Effect of cochlear implantation in pre- and postlingually deafened adults

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Prosjektoppgave ved det medisinske fakultet

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01.10.2014

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Effect of cochlear implantation in pre- and postlingually deafened adults
Abstract

Objectives: The aim of this study was to seek a greater understanding whether it is beneficial to implant pre- and postlingually deafened adults, and if it is beneficial to implant unilateral CI users with a second implant.

Study design: Review of the literature

Methods: Published literature on the topic of prelingual and postlingual deafness among adults was reviewed, as well as literature on the topic concerning additional benefits from a second CI. A total of 24 articles were included, and the content was systematically organized in tables.

Results: Oral communication and the use of hearing aids prior to implantation, are good prognostic factors for CI outcome in prelingually deafened adults. Prelingual deafness should not be an exclusion criterion for CI. No upper age limit were found, where a CI did not have effect in the postlingually deafened adults. An increasing age might be associated with poorer test performance in noisy environment. When receiving a second CI, a long inter-implantation delay should not be a contraindication, but a short inter-implantation interval is desirable. The inclusion criteria for CI recipients should be broader, and evaluated on a case-to-case basis.

Conclusion: CI is beneficial in all three examined patient groups.

Key words: Cochlear implant, prelingual, postlingual, second cochlear implant, adult.
Table of contents

1 Introduction 9
  1.1 Background 9
  1.2 Aim of the study 9
  1.3 Definitions 10
    1.3.1 Grading system hearing impairment 10
  1.4 Different types of hearing impairment 12
    1.4.1 Conductive hearing loss 12
    1.4.2 Sensorineural hearing loss 12
  1.5 CI-candidates and assessment 13
    1.5.1 CI evaluation criteria for children 13
    1.5.2 CI evaluation criteria for adolescents and adult 15
    1.5.3 Fulfilling the criteria 16
  1.6 About the cochlear implant 16
    1.6.1 The external part 16
    1.6.2 The internal part 16
2 Material and methods 17
3 Results 18
  3.1 Prelingual deafness 18
  3.2 Postlingual deafness 21
  3.3 Effect of a second CI 24
  3.4 List of different tests used in the studies 26
4 Discussion 28
  4.1 Prelingual deafness 28
    4.1.1 Study population 28
    4.1.2 Age at implantation and duration of deafness 28
    4.1.3 Communication mode and use of hearing aids 29
    4.1.4 Tests and results 29
    4.1.5 Other findings 30
  4.2 Postlingual deafness and age 30
    4.2.1 Study population 30
    4.2.2 Tests and results 31
    4.2.3 Age at implantation and CI outcome 31
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2.4</td>
<td>Other findings</td>
<td>31</td>
</tr>
<tr>
<td>4.3</td>
<td>Effect of a second CI</td>
<td>32</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Study population</td>
<td>32</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Tests and results</td>
<td>32</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Age at implantation and interval between CI’s</td>
<td>32</td>
</tr>
<tr>
<td>4.3.4</td>
<td>Other findings</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>Conclusion</td>
<td>33</td>
</tr>
<tr>
<td>6</td>
<td>References</td>
<td>34</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Background
Cochlear implant (CI) is a complex electronic implant, offered to children and adults with severe to profound hearing-impairment. The CI can provide deaf and hearing impaired persons the ability to perceive and interpret sounds and speech, and to communicate with speech. In Norway The Norwegian association for hearing-impaired individuals (HLF - Hørselhemmedes Landsforbund) reports that approximately 700 000 individuals have hearing impairment, and according to the Norwegian Deaf Accosiation (NDF - Norges Døveforbund) 5000 of these individuals are deaf, and may be potential CI-candidates. World Health Organization (WHO) has estimated that 328 million adults and 32 million children worldwide have disabling hearing loss, with a hearing loss in the better hearing ear greater than 30dB in children and 40dB in adults. In Norway, Oslo University Hospital Rikshospitalet has a national function for children and a regional function for adults who already have or are going to receive a CI (1). The hospital has a multidisciplinary team of doctors, audio pedagogues, clinical engineers and audiologists. They conduct the CI-assessment, operation, CI-activation and the follow-up of CI recipients. The team implanted the first adult CI-recipient in 1986, and a 6 year old child in 1988 (1). Since then the CI-team have implanted 500 children and over 1700 patients. These operations are registrated in the cochlear implant register in Rikshospitalet.

1.2 Aim of the study
The outcome of CI in patients with prelingual deafness or long-lasting sensorineural hearing loss/high frequent hearing loss is often unpredictable due to individual variability (2). When meeting these patients, clinicians must know what answers to give, and these answers is often found in research.
The aim of this study is to seek a greater understanding of the following question
- Is it beneficial to implant adults after prolonged prelingual deafness?
- Is it beneficial to implant adults after prolonged postlingual deafness?
- Will adults with one CI have an additional effect from a second CI?
1.3 Definitions

Classification of hearing loss is often dependent on when the hearing loss occurred, most often divided into following terms (3):

- **Congenital deafness** is used when the hearing impairment is present at birth.
- **Prelingual deafness** is used when the hearing impairment occurs before the child has learned to speak. Often defined as a confirmed bilateral, severe to profound hearing loss at age < 12 months (4, 5).
- **Perilingual deafness** is used when the hearing impairment occurs while/during the time the child learns to speak. Often defined as a confirmed bilateral, severe to profound hearing loss at age > 12 months and < 3 years (4).
- **Postlingual deafness** is used when the hearing loss occurs after the acquisition of speech and language.

1.3.1 Grading system hearing impairment

WHO have developed a grading system for hearing impairment (see table 1.), were the grades 2, 3 and 4 are classified as disabling hearing impairment. In Nordic countries we often use only three different grades of hearing impairment; mild (<40 dB), moderate (40-69dB), and profound (>70dB) as an indication for CI. Among international guidelines, the American Food and Drug Administration (FDA) believe that CI is indicated in adult patients with a pure tone audiometry (PTA) > 70 dB, while the guidelines in Belgium indicate CI with a PTA of > 85 dB, and Italian guidelines allow CI in adult patients with a PTA > 75 dB (6).
<table>
<thead>
<tr>
<th>Grade of impairment</th>
<th>Corresponding audiometric ISO value</th>
<th>Performance</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – No impairment</td>
<td>25 dB or better (better ear)</td>
<td>No or very slight hearing problems. Able to hear whispers.</td>
<td></td>
</tr>
<tr>
<td>1 – Slight impairment</td>
<td>26-40 dB (better ear)</td>
<td>Able to hear and repeat words spoken in normal voice at 1 metre</td>
<td>Counselling. Hearing aids may be needed</td>
</tr>
<tr>
<td>2 – Moderate impairment</td>
<td>41-61 dB (better ear)</td>
<td>Able to hear and repeat words spoken in raised voice at 1 metre</td>
<td>Hearing aids usually recommended</td>
</tr>
<tr>
<td>3 – Severe impairment</td>
<td>61-80 dB (better ear)</td>
<td>Able to hear some words when shouted into better ear</td>
<td>Hearing aids needed. If no hearing aids available, lip reading and signing should be taught</td>
</tr>
<tr>
<td>4 – Profound impairment, including deafness</td>
<td>81 dB or greater (better ear)</td>
<td>Unable to hear and understand even a shouted voice</td>
<td>Hearing aids may help understanding words. Additional rehabilitation needed. Lip-reading and sometimes signing essential</td>
</tr>
</tbody>
</table>
1.4 Different types of hearing impairment

There are many causes for hearing impairment, varying from congenital and infectious diseases, to trauma and noise damage. For practical reasons, a distinction is made between two types of hearing impairment. These are conductive hearing loss and sensorineural hearing loss.

