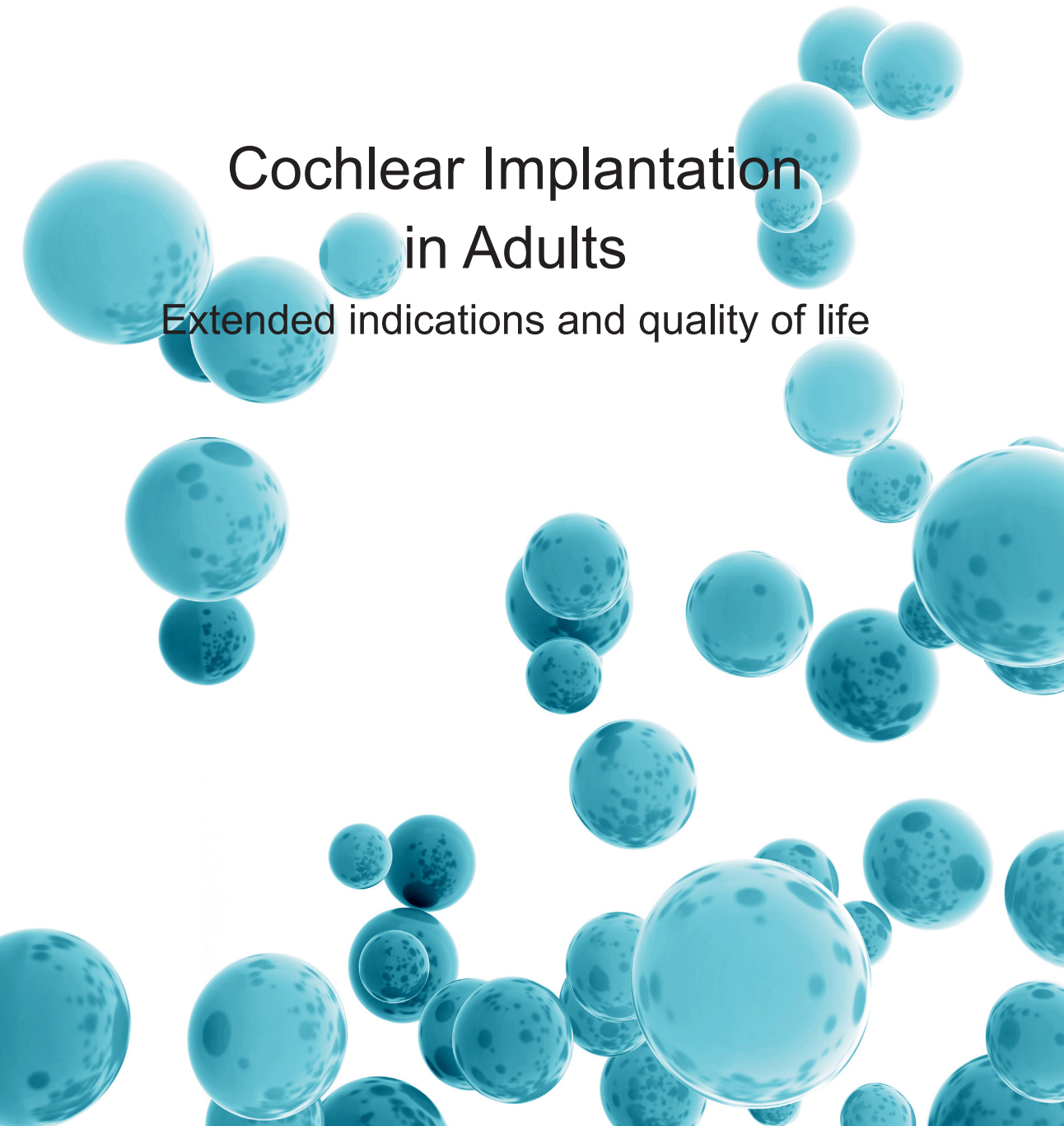


KATI HÄRKÖNEN

Cochlear Implantation in Adults

Extended indications and quality of life





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Cochlear Implantation
in Adults

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ACADEMIC DISSERTATION

To be presented, with the permission of
the Faculty Council of the Faculty of Medicine and Life Sciences
of the University of Tampere,
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of the Arvo building, Arvo Ylpön katu 34, Tampere,
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KATI HÄRKÖNEN

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ACADEMIC DISSERTATION

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To my beloved family

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Tampere, December 2017

Kati Härkönen

Abstract

Monaural hearing causes difficulties in determining the direction of sound and in speech perception and may lead to problems managing at work and in everyday life. In Finland, adults with postlingual severe bilateral sensorineural hearing loss (SNHL) are traditionally implanted unilaterally. Patients with unilateral deafness seldom need or want hearing rehabilitation, but if a patient so desires, a contralateral routing of signal (CROS) device or a bone conduction device (BCD) are offered. However, binaural hearing is not achieved with these options.

In the first study, we evaluated the benefits of sequential bilateral cochlear implantation in 15 patients. Quality of life (QoL), quality of hearing (QoH), working performance, and work-related stress were measured with specific questionnaires, and sound localization and speech perception in noise were measured with specific tests.

Results indicated that QoL, QoH, and working performance increased statistically significantly after a second cochlear implantation. In addition, sound localization performance and hearing in noise improved. As a result, patients managed much better at work and communication with co-workers was much easier. Furthermore, sequentially bilaterally implanted patients had less depression and distress after the second cochlear implant (CI). In this group, the impact of the second CI on QoL was almost as significant as the impact of the first CI.

In the second study, we explored the advantages of CI in seven single-sided deafness (SSD) patients. QoL, QoH, working performance, and work-related stress were measured with specific questionnaires, and sound localization and speech perception in noise were measured with specific tests.

This prospective study showed that working performance, QoL, and QoH improved statistically significantly. Furthermore, sound localization performance and hearing in noise improved. Tinnitus perception decreased after cochlear implantation.

In the third study, we explored long-term hearing results, QoL, QoH, work-related stress, tinnitus, and balance problems in 172 patients after unilateral idiopathic sudden sensorineural hearing loss (ISSNHL). The patients were divided into two groups based on whether their ISSNHL had recovered to normal or not.

Poor hearing outcome correlated with severity of initial hearing loss and vertigo and age together with ISSNHL. Patients with recovered hearing had statistically significantly better QoL and QoH, and they had less tinnitus and fewer balance problems. Pure-tone average (PTA; mean of 0.5, 1, 2, 4 kHz) deteriorated on average by 7 dB HL in the affected ear and by 6 dB HL in the healthy ear during the 8-year follow-up. Hearing deteriorated with age in a normal manner and ISSNHL did not appear to accelerate the hearing loss. The cumulative recurrence rate for ISSNHL was 3.5%.

In the fourth study, we evaluated the long-term effects of hybrid cochlear implant (HCI) on QoL, QoH, and working performance in eight adult patients, and compared these results to patients with conventional unilateral CI, bilateral CI, and SSD patients with CI. Residual hearing was preserved in all patients after HCI surgery. During the 3.6-year follow-up, the mean hearing threshold at 125 to 500 Hz decreased on average by 15 dB HL in the implanted ear. Sound localization accuracy was equal in the HCI, bilateral CI, and SSD+CI patients.

Our studies showed that binaural hearing clearly improved QoL and QoH in all study groups. Working performance, sound localization and hearing in noise were also statistically significantly better after cochlear implantation.

Tiivistelmä

Kaksi hyvin kuulevaa korvaa mahdollistavat ihmisen tarkan kuulemisen hiljaisuudesta poikkeavissa olosuhteissa, joita arkielämässä on jatkuvasti. Yhdellä kuulevalla korvalla on vaikea tunnistaa, mistä suunnasta ääni kuuluu ja puheen erottaminen etenkin hälyssä on hankalaa. Tämä voi aiheuttaa vaikeuksia pärjätä työssä ja arjessa. Suomessa puheenkehityksen jälkeen kuuroutuneet aikuiset ovat perinteisesti saaneet yhden sisäkorvaistutteen. Yhden korvan kuuroutuminen on jätetty kuntouttamatta tai sitä on kuntoutettu luuankkuroidulla kuulokojeella (BCD), jossa ääni ohjataan kallon luun kautta toisen puolen terveeseen sisäkorvan aistittavaksi tai CROS-kojeella, jossa ääni lähetetään langattomasti kuuron korvan kuulokojeesta terveessä korvassa olevaan vastaanottimeen. Kahden kuulevan korvan hyötyjä ei kuitenkaan saavuteta näillä kuntoutusmuodoilla.

Ensimmäisessä tutkimuksessa vertasimme yhden vs kahden sisäkorvaistutteen vaikutusta 15 puheenkehityksen jälkeen kuuroutuneella aikuispotilaalla. Selvitimme potilaiden elämänlaatua, kuulemisen laatua, työssä pärjäämistä ja työstressiä niihin soveltuvien kyselylomakkein. Suuntakuulo ja puheenerotus hälyssä mitattiin.

