cochlear implant system is associated with improvements in hearing of speech in quiet and noise. However, there are currently no available studies that compare the use of a standard hearing aid with a

hybrid cochlear implant, which would be an appropriate comparison to determine if a hybrid device improves outcomes for patients who currently have hearing loss, but might not be candidate for a cochlear implant. In addition, there is only limited data to suggest that the preservation of residual hearing associated with a hybrid device is associated with improved outcomes compared with a standard cochlear implant.

## Section Summary

Current evidence is insufficient to determine the effectiveness of hybrid cochlear implant/hearing aid systems compared with conventional cochlear implants. Nor is there sufficient evidence to determine the rates of adverse events and reoperations associated with these devices.

## PRACTICE GUIDELINE SUMMARY

### AMERICAN ACADEMY OF OTOLARYNGOLOGY- HEAD AND NECK SURGERY FOUNDATION (AAO-HNS)

In 2014, the AAO-HNS published a revised position statement on cochlear implants. The Academy “considers unilateral and bilateral cochlear implantation as appropriate treatment for adults and children with severe to profound hearing loss. Based on extensive literature demonstrating that clinically selected adults and children can significantly perform better with two cochlear implants rather than one, bilateral cochlear implantation is accepted medical practice.”<sup>[83]</sup>

## SUMMARY

There is enough research to show that cochlear implants improve health outcomes, specifically, speech reception (especially in noise) and sound localization, for patients aged 12 months or older who have severe to profound bilateral sensorineural hearing loss. Therefore, cochlear implants may be considered medically necessary in specific patients with bilateral hearing loss who meet the policy criteria. Cochlear implants are considered not medically necessary when the policy criteria are not met, including but not limited to unilateral hearing loss with or without tinnitus.

There are currently no cochlear implants that have approval from the U.S. Food and Drug Administration (FDA) for use in patients who are younger than 12 months of age. There is not enough research to show that cochlear implants improve health outcomes in patients younger than 12 months of age and it is unclear that the benefits of early cochlear implantation outweigh the risk of surgery and anesthesia in these very young patients. In addition, there are no clinical practice guidelines from U.S. professional societies that recommend cochlear implantation in these very young patients. Therefore, cochlear implantation in patients younger than 12 months of age is considered not medically necessary.

The current research on cochlear implantation in patients diagnosed with enlarged vestibular aqueducts (EVA) has limitations. Despite these limitations, there is enough research to show that cochlear implants improve health outcomes, specifically, speech recognition, for patients for patients with EVA. In addition, early placement of cochlear implants avoids atrophy and preserves hearing patients with EVA with moderate hearing loss. Therefore, cochlear

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implants may be considered medically necessary in patients with EVA when policy criteria are met.

The current research on hybrid cochlear implant/hearing aid systems has limitations. Despite these limitations, there is enough research to show that hybrid cochlear implant/hearing aid systems improve health outcomes, specifically, speech recognition, for patients aged 18 years or older who have high frequency sensorineural hearing loss with preserved low frequency hearing. Therefore, hybrid cochlear implant/hearing aid systems may be considered medically necessary in specific patients with high frequency sensorineural hearing loss with preserved low frequency hearing who meet the policy criteria. Hybrid cochlear implant/hearing aid systems are considered not medically necessary when the policy criteria are not met, including but not limited to unilateral hearing loss with or without tinnitus.

Replacement of an existing cochlear implant with a next-generation device may be considered medically necessary only in those patients whose response to the existing device is inadequate to the point of interfering with activities of daily living, including school or work.

An upgrade of a functioning external system to improve appearance is considered not medically necessary. Examples include components with a smaller profile, or to switch from a body-worn external sound processor to a behind-the-ear model.

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## CODES

Codes	Number	Description
CPT	69930	Cochlear device implantation, with or without mastoidectomy

	92601	Diagnostic analysis of cochlear implant, patient younger than 7 years of age; with programming
	92602	;subsequent reprogramming
	92603	Diagnostic analysis of cochlear implant, age 7 years or older; with programming
	92604	;subsequent reprogramming
	92630	Auditory rehabilitation; pre-lingual hearing loss
	92633	Auditory rehabilitation; post-lingual hearing loss
HCPCS	L8614	Cochlear device, includes all internal and external components
	L8615	Headset/headpiece for use with cochlear implant device, replacement
	L8616	Microphone for use with cochlear implant device, replacement
	L8617	Transmitting coil for use with cochlear implant device, replacement
	L8618	Transmitter cable for use with cochlear implant device or auditory osseointegrated device, replacement
	L8619	Cochlear implant external speech processor and controller, integrated system, replacement
	L8621	Zinc air battery for use with cochlear implant device and auditory osseointegrated sound processors, replacement, each
	L8622	Alkaline battery for use with cochlear implant device, any size, replacement, each
	L8623	Lithium ion battery for use with cochlear implant device speech processor
	L8624	Lithium ion battery for use with cochlear implant or auditory osseointegrated device speech processor, ear level, replacement, each
	L8625	External recharging system for battery for use with cochlear implant or auditory osseointegrated device, replacement only, each
	L8627	Cochlear implant, external speech processor, component, replacement
	L8628	Cochlear implant, external controller component, replacement
	L8629	Transmitting coil and cable, integrated, for use with cochlear implant device, replacement

**Date of Origin:** January 1996