1.4.1 Conductive hearing loss

Conductive hearing loss is a reduced or repealed ability to direct the sound waves from the atmosphere to the inner ear (cochlea) (7). This is a mechanical hearing loss, and includes pathological conditions in the auditory canal, eardrum (tympanic membrane), middle ear and the oval window. Examples:

- Auditory canal: Congenital malformations, earwax or foreign body
- Tympanic membrane: Absence of membrane, perforation or scars
- Middle ear: Fusion of auditory ossicles (otosclerosis), trauma, otitis media, benign tumors (cholesteatoma)
- Oval window: Torn membrane into the cochlea

Hearing aids is usually the first solution for many people with conductive hearing loss. If the hearing loss is mild or moderate, an amplification of the sound might be adequate.

1.4.2 Sensorineural hearing loss

Sensorineural hearing loss is a reduced or repealed dysfunction in the inner ear or the auditory nerve (7). This includes pathological conditions in the inner ear, cochlear nerve or in the auditory center in the brain cortex. Examples:

- Inner ear: Congenital malformations, ototoxic drugs, destruction if hair cells in the cochlea caused by noise damage.
- Auditory pathways: Auditory neuropathy spectrum disorder (ANSD), tumors, auditory processing disorder (APD)

Hearing aids may help some people with mild to moderate sensorineural hearing loss. If the hearing loss is more severe, hearing aids and their sound amplification might not help enough. Then a cochlear implant may be a solution, were the implant stimulates the cochlear nerve directly.
1.5 CI-candidates and assessment

Before receiving a CI, there are many criteria that must be met. Evaluation criteria for possible CI-recipients, at Oslo University Hospital Rikshospitalet are described below (1):

1.5.1 CI evaluation criteria for children

- Speech perception tests: Which tests are used, depends on each child’s developmental status and qualifications.
  
  o **Ling’s sounds**: Different speech sounds, ranging from the low-frequency sounds to the high-frequency sounds. The test examines whether the child can hear and detect a sound, or recognize and identify the sound. The test consists of six sounds, m – a – i – s – sh – o, that occur at different frequencies (3). By presenting the individual sounds in a normal voice, at a distance of 30 to 50 cm without the child seeing your face, you can get a quick response by observing the child’s reaction (8).

  o **Visual Reinforcement Audiometry (VRA)**: VRA is a hearing test for children from approximately 6 months to approximately 2.5 years. Ideally, the child is sitting on a parent’s lap and wearing headphones, but it is also possible to make measurements with speakers. VRA is conducted to find out how the child hears. The child will specify what sound is audible, by turning the head against the sound source. Testing one ear at the time. The child is rewarded with funny movements from a toy, when turning the head against the correct sound source (9).

  o **Play audiometry**: From the ages 2 to 3 years, the child can usually cooperate during this test. The child is often wearing headphones, and when he/she hears a sound, the child shall indicate this by for example adding a block into a box. A narrower frequency range is often used when testing children, compared with conventional audiometry tests in adults. In any case, one should at a minimum test hearing in voice frequency in both ears (500 - 4000 Hz) (10).

- **Examination**: Done by an ear-nose-throat doctor (ENT-doctor).
- Tympanometry: Testing the movement of the eardrum, and the pressure in the middle ear.
- Otoacoustic emissions (OAE): An objective test, often included in the newborn hearing screen test. Testing the outer hair cells in the cochlea. The cochlea does not only receive sound, but produces sounds with low intensity. These sounds can be detected using a microphone placed in the ear canal.
- Brainstem Response audiometry (BRA): An objective hearing test, which measures the weak electrical signal produced in the brain stem immediately after the ear have been stimulated from an external sound source. BRA measures the response of cochlea, auditory nerve and brainstem.
- Auditory Steady State Response (ASSR): An objective hearing test, often included in the newborn hearing screen test. The person must be very quiet, and children are often tested during natural sleep or under sedation/anesthesia. The test person listens to different sound stimuli of varying frequency and intensity (dB). The results and the brain activity are recorded from electrodes, attached to the forehead and behind the ears. Using statistical formulas, the results are presented as a presence or absence response. The lowest level of response for each frequency is determined, similar to traditional audiometric testing.
- Stapedial reflex examination: The stapedial muscle is attached to the stapes, which is the smallest of the three ossicles. This muscle is innervated by the facial nerve, and this muscle contracts as a response to loud sounds. This contraction protects the ear by changing the sound transmission through the eardrum and middle ear ossicles, when exposed to loud sounds. The test measures the volume/dB were the reflex and subsequent muscle contraction is triggered. In normal hearing individuals the reflex is triggered by sound stimuli louder than 70-80 dB (7). This reflex is usually absent with profound hearing loss.
- CT and MR imaging: To evaluate anatomical conditions in the inner ear.
- Blood samples: It is voluntary to take blood samples, to examine relevant genes that may explain the cause of hearing loss. The patient and the family will receive genetic counselling, if the hearing loss is due to genetic inheritance.
- Electrocardiography (ECG): A test recording the electrical activity in the heart. Where an abnormal ECG can help with the diagnosis of Jervell- and Lange-Nielsen syndrome.

1.5.2 CI evaluation criteria for adolescents and adults

- Speech perception tests:
  - Hearing in noise test (HINT): Measures the ability to distinguish speech from background noise. It measures the signal-to-noise ratio, where the next sentence is changed based on the patient’s response to the preceding sentences. Either by increasing/decrease the sound stimuli or noise stimuli
  - Pure tone audiogram: Sitting in a soundproof booth with headphones. Different sound frequencies are presented, and the person presses a button when he/she can hear the sound. The test shows how the person hears in different frequencies, and can say something about the basis of speech intelligibility (8).
  - Speech audiogram: Testing the ability to understand monosyllables. Words are presented into the headphones, and the person is asked to repeat the words. The test provides an overview of how much amplification the person needs to understand the words presented, compared to others without hearing loss. The result is presented as percent score.
  - IOWA-test: One of the measurements is to determine how much the test person relies on lip-reading. Lists of phrases are recorded on video, and then played for the test person. With audio and vision, only audio and only vision.