Tutkimustulokset osoittivat, että potilaat hyötyivät toisesta sisäkorvaistutteesta ja he kokivat elämänlaadun, kuulemisen laadun ja työkyvyn parantuneen merkitsevästi. Lisäksi suuntakuulo ja kuuleminen hälyssä parantuivat ja näiden seurauksena kommunikaatio helpottui esimerkiksi työkavereiden kesken. Potilaat kokivat myös masennuksen ja ahdistuksen oireiden lievittyneen ja he saivat toisesta istutuksesta lähes yhtä suuren avun kuin ensimmäisestä.

Toisessa tutkimuksessa tutkimme yhden sisäkorvaistutteen vaikutusta seitsemällä toispuolisesti kuuroutuneella aikuisella. Potilaiden elämänlaatua, kuulemisen laatua, työssä pärjäämistä ja työstressiä mitattiin niihin soveltuvien kyselylomakkein. Suuntakuulo ja puheenerotus hälyssä mitattiin.

Tulosten mukaan potilaiden elämänlaatu, kuulemisen laatu ja työkyky parantuivat merkitsevästi. Lisäksi suuntakuulo ja kuuleminen hälyssä parantuivat. Myös tinnitus vähentyi leikatussa korvassa sisäkorvaistutteen saamisen jälkeen.

Kolmannessa tutkimuksessa selvitimme äkillisen etiologialtaan tuntemattoman sisäkorvaperäisen kuulonlaskun aiheuttamaa pitkäaikaisvaikutusta kuuloon, elämänlaatuun, kuulemisen laatuun, työstressiin, tinnitukseen ja tasapainoon 172

potilaalla. Potilaat jaettiin kahteen ryhmään sen mukaan, oliko kuulo korjaantunut normaaliksi vai ei lyhyen seurannan aikana.

Kahdeksan vuoden seurannan aikana huonon ennusteen merkkejä äkillisessä sisäkorvaperäisessä kuulonlaskussa olivat suuri kuulonlasku alkutilanteessa sekä huimaus ja korkeampi ikä tapahtumahetkellä. Niillä potilailla, joiden kuulo korjaantui seurannassa, oli merkitsevästi parempi elämänlaatu, kuulemisen laatu ja heillä oli vähemmän tinnitusta ja huimausta. PTA (puhealueen kuulokynnysten keskiarvo) sairastuneessa korvassa laski 7 dB HL ja terveen korvan lasku oli 6 dB HL kahdeksan vuoden seurannan aikana. Iän mukainen kuulonlasku oli molemmissa korvissa samanlaista, eikä äkillinen kuulonlasku näyttänyt kiihdyttävän sitä. Kumulatiivinen uusiutuminen oli 3,5 % seurannan aikana.

Neljännessä tutkimuksessa arvioimme elektroakustisen sisäkorvaistutteen pitkäaikaisvaikutusta elämänlaatuun, kuulemisen laatuun ja työkykyyn kahdeksalla aikuispotilaalla ja vertasimme tuloksia tutkimuksen I ja II potilaisiin.

Elektroakustisten sisäkorvaistutepotilaiden jäännöskuulo säilyi leikkauksessa. 3,6-vuoden seurannassa kuulokynnykset 125–500 Hz taajuuksilla laskivat keskimäärin 15 dB leikatussa korvassa. Suuntakuulo oli yhtä hyvä elektroakustisella, kahdella sisäkorvaistutteella ja toispuoleiseen kuurouteen istutteen saaneilla potilailla.

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List of original publications

This dissertation is based on the following original publications:

- I. Härkönen K, Kivekäs I, Rautiainen M, Kotti V, Sivonen V, Vasama JP. Sequential bilateral cochlear implantation improves working performance, quality of life, and quality of hearing. *Acta Oto-Laryngologica*. 135(5):440-6, 2015.
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- III. Härkönen K, Kivekäs I, Rautiainen M, Kotti V, Vasama JP. Quality of life and hearing eight years after sudden sensorineural hearing loss. *Laryngoscope*. 127(4):927-931, 2017.
- IV. Härkönen K, Kivekäs I, Kotti V, Sivonen V, Vasama JP. Hybrid cochlear implantation: Quality of life, quality of hearing, and working performance compared to patients with conventional unilateral or bilateral cochlear implantation. (*European Archives of Oto-Rhino-Laryngology*. 274(10):3599-3604.

The publications are referred to in the text by their Roman numerals. The original publications have been reprinted here with the kind permission of their copyright holders.

Abbreviations

BCD	Bone conduction device
CI	Cochlear implant
CROS	Contralateral routing of signal
dB	Decibel
EAS	Electroacoustic stimulation
EI	Error Index
GBI	Glasgow Benefit Inventory
HA	Hearing aid
HCI	Hybrid cochlear implant
HL	Hearing level
ISSNHL	Idiopathic sudden sensorineural hearing loss
kHz	Kilohertz
MRI	Magnetic resonance imaging
PTA	Pure-tone average (mean of 0.5, 1, 2, 4 kHz)
QoH	Quality of hearing
QoL	Quality of life
SD	Speech discrimination
SNR	Signal-to-noise ratio
SPL	Sound pressure level
SSD	Single-sided deafness
SNHL	Sensorineural hearing loss
SSQ	Speech, spatial, and qualities
VAS	Visual analog scale

1 Introduction

In real-life listening situations, conversation often occurs in the presence of background noise. If there is more than one speaker, following and comprehending specific speech requires the ability to locate each sound source. Many people with hearing loss in one ear or both have difficulties to hear in noise.

According to World Health Organization (WHO) criteria, a person whose hearing threshold (PTA) is ≥ 25 dB HL has hearing loss (Smith, 1997). Hearing loss can be conductive, sensorineural, mild, moderate, severe, or profound, and it can affect one or both ears.

The WHO estimates that over 5% of the world's population, 360 million people, has disabling hearing loss (328 million adults and 32 million children) (World health organization, 2016). Disabling hearing loss (conductive or sensorineural) refers to hearing loss ≥ 40 dB HL in the better hearing ear in adults and ≥ 30 dB in children. The majority of hearing problems can be prevented or treated. Chronic ear infections, meningitis, rubella, noise and the use of ototoxic medications are the main causes of hearing problems, according to the WHO.

In Finland, there are an estimated 700 000 hearing impaired people and a further 280 000 people who would benefit from hearing rehabilitation (Sorri, Jounio-Ervasti, Uimonen, & Huttunen, 2001).

In the US population, the overall prevalence of unilateral and bilateral hearing loss (conductive or sensorineural) among adults aged 20 to 69 in the years 2003 to 2004 was 16.1% (7.3% bilateral and 8.9% unilateral), corresponding to 29 million Americans (Agrawal, Platz, & Niparko, 2008). Another national estimate of hearing loss in the US population, based on audiometric data and a large, well characterized representative sample, showed that in individuals over 12 years of age nearly 1 in 8 has bilateral hearing loss, and nearly 1 in 5 has unilateral or bilateral hearing loss (Lin, Niparko, & Ferrucci, 2011).

The most common device used to rehabilitate hearing is a hearing aid (HA). In severe to profound cases of sensorineural hearing loss (SNHL), however, a cochlear implant (CI) is used. CIs have provided hearing to hundreds of thousands of profoundly deaf people around the world.

Nowadays, children in many developed countries with profound bilateral SNHL get CIs to both ears, but adults usually only get one CI. Binaural hearing is necessary to localize sound and to separate speech from background noise. However, binaural hearing cannot be achieved with a single CI, and therefore adults without binaural hearing have difficulties to manage with their hearing in everyday life and at work. Many studies have shown the benefits of bilateral cochlear implantation, but in many countries increasing health care costs exclude the possibility for a second CI. In Finland, the Ministry of Social Affairs and Health recommends binaural hearing rehabilitation for every citizen suffering from bilateral hearing impairment (Sosiaalija terveysministeriö, 12/2016). In practice, however, this recommendation is true only for HAs.

In adults and children, hearing loss can lead to reduced quality of life (QoL), and work and academic performance. Adolescents with hearing loss experience significantly poorer QoL (hearing- and school-related) than their peers with normal hearing (Rachakonda et al., 2014). In adults, hearing loss negatively affects performance at work. Circumstances (such as meetings) where important spoken message or information is provided are examples of situations where hearing-impaired person may have difficulties, in spite of great effort. This explains why a person with hearing loss has a five times higher risk of developing stress-related complaints that result in sick-leave than a normally hearing person (Kramer, Kapteyn, & Houtgast, 2006).

2 Review of the literature

2.1 Anatomy and physiology of the auditory system

The external ear comprises the pinna and the external auditory canal (EAC). At the medial end of the EAC is the tympanic membrane (TM).

The middle ear is an air-filled space, situated inside the temporal bone, that is lined with ciliated mucosal epithelium. Auditory ossicles (malleus, incus, and stapes) form a chain with the malleus attaching to the TM in the umbo, and the stapes footplate is situated over the oval window. The ossicle chain is fixed to the roof of the middle ear via ligaments joined to the malleus and incus.

The mastoid cavity is a part of the tympanic cavity and is composed mainly of aerated, pneumatized cells or borders of important elements, such as facial nerve, semicircular canal systems, the jugular vein, and the medial and posterior cranial fossa.

The middle ear is connected to the nasopharynx by the Eustachian tube and blood supply to the middle ear mainly originates from branches of the internal maxillary artery branches.

The inner ear is encased in a bony labyrinth that comprises the cochlea, the vestibule of the ear and the semicircular canals. The cochlea is a snail-shaped structure, wide in diameter at the base but narrows for $2\frac{3}{4}$ turns until it reaches its apex. Its perilymph space forms the scala vestibuli (behind the oval window) and the scala tympani (behind the round window) that communicate at the apex of the cochlea (helicotrema).

The membranous labyrinth is filled with endolymph and floats inside the bony labyrinth encircled by the perilymph of the scala vestibuli and the scala tympani. The sensory organ of hearing, the organ of Corti, is in the membranous labyrinth. The membranous labyrinth's superior border is Reissner's membrane, the inferior border is the basilar membrane and the lateral border is the spiral ligament. In the lateral wall is also the stria vascularis, which is responsible for the metabolic environment of the scala media. The organ of Corti is situated on the basilar membrane. The basilar membrane is narrow at its base and widens towards the apex of the cochlea. It comprises many types of epithelial cells and structures, for example, inner and

outer hair cells. At the top of the hair cells there are actin filaments called stereocilia, and the tectorial membrane lies over the inner and outer hair cells. The labyrinth receives all its arterial blood supply from the *arteria labyrinthi*, a branch of the *arteria cerebelli inferior anterior*.

When sound stimulus enters the EAC, it causes the TM to vibrate. This in turn causes the entire ossicular chain to vibrate and transmit sound to the inner ear via the stapes footplate. The vibration of the stapes footplate results in a compressional wave in the inner ear fluid, which travels across the *scala vestibuli* to the *helicotrema*, out across the *scala tympani* towards the round window. The pressure in the *scala vestibuli* is higher than the pressure in the *scala tympani* and this causes a traveling wave on the basilar membrane and the organ of Corti and its displacement causes deflection of the stereocilia, resulting in depolarization/hyperpolarization of the hair cells. The inner and outer hair cells function as receptor cells that transduce mechanical movement into an electrochemical signal. The signals from outer haircells serve as cochlear amplifiers and the signals from inner hair cells stimulate the auditory nerve. The properties of the basilar membrane allow it to respond to various frequencies differently, with higher frequencies at its base and the lower frequencies at its apex.

The cochlear nucleus receives ascending auditory information from spiral ganglion cells through the auditory nerve. The axons of cochlear nucleus neurons project to other brainstem regions via the ventral, intermediate, and dorsal acoustic stria.

The superior olivary complex (SOC) is in the caudal aspect of the pons and the first auditory center to receive binaural innervation. Binaural innervation plays a major role in sound localization. From the SOC leaves ascending and descending pathways. The ascending fibers travel via the lateral lemniscus to the nucleus of the lateral lemniscus and to the inferior colliculus. The descending pathway provides efferent innervation to the outer hair cells and modulates their activity. The integration of afferent and efferent signals makes the SOC important in influencing hearing in noise and sound localization.

The inferior colliculus is in the midbrain and receives innervation from higher and lower brain regions. The most important functions of the inferior colliculus are related to sound localization, frequency determination, and integration of auditory and non-auditory systems.

In the medial geniculate and auditory cortex, auditory information integrates with multiple other sensory modalities.

2.2 Binaural hearing

Binaural hearing is the normal hearing process that is used to localize sound and to help separate speech from noise in adverse listening situations. The advantage of binaural hearing over monaural hearing is reduced listening effort. When subjects listen to monaural compared with binaural pure tones at suprathreshold levels, the stimulus in the monaural ear must be 6 dB to 10 dB higher than the stimulus during binaural presentation to result in equal loudness judgments (Haggard & Hall, 1982; Marks, 1978).

Binaural interactions occur primarily and almost simultaneously at three levels of the brain: the SOC, the nuclei of the lateral lemniscus, and the inferior colliculus. The beneficial effects of binaural hearing are based on three mechanisms. Binaural loudness summation and binaural squelch reflect central processing, and the head shadow effect is explained by listening through two ears separately (Avan, Giraudet, & Buki, 2015; Steven Colburn, Shinn-Cunningham, Kidd, & Durlach, 2006). These mechanisms rely on two acoustic cues: the interaural level difference and the interaural time difference. It has been suggested that binaural advantages may not exist in patients with a large asymmetry in hearing because only the head shadow effect does not rely upon fused information.

Binaural advantages are observed in adult bilateral CI recipients, and the greatest effects are the head shadow effect and improvement in localization, followed by loudness summation. The smallest benefit is the squelch effect (Firszt, Reeder, & Skinner, 2008). Normal binaural processes are disrupted when changes occur in the central auditory system as the result of an absence of input. In patients with postlingual bilateral profound hearing loss, reduction in cell size/count has been observed in the cochlear nucleus, superior olivary nucleus, and inferior colliculus (Moore, Niparko, Perazzo, Miller, & Linthicum, 1997).

2.3 Bilateral sensorineural hearing loss

2.3.1 Definition, symptoms, etiology, diagnosis

Sensorineural hearing loss (SNHL) results from cochlear hair cell, auditory nerve, or central auditory system dysfunction. A pure-tone average (PTA) of greater than 25 dB HL in both ears is defined as hearing loss, according to WHO criteria. Moreover,

it is at this level that hearing loss begins to impair communication in daily life (Smith, 1997).

Initially, patients have difficulties hearing in noise, and when the hearing loss progresses, they have difficulties hearing in silence too. Etiology includes genetic, infectious, vascular, neoplastic, traumatic, toxic, iatrogenic, degenerative, immunologic, and inflammatory pathologies that can affect the cochlea. In elderly people, presbycusis is the most common cause of bilateral SNHL. The prevalence of hearing loss is therefore increasing because of the growing number of aging people (Homans et al., 2017). In children, the most common causes of bilateral SNHL are genetic non-syndromic (29%), prenatal (12%), perinatal (10%), early postnatal (8%), and genetic syndromic (3%). In 38% of cases, the etiology remains unknown (Morzaria, Westerberg, & Kozak, 2004).

Patients with SNHL usually delay seeking medical attention. Otoloscopic examination of the ears is frequently unrevealing. Audiometric testing verifies and quantifies the degree of hearing loss. Bone- and air-conduction pure tone audiometry help to specify the type of hearing loss (sensorineural, conductive or mixed) and speech discrimination tests help to define the nature of the SNHL (cochlear or retrocochlear) and predict the benefits of amplification. Magnetic resonance imaging (MRI) and/or computed tomography (CT), auditory brainstem response measurement, and laboratory tests are sometimes needed in selected patients.

2.3.2 Effects of bilateral sound deprivation (QoL, QoH)

Bilateral hearing loss is not only a disability, but it can also be perceived by an individual as a handicap with related psychosocial effects. Patients often confront confusion, stigmatization or even mockery. Exclusion from communication can have a significant impact on everyday life and can cause feelings of loneliness, frustration, and isolation.

Several studies have shown that patients with bilateral SNHL have significantly poorer QoL than the general population for the physical and psychological domains, for example somatic complaints, and depressive and anxiety symptoms. (Ciesla, Lewandowska, & Skarzynski, 2016; Fellingner et al., 2005). Knutson et al. also found increased mental distress among patients with an acquired postlingual hearing impairment, when compared with the general population (Knutson & Lansing, 1990). Depressive and anxiety symptoms and social isolation were the most distinctive. In addition, teens with hearing loss had a higher percentage of mental

health problems compared with normal hearing teens (37% vs. 17%) (van Eldik, 2005).

Patients with bilateral hearing loss seem to have more dissatisfaction with their social lives than normal hearing or prelingually deaf people (Fellinger, Holzinger, Gerich, & Goldberg, 2007). Those with prelingual deafness can achieve satisfying social relationships by using sign language within the deaf community, but those who are hard of hearing may have relatively restricted social lives.

In the US, hearing loss is associated with a 42% unemployment rate compared with a 25% rate for the same working-age population with normal hearing (Ruben, 2000). Any level of hearing loss, even mild, can lead to academic underachievement (Antia, Jones, Reed, & Kreimeyer, 2009; Most, 2006). For example, in Denmark young adults who have been hearing-impaired since birth are more likely to undergo vocational training than to attain a university education (Parving & Christensen, 1993).

2.4 Unilateral sensorineural hearing loss

2.4.1 Definition, symptoms, etiology, diagnosis

In unilateral hearing loss, hearing is normal in one ear and impaired in the other. The hearing loss may be conductive, sensorineural, or combined and can range from mild to severe. Patients usually have difficulties in sound localization and separating target sounds from background noise (Douglas, Yeung, Daudia, Gatehouse, & O'Donoghue, 2007). An exact definition is lacking, but in the literature an interaural PTA (0.5, 1, 2, and 4 kHz) difference of more than 10 to 15 dB HL has been used (Noble & Gatehouse, 2004).