- Examination: Done by an ENT-doctor.
- Tympanometry
- Testing the stapedial reflex
- Brainstem Response audiometry (BRA)
- CT imaging: MR is no routine examination in potential adult CI-candidates in Norway.
1.5.3 Fulfilling the criteria
After finishing all tests, the assessment is completed with a final meeting with the ENT-doctor and the audio educator in the CI-team. If there is an indication for CI, each patient must determine whether he or she will accept this offer. For children under the age of 18, this is a parental decision.

1.6 About the cochlear implant
The CI consists of an external and internal part. The external part consists of a microphone, speech processor and a transmitter (7). The inner part consists of a receiver and electrode.

1.6.1 The external part
- The microphone: It is located near the entrance to the auditory canal, and picks up the sound. Then the sound is converted to electrical signals and sent to the speech processor
- The speech processor: It is located at the back of the ear, along with the batteries. Converting the electrical signals into particular patterns of electrical pulses, different frequency ranges.
- The transmitter: It transfers the signals using radio waves (FM) (3), from the external part to the internal part under the skin. The external and internal part is held together by means of a magnet.

1.6.2 The internal part:
- The receiver: It receives the radio waves and sends the signals to the electrodes in the cochlea.
- The electrode: Depending on the implant model, there are 8 to 22 stimulating points on the electrode (3) stimulating different parts in the cochlea. A dark sound (bass) will stimulate the inner electrodes in the cochlea, and a high sound (treble) will stimulate the outer electrodes (1). This stimulation leads to activation in the cochlear nerve, which will send electrical information to the brainstem and from there to the auditory brain cortex.
2 Material and methods

Published literature on the topic of prelingual and postlingual deafness among adults was reviewed, as well as literature on the topic concerning additional benefits from a second CI. In particular, we sought to identify the benefits of CI in these populations. A total of 24 articles were reviewed. A full text document was made, with a summary of each article. This was the starting point for the final tables made for each category: prelingual, postlingual and the second CI.
# 3 Results

## 3.1 Prelingual deafness

Table 2. Summary table of articles included for review on the issue "implantation in prelingually deafened adults".

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Sample size and methodology</th>
<th>Patient characteristics</th>
<th>Results evaluated</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schramm et al. (11) 2002</td>
<td>Cochlear implantation for adolescents and adults with prelinguistic deafness</td>
<td>15 patients (pts) 6 adolescents and 9 adults. Tested preop, and postop 6 and 12 months. Mean age at implantation 25.1 years (range 12-49). Mean duration of deafness 24.8 years (range 12-49). Retrospective study.</td>
<td>- Inclusion criteria: 12 years of age (yoa) or older at implantation. Prelingual deafness. - Oral language (English). Auditory-oral or auditory-verbal training during preschool/school years. - 13 pts congenital deafness. 1 patient (pt) deaf 3 months of age. 1 pt progressive hearing loss and profound from 4 years of age. All 13 pts used oral communication. - Etiology: not mentioned. - Use of hearing aid (HA) before implantation: not mentioned - Better or worse ear implanted: not mentioned</td>
<td>Speech perception tests. Words and sentences. PBK. NU-6. CID. Questionnaire: PIPSL.</td>
<td>- Achievement of open-set speech perception - The adolescent's scores were higher than the adult's scores. Maybe caused by auditory-verbal or auditory-oral therapy during their school years.</td>
</tr>
<tr>
<td>Kaplan et al. (12) 2003</td>
<td>Early-deafened adult cochlear implant users: assessment of outcomes</td>
<td>44 pts. Mean age at implantation 35 years and 10 months (range 14-62 years) Tested at 6, 12, 18 and 24 months after implantation. Questionnaire sent on email at 12, 24 and 60 months after implantation.</td>
<td>- Inclusion criteria: Severe to profound hearing loss (HL) before 6 yoa. Minimum 6 months CI use. Age at implantation &gt; 12 years. - Mean duration of CI use was 4 years and 4 months (range 7months -11 years). - 24 pts onset of deafness &lt; 12 months of age (moa). 10 pts deafened from 12-36 moa. 10 pts deafened from 36-72 moa - Etiology: congenital-unknown n = 12. Meningitis n = 8. Rubella n = 7. Hereditary n = 4. Measles n = 4. Febrile illness n = 2. Pendred’s syndrome n = 1. Mumps n = 1. Pertussis n = 1. Mondini’s aplasia n = 1. Chronic otitis media n = 1. Scarlet fever n = 1. Unknown n = 1. - HA use: 31 pts used HA prior to surgery. 12 pts used HA in the past. 2 pts never used HA. - Better or worse ear implanted: not mentioned</td>
<td>Open set speech recognition and subjective data. Questionnaire: Quality of life (QoL) CNC, CID. CUNY.</td>
<td>- Better results if raised in an auditory-verbal environment, than an environment dominated by signs. - Significant improvement in QoL. - Type of communication is strongly associated with open-set speech recognition.</td>
</tr>
</tbody>
</table>
Table 2. (follows)

Teoh et al. (13) 2004
Cochlear implantation in adults with prelingual deafness. Part I. Clinical results
103 pts. From clinical trials in three CI companies (Cochlear, MedEl and Advanced Bionics). Control group 58 pts postlingual deafness. Retrospective review.
- Inclusion criteria: onset of deafness < 3 yoa. Implantation older than 13 yoa.
- Etiology: not mentioned
- HA use: not mentioned
- Better or worse ear implanted: not mentioned
Speech perception.
PBK, CUNY-q, HINT-q, and CNC.
- significant improvement in speech perception
- plateau for improvement earlier than with postlingual deafness (pld)
- plateau at lower level than pld
- before 12 yoa is a sensitive period
- better results if implanted under 12 yoa
- implantation after 12 yoa resulted in very limited closed-set and minimal to no open-set speech understanding.

Teoh et al. (14) 2004
Cochlear implantation outcome in adults with prelingual deafness. Part II. Underlying constraints that affect audiological outcomes
Reviewed published literature on the topic of auditory pathway response to prolonged congenital deafness. Retrospective review.
- Etiology: not mentioned
- HA use: not mentioned
- Better or worse ear implanted: not mentioned
Peripheral auditory system, cochlear nucleus, auditory midbrain and auditory cortex.
- Deafness induces changes along the entire auditory pathway
- Recommendation of HA use before CI
- Sensitive period regarding auditory cortical colonization and reorganization
- Oral communication as an important criterion for CI, among long-term prelingual deafened adults.