In adults, unilateral hearing loss is usually caused by idiopathic sudden sensorineural hearing loss (ISSNHL), Meniere's disease, or trauma. In children, the most common etiology is congenital (45%). The risk factors, such as prematurity, neonatal intensive care, and ototoxic medication account for 10% of cases, and in 31% of cases the etiology is unknown. Etiologies that include hereditary, meningitis, cytomegalovirus, and trauma account for 14% of cases (Ghogomu, Umansky, & Lieu, 2014). Otoloscopic examination and audiometric testing is essential to determine the type and degree of hearing loss. MRI/CT, auditory brainstem response measurement, and laboratory tests are sometimes also needed in selected patients.

2.4.2 Idiopathic sudden sensorineural hearing loss

ISSNHL is defined as a decrease in hearing of ≥ 30 dB in at least three adjacent frequencies occurring within 72 hours (Stachler RJ et al., 2012; Wilson WR, Byl FM, & Laird N, 1980).

The hearing loss is usually cochlear in origin, and the hearing loss may be associated with tinnitus, vertigo, and a sensation of pressure in the ear. Because premorbid audiometry is not usually available, ISSNHL is defined as hearing loss associated with the opposite ear's thresholds.

The incidence of ISSNHL has been estimated to be between 5 and 20 per 100 000 (Byl, 1977; Wu CS, Lin HC, & Chao PZ, 2006), and the relapse rate varies from 0.8% to 4.99% (Furuhashi A, Matsuda K, Asahi K, & Nakashima T, 2002; Park IS, Kim YB, Choi SH, & Hong SM, 2013; Wu CM, Lee KJ, Chang SL, Weng SF, & Lin YS, 2014).

The proposed etiology includes viral infections, vascular disorders, genetic causes, labyrinthine membrane ruptures, and autoimmune processes or combinations of such factors (Chau JK, Lin JR, Atashband S, Irvine RA, & Westerberg BD, 2010; Lazarini PR & Camargo AC, 2006; Merchant SN, Adams JC, & Nadol JB Jr, 2005).

The severity of hearing loss, the presence of tinnitus or vertigo, the duration of the symptoms before treatment, age, audiogram type, treatment, and the presence of metabolic diseases are some of the reported prognostic factors for hearing recovery (Nagaoka J et al., 2010; Schreiber BE, Agrup C, Haskard DO, & Luxon LM, 2010; Wen YH, Chen PR, & Wu HP, 2014).

Although ISSNHL is often a surprising and dramatic experience for the patient, about half recover completely (Schreiber BE et al., 2010). Natural history and placebo-controlled studies have shown hearing recovery rates of 32% to 65% without any medical treatment, typically within 2 weeks after onset (Mattox DE & Simmons FB, 1977; Wilson WR et al., 1980).

Treatment options with variable efficacy are countless and include systemic and topical steroids, hyperbaric oxygen, diuretics, antiviral agents, carbogen inhalation and systemic betahistidine or other medications, middle ear surgery for fistula repair, and observation alone (Conlin & Parnes, 2007a; Conlin & Parnes, 2007b). Oral corticosteroids are probably the most widely used therapeutic intervention. The rationale behind the use of steroids is a potential decrease in any associated pathogenic inflammation and edema.

2.4.3 Effects of unilateral sound deprivation (QoL, QoH)

Unilateral hearing loss is often left untreated after the acute phase. Most patients manage with their hearing loss and do not want or need any hearing rehabilitation, or they are not satisfied with the available treatment options. Therefore, many patients manage their everyday life with noticeable asymmetric hearing.

Of patients with unilateral deafness due to vestibular schwannoma surgery, 94% thought they had significant problems hearing in noise and 84% of them had problems with sound localization (Andersen, Schroder, & Bonding, 2006).

Permanent unilateral deafness affects communication and speech perception in noisy settings in 87% to 93% of patients. Other symptoms are feeling of exclusion, reduced well-being, and the extensive use of speech perception strategies, for example, speech-reading and head turning (Wie, Pripp, & Tvette, 2010). The difficulties associated with hearing with one ear also diminish QoL. Studies by Sano et al. and Vannson et al. have shown that QoL decreases especially in terms of mental functioning, but also that social life and daily activities are affected (Sano H, Okamoto M, Ohhashi K, Iwasaki S, & Ogawa K, 2013; Vannson et al., 2015). Tinnitus is often related to unilateral sensorineural hearing loss and may decrease QoL even more (Carlsson PI, Hall M, Lind KJ, & Danermark B, 2011; Chen J, Liang J, Ou J, & Cai W, 2013).

Unilateral hearing loss may be detrimental to the academic success of children. The effects encompass not only auditory effects, such as difficulty hearing in noise, but also self-esteem and exhaustion (Kuppler, Lewis, & Evans, 2013). Children with unilateral hearing loss may experience barriers due to their hearing loss, but usually learn to adapt. They also have a significantly larger variance on the social functioning score than children with normal hearing or bilateral hearing loss (Borton, Mauze, & Lieu, 2010).

2.5 Hearing rehabilitation in severe hearing loss

2.5.1 Hearing aids

The most common treatment for mild and moderate uni- and bilateral SNHL is conventional HA amplification. A HA comprises a microphone that picks up the sound, an amplifier that makes the sound louder, a speaker that sends the amplified

sound into the ear canal, and a miniature battery that powers the HA (Einhorn, 2017). Most modern HAs use digital signal processing with high-fidelity signal reproduction and flexibility to match hearing loss and communication needs.

In patients with severe unilateral hearing loss, current rehabilitation options include a HA with contralateral routing of signal (CROS). A CROS HA conducts signals from the hearing field of the poor side wirelessly to a microphone in the ear canal of the better ear (Snapp, Holt, Liu, & Rajguru, 2017). Binaural hearing is not achieved with a CROS HA. A systematic review showed no beneficial effect of CROS HA regarding speech perception in noise and sound localization (Peters JP, Smit AL, Stegeman I, & Grolman W, 2015).

The consistent use of HAs remains low, despite evidence of the negative consequences of hearing loss on health and well-being. Estimates from the US National Health and Nutrition Examination Survey suggest that only 14% of hearing impaired Americans over 50 years of age use HAs, leaving 23 million untreated. The prevalence of HA use in the youngest group, 50 to 59 years, is just 4% (Chien & Lin, 2012). A substantial proportion (5% to 40%) of those who choose to be fitted with a HA do not use it (Barker, Mackenzie, Elliott, Jones, & de Lusignan, 01034). Many patients report that the nonuse of HAs is due to problems with discomfort, care, and handling of the device, and that they do not get enough benefit from the device (McCormack & Fortnum, 2013).

2.5.2 Bone conduction devices

Bone conduction devices (BCD) are very useful for patients with conductive hearing loss, but they are also used in patients with severe to profound unilateral SNHL (Wazen et al., 2003). The BCD comprises a sound processor, an implant, and an abutment or magnetic attachment. The sound processor picks up sound vibrations that are then sent directly through the bone to the inner ear.

In unilateral deafness, the BCD transfers signals from the deaf side to the better hearing ear. A preoperative test with the BCD must be carried out before surgery, for example, by attaching the BCD processor to a tight headband.

Andersen et al. and Faber et al. have shown that only 25% to 47% of patients with single-sided deafness (SSD) wanted a BCD after the test period (Andersen et al., 2006; Faber et al., 2012). The reasons for rejection are usually the following: limited benefit from the BCD trial, fear or contraindications for surgery, a CROS

HA preference, and cosmetic aspects or stigma (Siau, Dhillon, Andrews, & Green, 2015; Wendrich, Kroese, Peters, Cattani, & Grolman, 2017).

A BCD does not restore binaural hearing (Niparko, Cox, & Lustig, 2003). A systematic review showed no beneficial effect of BCD regarding speech perception in noise and sound localization (Peters JP et al., 2015). However, subjective speech communication improved moderately.

2.5.3 Middle ear implants

Middle ear implants can be an effective solution for cases of mild to severe sensorineural hearing loss, as well as for conductive or mixed hearing loss. The implants are designed for individuals who have not experienced an improvement with conventional HAs or cannot use them for medical reasons. This is often the case with permanent hearing loss after middle ear surgery or when HAs cannot be worn due to chronic ear canal inflammation.

In contrast to a HA, which can only make sounds entering the ear canal louder, a middle ear implant converts signals from the environment into mechanical vibrations. This mechanical energy directly stimulates the structures of the middle ear and allows even high-pitched tones to be perceived exceptionally well.

Middle ear implants pick up sounds using the microphone of the audio processor, and the audio processor then converts the sounds into electrical signals. These signals are transmitted through the skin to the implanted device. The implant then converts the signal into mechanical vibrations that directly stimulate the given middle ear structure (the ossicular chain) causing it to vibrate. These vibrations then conduct sound to the inner ear where they are passed on to the brain and are perceived as sound.

2.5.4 Cochlear implants

A cochlear implant (CI) is a device used to rehabilitate severe to profound sensorineural hearing impairment in adults and children when there is no more benefit from the HA.

2.5.4.1 History

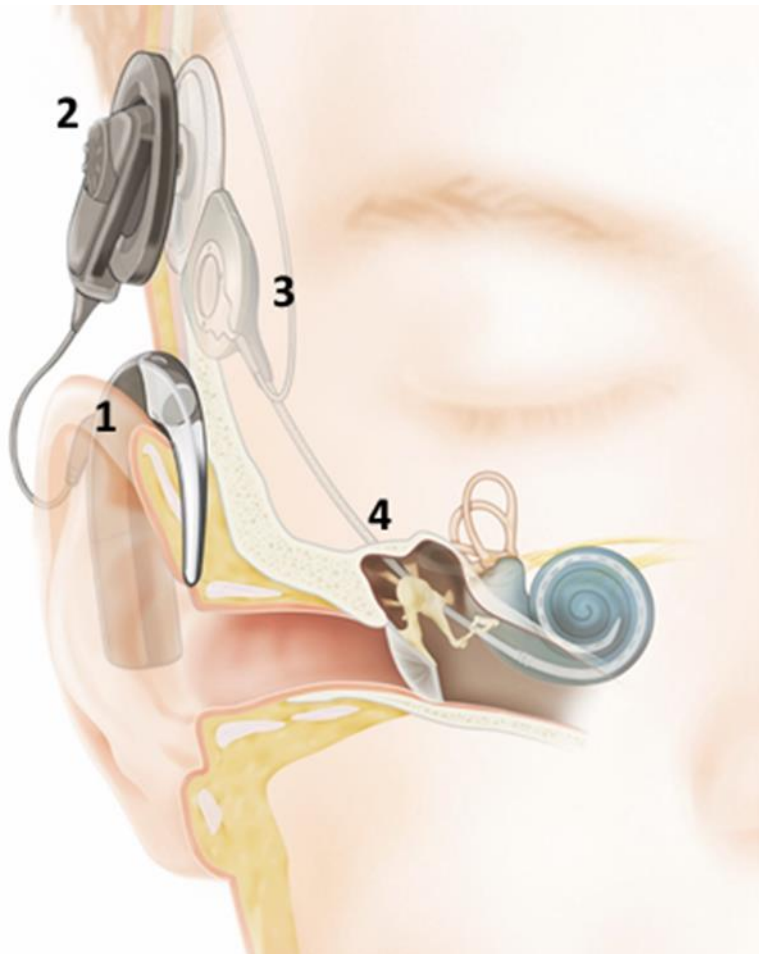
The first CI was implanted in humans in 1961 by William House and John Doyle (Mudry & Mills, 2013). The first multichannel CI was implanted in 1964 by Blair Simmons and Robert White at Stanford University Medical School (Simmons, 1966), and the first commercialized multi-electrode CI hearing prosthesis was implanted by Graeme Clark in 1978 (Clark et al., 1977; Mudry & Mills, 2013).

In Finland, the first CI was implanted in 1984 at Helsinki University Hospital. By the end of 1990s, all five university hospitals in Finland had started their own CI program. In Tampere, the first adult cochlear implantation was performed in 1995 and the first child was implanted with a CI in 1997. A bilateral CI program for children was started in 2007.

Today, there are hundreds of thousands of CI users around the world, with about 1500 in Finland. On average, Tampere University Hospital performs 40 CI surgeries annually.

2.5.4.2 Equipment and function

A conventional CI comprises a speech processor and a receiver (Figure 1). The speech processor includes a microphone (1) that collects sound and sends the processed electrical sound signal through a coil (2) across the skin to the implanted receiver (3). The receiver then sends electric impulses along the electrode array (4) placed in the cochlea. The electrodes stimulate the cochlea's spiral ganglion neurons (the auditory nerve), which then sends the impulses to the brain where they are interpreted as sound.



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Figure 1. Conventional CI

A CI with electroacoustic stimulation (EAS) comprises a speech processor and a receiver with acoustic and electric pathways (Figure 2). The external speech processor sends low frequency sounds to the acoustic component (1) which then amplifies the low frequency sounds and sends them via the normal hearing pathway. The amplified sounds activate the respective neurons of the auditory nerve and the acoustic stimulation is sent to the brain where it combines into a perceived sound. The external speech processor also captures sound and converts it into digital signals. The speech processor then sends digital high frequency signals to the implant (2).

The implant converts the high frequency signals into electrical signals, and sends them to an electrode array inside the cochlea where they activate the respective neurons of the auditory nerve. Impulses are sent to the brain which combines them into a perceived sound.



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Figure 2. Hybrid CI

2.5.4.3 General indications

The criteria for CI candidacy both in adults and children vary between countries and also between some regions within countries. According to an international survey for CI candidacy, the average thresholds for an individual to be considered as a candidate for CI should be greater than 75 to 80 dB HL at frequencies above 1 kHz (Vickers, De Raeve, & Graham, 2016). In Finland, there are no common criteria for CI candidacy between university hospitals, although the criteria do not significantly differ from each other. Decisions about implantation are usually made at tertiary centers by a multi-disciplinary team made up of surgical, audiological, medical, educational, and rehabilitation professionals.

At Tampere University Hospital, unilateral CI is provided if an adult patient with severe postlingual bilateral sensorineural hearing impairment does not manage with a HA. In children, all profoundly deaf newborns will have simultaneous bilateral cochlear implantation. A second CI is considered in adults and older children if there is not enough benefit from a single CI or bimodal CI/HA. Contraindications for surgery are medical reasons, anatomical reasons (ossified cochlea, missing cochlea or auditory nerve), severe mental retardation, acute/chronic otitis media, and mastoiditis without eradication of the disease. MRI and CT are used to exclude anatomical contraindications for surgery.

2.5.4.4 Extended indications

2.5.4.4.1 Tinnitus

Tinnitus is often related to sensorineural hearing loss, and cochlear implantation has been successfully utilized to treat incapacitating tinnitus. Cochlear implantation was first used in 2008 to treat tinnitus in patients with unilateral hearing loss (Van de Heyning P et al., 2008). Since then, several studies have reported a significant reduction in tinnitus loudness after cochlear implantation (Arndt et al., 2011; Punte, De Ridder, & Van de Heyning, 2013; Servais, Hormann, & Wallhausser-Franke, 2017; Sladen et al., 2017). Moreover, Van de Heyning et al. and Tavora-Viera et al. have reported a significant reduction in tinnitus distress (Tavora-Vieira D, Marino R, Acharya A, & Rajan GP, 2015; Van de Heyning P et al., 2008).

In addition, unilateral CI is also beneficial in patients with bilateral tinnitus (Quaranta, Fernandez-Vega, D'elia, Filipo, & Quaranta, 2008; Souliere, Kileny, Zwolan, & Kemink, 1992). Quaranta et al. have shown that unilateral CI is associated

with the disappearance of bilateral tinnitus in at least 42% of patients when the CI was off and in more than 55% when the CI was on. In the implanted ear, tinnitus disappeared in 56% and 66% of patients, respectively. In the contralateral ear, tinnitus disappeared in 54% and 66% of patients with the CI off and on, respectively. Soulier et al. reported that 43% to 54% of patients with preoperative tinnitus demonstrated a $\geq 30\%$ decrease in tinnitus loudness, annoyance, and duration after cochlear implantation. Contralateral tinnitus suppression was reported by 42% of patients.

These findings show that unilateral electric stimulation has beneficial effects on both ipsilateral and contralateral tinnitus even when the implant is switched off. The mechanisms by which tinnitus is suppressed by CIs remain unclear. However, habituation, acoustic masking, direct stimulation of the spiral ganglion neurons, and reorganization of the right auditory associative cortex induced by the CI are possible reasons.

2.5.4.4.2 Single-sided deafness

Recent studies have shown that CI in SSD results in improved speech perception in noise and sound localization performance (Rahne & Plontke, 2016; Tokita, Dunn, & Hansen, 2014; Vlastarakos PV, Nazos K, Tavoulari EF, & Nikolopoulos TP, 2014). In addition, Arndt et al. have shown that cochlear implantation is superior to implantable BCD or CROS HAs in patients with SSD (Arndt et al., 2011). Furthermore, Sladen et al. and Kitterick et al. have shown that CI improves hearing loss-related QoL for patients with SSD (Kitterick, Lucas, & Smith, 2015; Sladen et al., 2017). The improvements resulted from reductions in difficulty understanding speech in background noise and reverberation, and in determining the location of sounds.

Because of the low number of cases, it is difficult to conclusively compare outcomes achieved with CIs and those provided by other devices. On the basis of encouraging early results and the ability to restore binaural sound processing, a growing number of centers offer CIs as a treatment for SSD. However, some SSD patients can adapt well without any intervention. Forthcoming studies will hopefully help to define outcome expectations in different populations.

2.5.4.4.3 Partial deafness

Individuals with mild to moderate low frequency sensorineural hearing loss with absent high frequencies are considered candidates for cochlear implantation with

EAS. These patients can be divided into two subgroups. The first subgroup is those patients who would benefit only from electrical complement and preserved low frequency hearing would not require any additional source of amplification. The second subgroup of candidates would have indications for combined electrical and amplified acoustic stimulation (Podskarbi-Fayette, Pilka, & Skarzynski, 2010).

Advanced techniques and less traumatic surgical electrodes enable residual hearing preservation and provide better speech perception. Sato et al. discovered that EAS provides additional low-frequency information and expands the dynamic range of the input compared with pure electrical stimulation. (Sato, Baumhoff, Tillein, & Kral, 2017).