Santarelli et al. (2) 2008
Cochlear implantation outcome in prelingually deafened young adults. A speech perception study
18 pts. age 13-30. Mean age at implantation 19.9 years (range 13-30). Testes 6 months, 1, 2 and 3 years after implantation.
- Etiology: unknown n = 8, connexin 26 n = 4, usher n = 1, rubella n = 1, familiarity n = 1, birth asphyxia n = 1, meningitis n = 1, ototoxic drugs n = 1.
- CI implanted in the better ear, except 3 pts who requested the worse ear.
- Significant improvement in all tests after CI
- Mean scores lower than pld pts
- Positive influence if HA use before CI
- Positive influence if oral-communication or auditory-oral therapy before CI

Most et al. (15) 2009
Cochlear implantation in late-implanted adults with prelingual deafness
38 adult pts. (range 19-71 yoa). Mean age at implantation 33.58 years (range 16-70).
4 self-report questionnaires, before and after CI.
- Most pts had at least 6 months implant experience.
- 32 pts used spoken language, 6 pts used spoken language + signs.
- 31 of the pts were prelingually deaf. 7 other pts became deaf by10 yoa.
- HA use: not mentioned
- Better or worse ear implanted: not mentioned
- Etiology: not mentioned
4 questionnaires:
- Personal info
- individual satisfaction regarding communication, family climate, social skills, education and work
- self-esteem
- loneliness
- Significant increase in individual satisfaction regarding communication, social skills, education and work
- Significant different in loneliness – pts were less lonely after CI
- No significant difference regarding the family climate or self-esteem.
- Pts with prelingual HL can still benefit from a CI, even when late implanted
Table 2. (follows)

<table>
<thead>
<tr>
<th>Study</th>
<th>Title</th>
<th>Inclusion criteria</th>
<th>Speech perception</th>
<th>Intelligibility tests</th>
<th>Other findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Dijkhuizen et al. (16) 2011</td>
<td>Speech intelligibility as a predictor of cochlear implant outcome in prelingually deafened adults</td>
<td>- Inclusion criteria: profound HL &lt; 4 yoa. Pure-tone audiometry &gt; 90 dB in the better ear. No abnormal cognitive abilities. - HA use: 23 pts used HA on a daily basis before implantation. Average duration of HA use was 33 years (range 12 to 53). - 25 pts used oral communication - Etiology: unknown n = 7. Rubella n = 6. Perinatal asphyxia n = 2. Mumps n = 1. Family history n = 2. Meningitis n = 5. CMV n = 1. Rhesus antagonism n = 1. - Better or worse ear implanted: not mentioned</td>
<td>Speech perception: vowels, consonants, words, sentences, text and conversation.</td>
<td>Intelligibility tests had good validity as a predictor for post implant outcome - It seems to be preferable to use vowels as the single measure of speech intelligibility before implantation - Pts with high intelligibility scores before implantation achieved better post implant speech perception scores than pts with lower intelligibility scores. - Early onset of deafness should not be an exclusion criterion for late cochlear implantation.</td>
<td>- Duration of deafness, duration of implant use and age at implantation showed no significant association to speech-perception in open-set after implantation. - Main disadvantage was related to battery consumption.</td>
</tr>
<tr>
<td>Yang et al. (17) 2011</td>
<td>Delayed cochlear implantation in adults with prelingual severe-to-profound hearing loss</td>
<td>- Inclusion criteria: severe-to-profound HL &gt; 70 dB in better ear. Deafness before 4 yoa, implantation after 16 yoa. - Etiology: Rubella n = 2, meningitis n = 2, inner ear anomaly n = 4, trauma n = 1, unknown n = 23. - 6 pts used sign language. 23 pts used oral communication. 3 pts used both signs and oral communication. - 28 pts implanted in the poorer ear. 4 pts implanted in the better ear.</td>
<td>Speech perception Monosyllables, disyllables, word and sentence recognition</td>
<td>No significant difference postop regarding implanted in poorer or better ear. - No significant correlation with HA use before implantation, and postop test performance. - Lower postop performance scores if HA use before implantation was &lt; 3 hours/day. - Significant prognostic factors: educational environment and communication mode. - Duration of deafness is not a critical factor for post implant performance. - CI should not be excluded in prelingually deaf adults.</td>
<td></td>
</tr>
<tr>
<td>Caposecco et al. (4) 2012</td>
<td>Cochlear implant outcomes in adults and adolescents with early-onset hearing loss</td>
<td>- Inclusion criteria: onset of bilateral sensorineural HL &lt; 3 yoa. Implanted &gt; 14 yoa. Minimum 6 months CI use. - 28 pts had a stable loss, and 10 pts had a progressive loss. - 20 pts used oral communication. 16 pts used total communication or sign alone. 2 pts no info regarding communication. - HA use: not mentioned how many pts used HA - Better or worse ear implanted: not mentioned - Etiology: not mentioned</td>
<td>Speech perception. Open-set test: CID, CUNY. Self-report surveys: GBI, IOI-CI Study survey (designed for this research project): communication with family and in groups. Satisfaction. Advantages and disadvantages of the implant.</td>
<td>CID and CUNY scores improved significantly after implantation - Pts with a progressive HL performed better in open-set speech tests, than pts with a confirmed HL &lt; 3 yoa. - Most significant factor for speech perception outcome was communication mode. - Use of HA before implantation increased speech perception, compared to no HA use. - Duration of deafness, duration of implant use and age at implantation showed no significant association to speech-perception in open-set after implantation.</td>
<td></td>
</tr>
</tbody>
</table>

25 adult pts. Average age at onset of deafness: 8 months (range 0-4 years). Average age testing 39 years (range 20-62 years). Average duration of deafness 38 years (range 20-59). Only 9 pts with above-average intelligibility were implanted. 12 months post implant. |
Table 2. (follows)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Sample size and methodology</th>
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<th>Results evaluated</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bosco et al.</td>
<td>Long term results in late implanted adolescent and adult CI recipients</td>
<td>23 pts. 10 adolescents, mean age at implantation 14.3 years (range 12-18) 13 adults implanted after 18 years. Man age at implantation 30.1 years (range 22-40) and mean time of implant use 7.5 years.</td>
<td>- Inclusion criteria: PTA in better ear &gt; 90 dB. Congenital or acquired HL before 3 yoa. No benefit from use of hearing aids since early childhood. Speech therapy with oral or mixed rehabilitative approach. CI use &gt; 5 years. Age at implantation &gt; 12 years. Absence of psychiatric symptoms. - Etiology: unknown n = 11. Rubella n = 5. Meningitis n = 3. Usher n = 1. Measles n = 1. Mumps n = 1. Ototoxic drugs n = 1. - 8 pts had profound HL between 12-36 months. 15 pts had profound HL &lt; 12 months. - HA use not mentioned - Better or worse ear implanted: not mentioned</td>
<td>Speech perception: Boston naming test. Peabody Vocabulary test, and test for reception of grammar.</td>
<td>- Significant improvement in auditory skills for word recognition and question comprehension. - Improvement in self-esteem - 70 % of the adolescents and 100 % of the adults used their implant &gt; 8 hours/day. - 92.3 % would have opted for implantation again. - When selecting prelingual deaf adult CI recipients, motivation and communication competence are main points to be taken into consideration.</td>
</tr>
</tbody>
</table>