Jurawitz et al. have shown that residual hearing was preserved for the majority of the 197 patients implanted with the Hybrid L24 and CI422 implants (Jurawitz et al., 2014). Nevertheless, there is always the risk with cochlear implantation that residual hearing will disappear partially or entirely. A systematic review by Talbot et al. showed that 13% of EAS patients suffered total hearing loss after implantation and 24% had >20 dB hearing loss across all frequencies or total hearing loss (Talbot & Hartley, 2008).

2.5.4.5 Surgery

CI surgery involves a procedure called cortical mastoidectomy followed by posterior tympanotomy. The bed for the receiver is prepared on the skull. An electrode array is then inserted into the cochlea (scala tympani) either via the round window membrane or via a separate cochleostomy anteroinferior to the round window (O. Adunka et al., 2004; Mangus, Rivas, Tsai, Haynes, & Roland, 2012). EAS surgery is commonly performed using the hearing preservation round window technique developed and described by Skarzynski et al. (Skarzynski, Lorens, Piotrowska, & Anderson, 2007).

2.5.4.6 Complications after CI surgery

Cochlear implantation is a rather safe procedure with a low percentage of severe complications. Terry et al. have shown that 5.7% out of 22 842 patients had delayed (>3 days after surgery) complications. Vestibular complications were found in 3.9% of patients, device failures in 3.4%, and taste problems in 2.8% (Terry, Kelt, & Jeyakumar, 2015). Uncommon complications (incidence of 0.2% to 1.9%) included skin infections, mastoiditis, electrode issues, seroma/hematoma, device rejection or migration, recurrent otitis media, cholesteatoma, facial nerve weakness, meningitis, chronic headaches, cerebrospinal fluid otorrea, and tympanic membrane perforation.

The most common reason for CI revision surgery is internal device failure. The other causes involve skin flap complications, optimization of electrode placement, unexplained deterioration in performance, technology upgrade, and intratemporal pathology (Cote, Ferron, Bergeron, & Bussieres, 2007; Fayad, Bains, & Parisier, 2004; Lassig, Zwolan, & Telian, 2005).

2.5.4.7 Hearing with unilateral and bilateral CI

Patients with unilateral CI perform almost equally as well as those with bilateral CI in quiet or when the sound is presented to the implanted ear (Smulders, van Zon, Stegeman, Rinia et al., 2016). However, at work and in everyday life, sounds come from different directions, and background noise is usually present. Patients with two CIs benefit significantly from their second implant in these situations. Sound localization accuracy and speech perception in noise is improved in the bilateral condition compared with unilateral (Dunn et al., 2010a; Laszig et al., 2004; Nopp, Schleich, & D'Haese, 2004; Smulders et al., 2016).

Bilateral cochlear implantation is capable of providing the majority of the known binaural hearing mechanisms. Studies have shown that with two CIs the largest benefit for speech understanding in noise is when the patient can take advantage of the head shadow effect (Litovsky, Parkinson, Arcaroli, & Sammeth, 2006). Moreover, studies have shown a significant binaural summation effect and squelch effect in adults with bilateral CIs (Dunn et al., 2010b; Eapen, Buss, Adunka, Pillsbury, & Buchman, 2009; Ricketts, Grantham, Ashmead, Haynes, & Labadie, 2006; Schleich, Nopp, & D'Haese, 2004).

Bilateral cochlear implantation enhances QoL in both adults and children. King et al. have shown subjective improvement in all measured domains - hearing and balance, psychological, and social (King, Nahm, Liberatos, Shi, & Kim, 2014).

Summerfield et al. and Olze et al. have reported improved hearing-related QoL (Olze, Grabel, Haupt, Forster, & Mazurek, 2012; Quentin Summerfield et al., 2006). Sparreboom et al. found that sequential bilateral cochlear implantation in children is associated with an improvement in disease-related aspects of QoL (speech perception, and directional hearing) (Sparreboom, Snik, & Mylanus, 2012).

In addition, patients have less social restriction and better emotional well-being and cognition with two CIs (Bichey & Miyamoto, 2008; Noble, Tyler, Dunn, & Bhullar, 2008).

Simultaneous bilateral cochlear implantation becomes a cost-effective intervention in postlingually deafened adults after a period of 5 to 10 years of bilateral implant use (Smulders, van Zon, Stegeman, van Zanten et al., 2016). Sequential bilateral cochlear implantation has also been found to be cost-effective compared with unilateral cochlear implantation in long-term gains or cost-saving measures (Chen, Amoodi, & Mittmann, 2014).

2.5.4.8 Hearing with electroacoustic stimulation

EAS combines the electrical stimulation of high-frequency hearing and the acoustic stimulation of low-frequency hearing.

EAS has been shown to improve hearing in noise and music perception over traditional CIs (O. F. Adunka et al., 2013; Gfeller, Olszewski, Turner, Gantz, & Oleson, 2006; Gifford et al., 2013; Talbot & Hartley, 2008). Studies have shown that EAS patients were able to recognize melody better than conventional CI recipients, and they also had better instrument recognition skills. Results also suggested a clear speech-perception advantage when ipsilateral acoustic stimulation is added to the electrical signal, especially in hearing in noise. The interaction of the electrical and acoustic signals in the auditory pathway improved patients hearing in reverberant noisy situations. Rader et al. found that patients with EAS and a HA in the contralateral ear had statistically significantly better speech perception in noise than patients with two CIs (Rader, Fastl, & Baumann, 2013).

Binaural advantages are also shown with bilateral EAS. A study by Moteki et al. reported that bilateral EAS improved speech perception in noise and sound localization more than unilateral EAS (Moteki et al., 2015).

2.5.4.9 Bimodal hearing

To avoid asymmetrical auditory deprivation, the provision of bilateral stimulation of the auditory system should be standard practice (Offeciers et al., 2005). Hearing with a bimodal combination means a CI or EAS supported by a HA in the contralateral ear. In this way, binaural hearing is achieved.

The use of a HA in combination with a CI significantly improved performance for speech perception in quiet, in noise, and for localization compared with the monaural condition (Ching, Incerti, & Hill, 2004; Morera et al., 2012; van Loon, Smits, Smit, Hensen, & Merkus, 2017). Results clearly indicate that binaural advantages can be obtained from using a HA with a CI in the opposite ear. Sometimes patients relinquish a HA in the opposite ear after cochlear implantation. The reasons for this are usually that benefits from the HA are too minor and that fitting problems are experienced with a CI and a HA.

3 Aims of the study

The aim of the study was to evaluate the benefits of cochlear implantation on hearing performance and quality of life in patients with uni- or bilateral severe sensorineural hearing loss.

The specific aims of the individual studies were the following:

1. To evaluate the benefits of sequential bilateral cochlear implantation in QoL, QoH, and working performance (**I**).
2. To evaluate the effect of CI on QoL, QoH, and working performance in patients with SSD (**II**).
3. To explore long-term hearing results, QoL, QoH, work-related stress, tinnitus, and balance problems after ISSNHL (**III**).
4. To evaluate the long-term effects of HCI on QoL, QoH, and working performance and to compare these results to patients with conventional unilateral and bilateral CI (**IV**).

4 Patients and Methods

4.1 Patients

Study I comprised 15 patients with unilateral CI (9 females, 6 males, mean age 41 years, range 19 to 58 years). Inclusion criteria were profound bilateral sensorineural hearing loss, SD less than 50% in the non-implanted ear, and difficulties to manage at work with one CI. The etiology was bilateral progressive postlingual sensorineural hearing loss in 14 patients, and one patient had had severe bilateral hearing impairment since birth. Ten patients had used a HA in the contralateral ear before the second CI. The first CI had been implanted on average 4.7 years (range 1 to 14 years) earlier.

Study II comprised seven SSD patients (5 females and 2 males, mean age 48 years, range 36 to 61 years). The etiology was sudden deafness of unknown origin in five patients and stapes surgery in two patients. The average time between deafness and cochlear implantation was 2.5 years (range 1 to 7 years). All patients had normal contralateral hearing with a PTA of ≤ 20 dB HL. None of the patients had used a CROS HA or BCD before CI surgery.

Fifteen healthy volunteers (9 females, 6 males, mean age 43 years, range 20 to 59 years) with normal hearing served as controls in the sound localization and speech-in-noise test in studies I and II.

In study III, audiograms of 680 patients with unilateral ISSNHL were reviewed and those whose initial hearing loss was ≥ 30 dB in at least three adjacent frequencies occurring within 72 hours and had normal hearing in the contralateral ear were selected for the study. Patients were excluded from the study if the etiology was clear at the onset of the hearing loss or at 1 to 2-month controls. The audiograms of 217 (32%) patients fulfilled the criteria and 172 out of 217 (79%) patients participated in the study. The patients were divided into two groups based on whether their ISSNHL had recovered to normal (PTA ≤ 30 dB HL) or not (PTA > 30 dB HL) during the short 1 to 2-month follow-up period. Group 1 (recovered hearing) comprised 100 patients (46 females and 54 males, mean age 51 years, age range 26 to 65 years). Group 2 (no hearing recovery) comprised 72 patients (41 females and

31 males, mean age 56 years, age range 23 to 66 years). The interval between the onset of ISSNHL and the study was on average eight years (range 3 to 13 years).

In study IV, eight HCI patients (5 females, 3 males, mean age 49 years, range 25 to 70 years) participated in the study. Six patients had unilateral and two patients had bilateral HCIs. Five patients with unilateral HCIs used a HA in their contralateral ear. Six patients used electro-acoustic stimulation in the implanted ear and two patients used only the electrical stimulation mode. The etiology of bilateral high frequency sensorineural hearing loss was unknown in all patients. The duration between the HCI implantation and the study was on average 3.6 years (range 1.7 to 5.1 years).

4.2 Methods

4.2.1 Study design

In study I, QoL, QoH, working performance, and work-related stress were evaluated with specific questionnaires. The patients completed questionnaires for work-related stress, QoL, and QoH before and after (6 and 12 months postactivation) the second CI. The questionnaire for working performance with two CIs was completed once, on average, two years after the second CI activation.

The patients' QoL was measured using the Glasgow Benefit Inventory (GBI) questionnaire (Robinson, Gatehouse, & Browning, 1996) and the 15D health-related questionnaire (15D) (Sintonen, 2001). QoH was measured with the Speech, Spatial and Qualities of Hearing Scale (SSQ; version 3.1.2) questionnaire (Gatehouse & Noble, 2004), and work-related stress was measured using the Occupational Stress Questionnaire from the Finnish Institute of Occupational Health. Working ability with two CIs was measured using a self-formulated questionnaire.

Preoperative hearing tests of the non-implanted ear included pure tone audiometry and SD test. Best-aided binaural hearing, speech recognition in noise, and sound localization were tested in a sound field before the second CI and 6 and 12 months after its activation.

In study II, perceptions of QoL, QoH, working performance, work-related stress, and tinnitus were evaluated. The patients completed questionnaires for work-related stress and QoH before and after (6 and 12 months) CI activation. The QoL

questionnaire was completed 6 and 12 months after cochlear implantation, and the working performance questionnaire was completed on average 22 months after CI activation. The possible change in tinnitus perception was evaluated on average 28 months after CI activation using the visual analogue scale (VAS 0 to 10; 0= no tinnitus).

Preoperative hearing tests included pure tone audiometry and SD test. Binaural hearing, speech recognition in noise, and sound localization were tested in a sound field before CI surgery and 6 and 12 months after CI activation.

In study III, 147 patients participated in pure tone audiometry and SD tests. 25 patients (17 in group 1 and 8 in group 2) skipped the hearing tests due to the long travel distances to the hospital.

QoL (15D), QoH, and work-related stress were evaluated with specific questionnaires. Possible tinnitus and balance problems in daylight and in the dark were evaluated by VAS (0 to 10; 0=no tinnitus, no balance problems). Patients' medical records were reviewed to evaluate their medical condition, possible ISSNHL treatment, and related investigations.

In study IV, preoperative hearing was measured from both ears (pure tone audiometry, and SD). The residual hearing in the implanted ear was tested one month after surgery and at the end of follow-up (3.6 years). Binaural hearing and hearing with a CI alone was tested in a sound field. Hearing in the non-implanted ear was also tested at the end of the follow-up. Patients' QoL (GBI), QoH, working performance, speech recognition in noise, and sound localization performance were measured after the follow-up. Comparison groups in this study were SSD patients with unilateral CI (study II) and sequentially bilaterally implanted patients (study I). Table 1 shows the flowchart for all studies.

Table 1. Flowchart of the studies.

	Study I	Study II	Study III	Study IV
Preoperative (study I, II, IV)/ at the time of ISSNHL (study III)	PTA + SD	PTA + SD	PTA + SD	Preoperative hearing + SD
	GBI		Tinnitus +/-	
	SSQ	SSQ	Vertigo +/-	
	Sound localization	Sound localization	PTA + SD after 1 month	
	Speech in noise	Speech in noise		
	Work-related stress	Work-related stress		
	15D			
Postoperative (study I, II, IV)/ end of follow-up (study III)	PTA + SD	PTA + SD	PTA + SD	Residual hearing + SD after 1 month
	GBI	GBI		GBI
	SSQ	SSQ	SSQ	SSQ
	Sound localization	Sound localization	Tinnitus VAS	Sound localization
	Speech in noise	Speech in noise	Balance problems	Speech in noise
	Work-related stress	Work-related stress	Work-related stress	Postoperative hearing + SD
	Working performance with CI	Working performance with CI	Recurrence	Working performance with CI
	15D	Tinnitus VAS	15D	Residual hearing after follow-up

ISSNHL= idiopathic sudden sensorineural hearing loss; GBI= Glasgow benefit inventory questionnaire; 15D= 15D health related questionnaire; PTA= pure tone average; SD= speech discrimination; SSQ= speech, spatial, and qualities of hearing scale.

4.2.2 Surgical methods

In studies I and II, patients were implanted with a Cochlear™ Nucleus® CI24 RE (CA) implant with Nucleus® CP810 processor. In study I, one patient had a MED-EL™ Sonata® implant with Opus 2 processor and received a MED-EL™ Concerto® implant with Opus 2 processor in the other ear. In study IV, all patients were implanted with Cochlear™ Nucleus® Hybrid L24 implants.

Cochlear implantations were conducted under general anesthesia and performed with a standard mastoidectomy and the facial recess approach. The bed for the receiver was prepared on the skull. In studies I and II, the round window niche was identified and the cochleostomy was performed anteroinferiorly from the round window. The endosteum was exposed and opened to the size of 0.8 to 1.0 mm. Carefull insertion of the electrode was performed via the endosteum opening. The opening was sealed with periosteum patches. In study IV, the round window niche was identified and the bony overhang was carefully removed to provide good access to the round window membrane. Electrode insertion was performed carefully via an incision to the round window membrane.

4.2.3 Questionnaires

4.2.3.1 Glasgow Benefit Inventory

The Glasgow Benefit Inventory questionnaire is validated in English (translated in Finnish) and generally accepted tool to measure changes in health status, especially for otorhinolaryngological interventions (appendix 1) (Hendry, Chin, Swan, Akeroyd, & Browning, 2016). The limitations of the GBI is that it is intended for post-procedural use, and is therefore not appropriate for assessing the severity of symptoms before surgery.

The questionnaire contains 18 questions and the response to each question is placed on a 5-point scale ranging from a large deterioration to a large improvement in health status. The GBI comprises a total score and 3 subscores (general, social support, and physical health). The total score is transposed onto a benefit scale ranging from -100 (maximal negative benefit), through 0 (no benefit), to +100 (maximal positive benefit) (Robinson et al., 1996).

4.2.3.2 15D health-related QoL

The 15D questionnaire is a standardized, self-administered instrument for measuring health-related QoL in adults (appendix 2) (Sintonen, 2001). It is validated in Finnish. The test comprises 15 dimensions: moving, seeing, hearing, breathing, sleeping, eating, speaking, eliminating, usual activities, mental function, discomfort and symptoms, depression, distress, vitality, and sexual activity. The respondents choose the alternative which best describes their present health status (best = 1; worst = 5). The single index score on a scale of 0 to 1, representing the overall QoL, is calculated from the health state descriptive system using a set of population-based preference or utility weights. The maximum score is 1 (no problems on any dimension), and the minimum score is 0 (equal to being dead).

4.2.3.3 Speech, Spatial, and Qualities

The Speech, Spatial, and Qualities test covers speech perception in the quiet conditions of a soundproof room and in spatial hearing situations, localization tasks, and rating the quality of speech perceived (naturalness, clarity, ability to differentiate speakers, and perception of music) (Gatehouse & Noble, 2004). It is validated in English (translated in Finnish). The questionnaire contains 48 questions using a visual analog scale from 0 to 10 for each question (appendix 3).

4.2.3.4 Work-related stress

Work-related stress was measured using the Occupational Stress Questionnaire from the Finnish Institute of Occupational Health (appendix 4). The questionnaire contains 53 negative claims that the patient must respond to; each response is placed on a 6-point scale ranging from total disagreement to total agreement. This questionnaire is not validated.

4.2.3.5 Working performance

The working performance after CI surgery questionnaire was self-formulated by the research team and is not validated. The test contains six claims about CI and working performance (appendix 5).

4.2.4 Speech-in-noise test

The test measures speech discrimination at different noise levels. The test was performed in a sound field and in a soundproof room. Five active loudspeakers (Genelec® 8040A, Iisalmi, Finland) were used at a one-meter distance from the test participant and positioned at 0° , $\pm 45^\circ$, and $\pm 90^\circ$ of azimuth on the horizontal plane. The participant's responses were collected via a microphone connected to an audiometer (Madsen Aurical, GN Otometrics A/S, Taastrup, Denmark) outside the room by the audiologist performing the test over headphones. Phonetically balanced bisyllabic Finnish words were used as speech material for the speech-in-noise test (Jauhiainen, 1974). The speech signal was played back at a fixed level (65 dB SPL) from the loudspeaker in front of the participant (0°). The noise signal was an unmodulated artificial noise signal with a long-term spectrum that corresponded to human speech (Dreschler, Verschuure, Ludvigsen, & Westermann, 2001), and it was fed to the other four loudspeakers by delaying the signal to each loudspeaker by increments of 100 milliseconds to avoid problems with coherence. The level of the noise signal was varied in 5 dB steps to achieve various signal-to-noise ratios (SNRs). The speech material comprised six lists of 25 words each. The order of the words in each list was randomized, and each participant listened to the word lists with six different SNRs: -5, 0, +5, +10, +15, and +20 dB. The presentation order of the SNRs, as well as which word list was presented with a given SNR, was randomized across the participants to minimize the effect on the results of potential differences in the speech reception threshold in noise between each list.