3.2 Postlingual deafness

Table 3. Summary table of articles included for review on the issue "implantation in postlingually deafened adults". 
Table 3. (follows)

Lenarz et al. (18) 2012
Cochlear implant performance in geriatric patients
1005 pts.
130 pts > 70 years.
875 pts < 70 years.
Tested 3, 6, 12, and 24 months after implantation.
Retrospective cohort study.
- Inclusion criteria: all postlingually deafened and implanted > 18 yoa. German as the native language.
- HA use not mentioned
- Etiology: not mentioned
- Better or worse ear implanted: not mentioned

Freiburger monosyllabic test. Speech tracking test. HSMq and HSM-n.
- No significant difference in performance between younger adults or adults > 70 yoa, 1 year after implantation, regarding speech tracking test and HSM-q.
- HSM-n: pts > 70 yoa showed significant lower performance than pts < 70 yoa.
- Adults > 70 yoa have a similar learning curve as younger adults

Lin et al. (19) 2012
Cochlear implantation in older adults
445 adult pts.
Age > 60.
65 pts HL < 18 yoa.
339 pts HL > 18 yoa.
Tested pre- and postop.
6 months before surgery.
Only 83 pts had pre- and 1-year postop HINT scores.
Retrospective study.
- Inclusion criteria: pts > 60 yoa when receiving first CI. Divided in two groups HL < 18 yoa and HL > 18 yoa.
- HA use: not mentioned
- Etiology: not mentioned
- Better or worse ear implanted: Not mentioned

HINT-q, CNC, AzBio
- A 1.3 % decline in HINT scores postop, for every increasing yoa at time of CI.
- Pts with preop HINT scores > 40 % associated with significant higher post-CI scores, than pts with preop HINT scores < 40 %.
- Age at implantation significantly associated with post CI outcomes.
- Preop sentence scores significantly associated with speech perception gain post CI.
- Adults with high preop speech scores and younger age at implantation, may have the greatest benefit from CI.
- Expand preop inclusion criteria for CI from < 40 % speech scores, to < 60 % speech scores.

Gaylor et al. (20) 2013
Cochlear implantation in adults: a systematic review and metaanalysis
45 articles included in the review.
Search on Medline, Cochrane Central Register of Controlled Trials, Scopus.
- Inclusion criteria: studies of adults > 18 yoa with unilateral or bilateral CI. Use of HA
- Etiology: not mentioned
- Better or worse ear implanted: not mentioned

QoL, open-set sentences or disyllable test. AzBio sentence list, sound localization (for BiCI users), BKB-SIN, CUNY, HINT, HSM, CID, OLSA
- QoL and speech perception improves with unilateral and bilateral CI
- Significant improvements in speech outcomes in the identified literature
- For BiCI, improvements in sound localization are noted

Benatti et al. (21) 2013
Cochlear implantation in the elderly: surgical and hearing outcomes
17 adult pts mean age 70.47 (range 65-79). Tested before, and 4, 7, 11 and 15 months after CI activation. Duration of HL ranged from 1-50 years.
Retrospective study.
- Inclusion criteria: age > 65 years and unilateral implantation.
- 8 pts were deaf < 15 yoa. 9 pts were deaf > 15 yoa.
- HA use: tested preop with HA. Not mentioned HA use.

PTA, SDT, SRT
- Pts > 65 yoa had higher incidence of comorbidities, but no surgical complications were observed.
- Significant improvement in PTA values.
- Significant improvement in speech perception scores, SDT and SRT.
- CI in elderly pts is a safe procedure.
<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Title</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramos et al. (22) 2013</td>
<td>Cochlear implants in adults over 60: a study of communicative benefits and the impact on quality of life</td>
<td>26 adult pts &gt; 60 years. Mean age 69 years. Average duration deafness 21.8 years (range 2-65) study group. Control group: 10 pts 40-60 years. Average duration deafness 15.7 years (range 1.8-18). Tested pre- and postop. Observational retrospective study.</td>
<td>- Number of years wearing CI: 3.38 years in study group, and 6.2 years in control group. - HA use: 11 pts in the control group used HA + unilateral CI. - Etiology: Not mentioned - Worse or better ear implanted: not mentioned</td>
<td>PTA, QoL, GBI, Specific questionnaire (SQ) - Significant improvement in QoL - Pts with long progressive HL scored better in QoL. - Duration of deafness before CI was statistically associated with QoL. - Longer CI use, statistically higher satisfaction - No reported complications during surgery - Pts at 40-60 yoa have better speech recognition scores than pts &gt; 60 yoa</td>
</tr>
<tr>
<td>Lachowska et al. (23) 2013</td>
<td>Is cochlear implantation a good treatment method for profoundly deafened elderly?</td>
<td>31 adult pts &gt; 60 yoa. Mean age at implantation 72.4 years (range 60-87). Mean post implant follow-up 2.34 years (range 4 months - 9.61 years). Testes preop, and at 3, 6, and 12 months postop.</td>
<td>- Inclusion criteria: Severe to profound bilateral sensorineural HL. Postlingual onset of HL. Limited/no benefit from HA. No medical or radiological contraindications. - All implanted unilaterally - Majority had aural rehabilitation postop. - HA use: not mentioned - Etiology: not mentioned - Worse or better ear implanted: not mentioned</td>
<td>PTA, monosyllables, word recognition test, Ling's six sounds, Multisyllable word recognition. - All pts significantly improved their speech perception and audiological performances. - Older pts should not be denied CI based on age alone.</td>
</tr>
<tr>
<td>Sandmann et al. (24) 2014</td>
<td>Rapid bilateral improvement in auditory cortex activity in postlingually deafened adults following cochlear implantation</td>
<td>24 adult pts. Tested 0.5, 8, 15 and 59 weeks after initial CI activation. Prospective longitudinal study.</td>
<td>- Etiology: Progressive = 5. Mb. Menier + gentamycin = 1. Congenital = 1. Meningitis = 1. Congenital (left) + progressive (right) = 1. Scarlatina = 1. Sudden deafness (left) + progressive (right) = 1. - HA use: not mentioned - Worse or better ear implanted: not mentioned</td>
<td>AEP, OLSA, Freiburg number test, Freiburg monosyllabic word test. EEG. - Remarkable AEP changes in ipsi- and contralateral auditory cortex, within 8 weeks after CI activation - Significant improvement in speech recognition, within 8 weeks after CI activation - Rapid but limited adaptation in the bilateral auditory cortex.</td>
</tr>
</tbody>
</table>
### 3.3 Effect of a second CI

Table 4. Summary table of articles included for review on the issue "implantation of a second CI"

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Sample size and methodology</th>
<th>Patient characteristics</th>
<th>Results evaluated</th>
<th>Conclusions</th>
</tr>
</thead>
</table>
| Litovský et al.  | Bilateral cochlear implants in adults and children                    | 17 adult pts and 3 children. Tested 3 months after BiCI activation. Adults implanted simultaneously, and children implanted sequential (3-8 years apart). Average age adults 52.7 years. | - The children were prelingually deaf  
- 14 adult pts were postlingually deaf. 3 adult pts were congenital/prelingual deaf.  
- HA use: Adult used between 8 - 30 years. Not mentioned how many pts used HA.  
- Etiology: not mentioned                                                                                     | Sound localization.  
Speech intelligibility, BKB.  
Children used the CRISP. Right-left discrimination in children.                                                            | - Bilateral condition significantly lower errors, than each ear alone.  
- Best predictor for BiCI improvement was duration of bilateral HA use before implantation. Best results if HA use > 10-30 years.  
- BiCI advantage when babble near poor ear. Minimal or no advantage of BiCI when babble near best ear.               |
| Zeitler et al.   | Speech perception benefits of sequential bilateral cochlear implantation in children and adults: a retrospective analysis | 43 children < 18 yoa, and 22 adults > 18 yoa. Mean age second implant children 7.8 years. Mean interimplant interval 5.16 years. Adults: mean age at second implant 46.6 years, mean interimplant interval 5.6 years. All pts tested pre-and postop for the second CI. Retrospective review | - Inclusion criteria: bilateral severe to profound sensorineural I (> 80 dB). Minimal or no benefit from HA. English speaking. A minimum of 6 months between implantations  
- HA use: all pts used HA before second CI. Mean usage of HA 20.5 years (range 0-49.9 years)  
- Mean duration of deafness adult pts 32.1 years (range 3-58.3 years)  
- Mean duration of deafness children 2.3 years (range 0.3 – 14.4 years).  
- Etiology: not mentioned                                                                                     | Adults: CNC, HINT-q, HINT-n, BKB-SIN, sentences presented in 4-talker babble noise.  
Children: MLNT, PKB, GASP, LNT                                                                               | - Significant improvement in the second implanted ear and BiCI condition, for adults and children 3 months after second implantation.  
- Earlier implantation in first implanted ear had a significant positive effect on the outcome after second implantation.  
- Sequential BiCI can provide better open-set speech understanding, which continues to increase over time.  
- Despite the length of deafness in either ear, time between implantation and age at implantation; the auditory perception improves. |
| Galvin et al.    | Can adolescents and young adults with prelingual hearing loss benefit from a second, sequential cochlear implant? | 9 pts > 10 yoa, all with approx. 12 months bilateral experience. Follow-up 12 months after second CI. Age range at second implantation (10.2-19.9 years). Age at CI1 (range 1.9-11.3 years) | - Inclusion criteria: >10 yoa. Profound HL in the unimplanted ear (> 90 dB). Full time use of first implant. No radiological contraindications for electrode insertion. No cognitive or developmental delay.  
- All pts had approx. 12 months BiCI use  
- HA use: All pts used HA prior to first implantation. 2 pts used HA full time in second ear between implantations. 7 pts did not use HA between implantations. | BKB, PPVT, SSQ                                                                                               | - Within 5 months the majority preferred BiCI over unilateral CI  
- CI1 remained the superior implant  
- A second implant should be considered for all unilaterally implanted children  
- Being older should not be an exclusion for a second implant  
- Full time HA use associated with similar communication with either CI  
- Pts < 13 yoa may gain additional benefit form a second CI, even if their HL is congenital and the interval between implants are > 16 years. |
Table 4. (follows)

Smulders et al. (28) 2011

What is the effect of time between sequential cochlear implantations on hearing in adults and children? A systematic review of the literature


- HA use: not mentioned
- Etiology: not mentioned

Galvin et al. (29) 2013

Longer-term functional outcomes and everyday listening performance for young children through to young adults using bilateral implants

57 pts. 50 children implanted sequential. 7 children implanted simultaneous. Median age at implantation in both groups was 4.1 yoa (range 0.7-19.8 years). Median time between implantations 2.7 years (range 0.0 – 16.7 years). Questionnaire was administered to the parents > 3.5 years after last implantation.

- 51 children bilateral profound HL < 2 year and 2 months. Remaining 6 pts had only severe to profound HL in one ear
- HA use before first implant. Consistent n = 28. Half time or less n = 25. HA < 1 month n = 4.
- HA use between CI1 and CI2 operations. Consistent n = 8. Partial < 30 % n = 8. Initially consistent until 7-11 months before CI2 n = 6. At school n = 3. Refused to wear HA n = 25.

Reeder et al. (30) 2014

A longitudinal study in adults with sequential bilateral cochlear implants: time course for individual ear and bilateral performance

21 adult pts. tested at 6 intervals, prebilateral through 12 months post bilateral implantation. Mean age at first implantation 48.5 years (range 36-74). Mean age at second implantation 53.8 years (range 44-75). Mean time between surgeries 5.2 years (range 1-17) Prospective longitudinal study.

- 3 pts prelingual onset of HL. 18 pts postlingual onset of HL.
- Length of deafness in first implanted ear: mean 16.8 years (range 1-45)
- Length of deafness in second implanted ear: mean21.4 years (range1-55)
- HA use: 19 pts used HA before first implantation. 16 pts used HA before second implantation.

Adults:
- Speech intelligibility in quiet and in noise. Sound localization. OLSA-q, OLSA-n, CNC, CUNY.

Study-specific questionnaire: Device use, benefit and performance with BiCI. Adaptation, attitude and device preference over time. Worth of a second implant.

CNC words, HINT sentences, TIMIT sentences. BKB-SIN. SSQ self-report measures.
- None of the included studies considered a great interimplantation delay a contraindication for a second CI.
- The binaural auditory system and auditory cortex is well developed in postlingually deafened adults, and an early second CI is less trivial.
- Auditory performances are better with BiCI than with either CI alone.
- A second CI can be beneficial even after long delay between implantations

Children:
- Evidence of a critical point between 3.5 – 4 yoa, and implantation interval < 2 years.
- BiCI superior to unilateral CI regarding sound localization, less need for repetition, increased responsiveness, improved listening in noise.
- Positive functional outcomes across all ages, even when the delay between implantations was long

- Significantly higher BiCI scores than either ear alone, regarding HINT-n, TIMIT-n, TIMIT-q.
- Significantly improved sound localization in BiCI, compared with either ear alone.
- Ongoing significant improvement in CI1 performance over time for TIMIT-q.
- Significant reduction in self-reported disabilities
- Postlingually deaf adults can expect CI2 outcomes similar to CI1 outcomes within 3-6 months of BiCI use.
- Length of deafness an important variable, shorter interval between surgeries is desirable
3.4 List of different tests used in the studies.

- PBK: Phonetically Balanced Kindergarten. List consisting of 50 monosyllabic words (11, 13, 26).
- NU-6: North-western University Auditory Test #6. List consisting of 50 monosyllabic words (11).
- CID: Central Institute for the Deaf. Open-set sentence test. Total of five lists, each consists of 20 sentences (4, 11, 12, 20).
- PIPS: Performance Inventory for Profound and Severe Loss. A self-rating inventory with 58 different items, divided into six categories (11).
- CNC: Consonant-nucleus-consonant test. Ten lists, each consists of 50 monosyllabic words (6, 12, 13, 19, 26, 28, 30).
- CUNY: City University of New York. 40 different recorded sets of 20 sentences. CUNY-q: CUNY in quiet. (4, 6, 12, 13, 20, 28).
- HINT: Hearing in noise test. Repeat sentences when stimuli is presented in quiet and noisy environment (6, 13, 19, 20, 26, 30).
- GBI: Glasgow Benefit Inventory. Measures changes in health status after a surgical (otorhinolaryngological) intervention, 18 questions. (4, 6, 22).
- IOI-CI: Inventory for Cochlear Implants. CI usage, benefit, residual activity limitations, satisfaction, quality of life (4).
- SSQ: Speech Spatial and Quality of Hearing Scale. Measures self-reported auditory disability in different domains (6, 30).
- Freiburg Monosyllabic test: 20 monosyllabic words presented in a recorded mode (6, 24).
- Speech tracking test: in live voice, reading a story to the patient. Patient repeats the sentences and words (6).
- HSM-q and HSM-n: Hochmair-Schulz-Moser Sentence test in quiet and in noise. 30 lists of 20 sentences (6, 20).
- AzBio: A list of 1000 recorded sentences. Two male and two female talkers (19, 20).
- OLSA: Oldenburg Sentence Test. 40 test lists with 30 sentences presented in quiet or noisy environment (20, 24, 28).
- SDT: Speech Detection Threshold. Testing at which sound intensity a verbal message is no longer understood (21).
- SRT: Speech Recognition Threshold. Testing the level of sound intensity, where the patient correctly repeats 50% of the words (21).
- SQ: Specific questionnaire. Evaluates speech recognition, social interaction, telephone use, confidence, family life, satisfaction (22).
- EEG: Electroencephalography. Recording electrical activity in neurons in the brain (24).
- CRISP: Children’s realistic index of speech perception. Closed-set tests, with book or pictures (25).
- MLNT: Multisyllabic Lexical Neighbourhood Test. 15 bi- and trisyllabic words (26).
- GASP: The Glendonald Auditory Screening Procedure. 12 words and 10 questions (26).
- LNT: Lexical Neighbourhood Test. 25 monosyllabic words (26).
- SSQ: The Speech, Spatial and Qualities of Hearing Scale. Measures hearing disabilities in several domains (27).
- OLKI: Oldenburger Kinder Reimtest. Audiometric test to determine the intelligibility of speech in quiet and in noise (28).
- TIMIT: The Texas Instruments Massachusetts Institute of Technology sentences. Consists of sentences of four to eight words in length, spoken by different speakers from major dialect regions in the USA. In noise and in quiet. (30)
4 Discussion
The purpose of this study was to examine if it is beneficial to implant CI in adult patients, regarding if their hearing loss was prelingual, postlingual or if they were to receive a second CI. There is currently no known international consensus for these cases. We wanted to investigate the literature to find out if there is enough published data to make conclusions. This kind of literature review would have a great value for the clinical decision-making.

In general, the recent articles are more positive in terms of implantation in adults and senior citizens. Advanced implant techniques are now available. Inclusion criteria have been milder, including patients with residual hearing and better pre implant test scores. This can be seen from the published results.

4.1 Prelingual deafness.
4.1.1 Study population
A total of 10 articles on prelingual deafness were reviewed. They all had quite similar study population or inclusion criteria, such as onset of sensorineural hearing loss under 3 – 4 years of age (2, 4, 5, 11, 13, 16, 17), and implantation of CI after 12 – 14 years of age (4, 5, 11-14). This similarity is beneficial in the context of research, to obtain comparable groups. However, the criteria may have excluded other candidates, which the clinicians can meet in the reality. Example: None of the studies included patients with cognitive impairment or other disabilities. All studies had few participants, below 44 patients, with the exception of one study (13) with 103 included patients. This is small study populations, making it difficult confidently to generalize the results to a larger population.

4.1.2 Age at implantation and duration of deafness
The youngest patient implanted was 12 years of age (5) and the oldest was 70 years of age (15), describing the great variation in age in this patient population. They will have different duration of deafness and therefore different starting point before implantation. The studies do not provide the same results, regarding how duration of deafness affects the test results after implantation. Two studies (4, 17) state that duration of deafness is not a critical factor, or not significantly associated with speech
perception in open-set after implantation. These are recent studies. In one of the oldest studies it is concluded that before 12 years of age is a critical point for implantation. A later implantation will result in minimal to no open-set and limited closed-set speech understanding (13). There is a clear tendency in the most recent articles towards a more liberal policy with long-lasting deafness before implantation. None of these articles would use long-lasting deafness as a single exclusion criteria for implantation. Recent articles also agree, that a high age alone is not an exclusion criteria for CI.

4.1.3 Communication mode and use of hearing aids
In five studies the majority, or all the patients, used oral communication prior to implantation (2, 4, 11, 16, 17), and six studies concluded or implied the importance of oral communication prior to implantation (2, 4, 5, 12, 14, 17). This suggests that any form of oral communication before implantation, is a good prognostic factor. Use of hearing aids prior to implantation did not receive much attention in the selected studies. Three studies mentioned the number of patients using hearing aids prior to implantation (2, 12, 16), and three studies mentioned the possible effects hearing aids could give. One study recommend the use of hearing aids before CI (2). Another study concluded with increased speech perception scores after CI among former hearing aid users, compared with non-users (4). Only a few articles reported the use of hearing aids before implantation, and the number of patients in these articles was also sparse. Despite of these shortcomings there is a trend in which the use of hearing aids before CI is recommended. Hearing aids are important to stimulate the auditory pathways, not only for the patient to be able to hear.

4.1.4 Tests and results
All studies used different tests, but each study investigating different speech perception outcomes concluded with better or significantly better results after CI (2, 4, 5, 11, 13). In one of the oldest studies, the results were lower and the plateau for improvement were lower compared with patients with postlingual onset of deafness (13). Different questionnaires about quality of life, individual satisfaction, loneliness and self esteem showed significantly better outcomes after CI (5, 12, 15). The use of so many different tests makes it difficult to compare the study results with each other. Although different test were used for both speech perception, sentence recognition,
and different questionnaires administered, all studies demonstrated better or significantly better results after CI. One study wanted to investigate which tests can be used before implantation, to predict the post implant outcome (16). They demonstrated that speech intelligibility tests had a good validity as a predictor for CI outcome, and speech intelligibility of vowels seems to be preferable as a single measure before implantation. Since this is the only study recommending a single test for predicting CI outcome, it is difficult to generalize that this is the only intelligibility test adult prelingual deafened CI candidates must complete.

4.1.5 Other findings
Among the studies that mention etiology, no further elaboration is made regarding how the etiology correlates with the post implantation outcomes. This may imply that the cause of deafness is not a decisive factor for the CI outcomes. Some patients may fear an unsatisfactory speech comprehension and speech perception if the worse ear is implanted. One study demonstrated no significant difference in test performance after implantation, comparing patients implanted in their better versus poorer ear (17). Since there is only one study mentioning this, one should be careful to generalize these findings to all patients.

4.2 Postlingual deafness and age
4.2.1 Study population
A total of 8 articles on postlingual deafness were reviewed. The study population was similar regarding postlingual onset of deafness, and most studies included adult patients above 60 years of age at the time of implantation (6, 19, 21-23). The number of patients included in the different studies varied, ranging from 17 patients (21) to 1005 patients (18). Given such a large difference in the number of participants, the results are often of different value. Because of their age, his study population may be expected to have several other comorbidities, and surgery may be associated with higher risk. However, studies have reported no surgical complications (21, 22), and CI can be regarded as a safe procedure for older patients.
4.2.2 Tests and results
Several different tests were used, in quiet and noisy environments, as well as different questionnaires. Although there were used different tests, several studies showed significant improvement in speech outcomes (20, 21, 23, 24) and quality of life (22) after CI. None of the tests has been used more often than others, suggesting no test is known to be superior to another.

4.2.3 Age at implantation and CI outcome
Two studies compared adults aged older than respectively 60 and 70 years, with a group of younger CI patients (18, 22). The comparison of different age groups is important to determine whether there is an age where CI no longer has an effect, an upper age limit. One study reported no significantly difference in performance between patients under and above 70 years of age the first year after implantation (18). They found significantly lower results in the oldest patients when tests were performed in a noisy environments. The other study found patients aged between 40-60 years to have better speech recognition scores, than patients older than 60 years (22). Another study had similar results regarding listening in a noisy environment, were HINT scores declined with 1.3 % for every increasing year of age at the time of CI (19). It has been concluded that there is no upper age limit for receiving a CI (6). However, with an increasing age it might be expected to have poorer performance regarding tests performed in noisy environments. Age at implantation is not a decisive factor to the overall speech perception and speech comprehension after CI. Hearing and cognitive skills go hand in hand, and age can affect both of these.

4.2.4 Other findings
There is currently no known international consensus regarding the inclusion criteria for possible adult CI recipients. Some studies have recommended and concluded that CI is appropriate for adult postlingually deafened patients with an open-set speech recognition score below 50 % without lip-reading (6) or below 60 % (19), and that older patients should not be denied CI based only on their age (23). It seems that the inclusion criterion is determined by the individual CI-departments, and in a case-to case basis. The etiology and use of hearing aids has not been mentioned in the included articles, and may not be an important factor for the postlingual deafened adults. Maybe since these patients already have learned and used spoken language.
4.3 Effect of a second CI.

4.3.1 Study population
At total of 6 articles on the effect of a second CI were reviewed. The studies included both children and adults, with prelingual and postlingual deafness, and are therefore very heterogeneous.

4.3.2 Tests and results
Different tests were administered, but some were used in several studies, for example sound localization, BKB and HINT. This demonstrates that specific tests may be desirable for finding differences between conditions with unilateral CI and bilateral CI. The majority of the studies found significantly or better auditory performances, both in quiet and in noise, with bilateral CI compared to unilateral CI (25, 26, 28-30). This may indicate a strong consensus in the benefits from a second CI.

4.3.3 Age at implantation and interval between CI's
The children were implanted with a second CI between 3 to 19.9 years of age, with different intervals between implantations. Time between first and second CI in children, ranged from 0 to 16.7 years (26, 28, 29). For adults the mean age at second CI ranged from 46.6 to 53.8 years of age, and time between implantation ranged from 0 to 19 years. (26, 28, 30). Although the inter implantation interval is long, studies have concluded that a longer delay is not a contraindication for a second CI (28), and improvement in auditory perception and functional outcomes are found despite a longer inter implantation interval (26, 29). Since the binaural auditory system and auditory cortex is well developed in postlingual deafened adults, a early second CI is less trivial (28). It appears that the length of the inter implantation interval is irrelevant, but according to another study there is evidence of a critical age for children between 3.5 and 4 years of age, with an implantation interval less than 2 years (29). None of the included studies have discussed or found a similar critical age for adult recipients, but the length of deafness is demonstrated to be an important variable and therefore a shorter inter implantation interval is desirable in adult CI recipients (30).
4.3.4 Other findings
The first CI is described to be the superior implant (27), with an ongoing significant improvement over time (30). Postlingual deafened adults can expect outcomes in the second implant, similar to the first implant within 3 to 6 months of bilateral CI use (30). This indicates an ongoing improvement beyond the study’s follow-up time, and testing after several years with bilateral CI is therefore desirable. It would be very important to find out when the second implant will not have an additional effect. We do not find an answer in these articles.

5 Conclusion
CI is beneficial in all the examined patient groups. The use of hearing aids and oral communication prior to implantation are good prognostic factors for CI outcome, in the group of prelingual deafened adults. There is no common agreement regarding effect of deafness duration, and time of implantation. However, early implantation is desirable, and prelingual deafness should not be an exclusion criterion for CI. In the group of postlingual deafened adults, no upper age limit was found where a CI did not have an effect. An increasing age might be associated with poorer test performance in noisy environments. CI is appropriate for adult postlingual deafened adults with moderate speech perception, and broader inclusion criteria are desirable. A long inter-implantation delay is not a contraindication for receiving a second CI. However, a shorter inter implantation delay is desirable and associated with better outcomes. When receiving a second implant, results similar to the first CI may be achieved, and an ongoing improvement in the first CI is described. More research with a longer follow-up, for example 10 to 20 years are required, to see how long the effect of CI continues, and other long-term effects of CI.
6 References