The participants were instructed to face the loudspeaker in front of them at 0° azimuth and not to move their heads during the test. They were then instructed to repeat the word they heard.

4.2.5 Sound localization test

The sound localization test measures the patient's ability to locate the speech segment. For the localization test, short speech segments were played back randomly from each of the five loudspeakers. The overall presentation level was 65 dB SPL and it was roved within ± 5 dB to avoid the participants using loudness as a cue to localize sound. The overall sound localization accuracy was quantified by an error index (EI) as a measure of variance (Gardner & Gardner, 1973). The scale of the EI was from 0 to 1 (Asp, Eskilsson, & Berninger, 2011). The EI was calculated as the average of all azimuth errors during the test, where the azimuth error is the number

of loudspeakers (0 to 4 in the current setup) between the perceived and presented loudspeaker (0 corresponds to coinciding perceived and presented sound-source azimuth), divided by the average random error (1.6 in the current setup). $EI=0$ means a perfect match between all perceived and presented sound source azimuths, while $EI=1.0$ corresponds to change performance.

The participants were instructed to face the loudspeaker in front of them at a 0° azimuth and to not move their heads during the test. They were instructed to repeat the name of the loudspeaker from which they thought the sound signal was emanating.

4.2.6 Statistics

In all studies, patient characteristics and variables were analyzed with Statistical Package for Social Sciences (SPSS software version 19.0 for window, SPSS Inc., Chigago, USA). P-values below 0.05 were considered statistically significant.

In study I and II, the comparison between the pre- and postoperative data was performed using a nonparametric Wilcoxon signed-rank test. Bonferroni corrections were used in the Wilcoxon test in the SSQ analysis.

In study III, the Mann–Whitney U and Fisher’s exact tests were used to compare the two groups regarding the categorical variables belonging to the study. A repeated measures ANOVA test was used to compare vertigo, hearing loss, and age in both groups.

In study IV, the comparison between the pre- and postoperative data was performed using a nonparametric Wilcoxon signed-rank test. The Mann–Whitney U and the Kruskal–Wallis tests were used when comparing the HCI, SSD, and unilateral and bilateral CI groups.

4.2.7 Ethical aspects

The studies were approved by the Research Ethics Committee of Pirkanmaa Hospital District, Tampere, Finland (decision numbers R11078, R11192, R11008 and R15088). The patients were given oral and written information of the trial protocol, and they provided informed written consent. The principles of good clinical practice were followed in the trials.

5 Results and discussions

5.1 Sequential bilateral cochlear implantation improves working performance, quality of life, and quality of hearing (Study I)

The GBI and 15D scores showed the positive effect of implantation on QoL. The GBI total score was +43 after the first and +39 after the second CI. The 15D questionnaire showed that the second CI decreased depression and distress.

Working performance improved after the second CI. Patients managed much better at work and were more alert after their workday. Communication with co-workers was easier and speaking on the phone was slightly easier. The patients were also more active in their working environment, and the second CI had a slight positive influence on their career development or planning. The mean work-related stress had a tendency to decrease during the first follow-up year, but the change was not statistically significant.

Sound localization and speech perception were better with bilateral CIs. With the single CI \pm HA, the EI score was 0.73. One year after activation of the second CI, the EI score had decreased to 0.32. In the normal hearing control group, the EI was 0. Compared with the best-aided measurements before the second CI, the mean percentage of correct words in the speech-in-noise test increased from 57% to 78% at 0 SNR and from 32% to 50% at -5 SNR during the follow-up. In the normal hearing control group, speech perception in noise was 98% at 0 and 98% at -5 SNR.

Before the second CI, the mean best-aided sound-field PTA was 27 dB HL. After 1 year, the PTA was 23 dB HL. The mean best-aided sound-field SD was 91% with a single CI. After the activation of the second CI, it improved to 93% during the first follow-up year. QoH (all SSQ categories) improved during the one-year follow-up.

The results indicate that bilateral CIs provide better opportunities to manage at work than a unilateral CI. Patients experienced that a second CI reduced their fatigue after their work day and communication with colleagues and clients was easier. These benefits are important in preventing possible burnout symptoms or early retirement. In addition, only bilateral cochlear implantation can ensure that the ear with the best

postoperative function has been implanted, and that the patient has continuous auditory input if there is a device failure.

Patients' QoL improved after the first CI, and the impact of the second CI was almost as significant. The reason for the improvement in QoL might be the better working performance and QoH (spatial hearing and hearing in noise) and less depression and distress with two CIs. The latter might be explained by amendment in self-confidence along with hearing improvement.

Enchantments in speech intelligibility, spatial perception, and sound quality may reflect an improvement of the binaural hearing mechanism and correspond well with improved performance and efficacy at work.

5.2 Single-sided deafness: The effect of cochlear implantation on quality of life, quality of hearing, and working performance (Study II)

QoL and working performance in SSD patients improved after cochlear implantation. The total GBI score (+28) was positive. Communication with co-workers was easier and the patients were more active in their working environment. Fatigue after the working day decreased and the CI had a positive influence on the patients' career development or planning. The mean work-related stress score did not change after the CI.

QoH (sound localization, speech perception in noise, spatial perception, and speech intelligibility) also improved during the follow-up. In the sound localization test, the EI score was 0.94 before the CI and the score was 0.31 after one year. In the normal hearing control group, the EI was 0. Speech perception in noise was better with the CI at -5 SNR. The VAS score for tinnitus perception decreased from 6.1 (preimplantation) to 1.2 during the follow-up.

The mean preoperative PTA in the affected ear was 96 dB HL (range 78 to 118 dB HL). One year after CI surgery, the sound field PTA was on average 22 dB HL (range 18 to 25 dB HL). The preoperative SD was 0% in six patients and 44% in one patient. After one year of CI use, the mean sound field SD was 82% (range 68% to 92%).

The results of the study demonstrate that cochlear implantation in SSD patients raises QoL and improves working performance. This is probably due to a partly restored binaural function and subsequent improvement in QoH.

Tinnitus is often related to SSD, and CI has been successfully exploited to treat incapacitating tinnitus after SSD. In our study, 6 out of 7 patients suffered from tinnitus, and they all reported relief in their tinnitus perception after CI surgery. Other studies have reported similar results (Arndt et al., 2011; Tavora-Vieira D et al., 2015; Van de Heyning P et al., 2008).

Although CI offers more benefits than HA or BCD, it is not a routine rehabilitation practice in SSD. Cost-effectiveness may be questionable because most of the patients manage well without rehabilitation. In Tampere University Hospital, CI is provided to SSD patients if the patients have incapacitating tinnitus, or their working ability is threatened or hearing is lost due to ear surgery.

5.3 Quality of life and hearing eight years after sudden sensorineural hearing loss (Study III)

The patients in group 1 (recovered hearing) were on average 5 years younger than patients in group 2 (no hearing recovery), and the hearing in the affected ear at the time of ISSNHL was better. In total, 23% of patients in group 1 and 54% in group 2 had concurrent vertigo. The relationship between age and vertigo was not statistically significant, but vertigo was related to greater hearing loss in group 2.

During the short-term follow-up, the hearing improved in both groups. Three patients (3%) in group 1 and three (4%) in group 2 had had a recurrence of ISSNHL in their affected ear during the 8-year follow-up. The hearing of all patients in group 1 recovered after the recurrence.

Table 2. depicts the short- and long-term hearing results after ISSNHL and the recurrence rate.

Table 2. Short- and long-term hearing results after ISSNHL.

	Group 1	Group 2
PTA/SD (%), at the time of ISSNHL, affected ear	50/75	79/29
PTA/SD 1-2 months, affected ear	12/99	65/50
PTA/SD 8 years, affected ear	18/97	72/43
PTA/SD, at the time of ISSNHL, healthy ear	8/100	10/100
PTA/SD 8 years, healthy ear	12/99	18/96
Recurrence (%)	3	4
ISSNHL in healthy ear (%)	1	3

ISSNHL = idiopathic sudden sensorineural hearing loss; PTA = pure tone average; SD = speech discrimination

QoL and QoH were better in patients with recovered hearing, and they had fewer tinnitus and balance problems at the end of follow-up. The mean 15D total score was bigger in group 1, and the dimension of hearing and vitality were better. The VAS score for all SSQ categories (spatial perception, sound quality, speech intelligibility) was better in group 1. Eight years after the ISSNHL, the mean VAS score for tinnitus was 1.5 in group 1 and 4.7 in group 2.

There were no differences between the groups concerning the prevalence of diseases (diabetes, blood pressure, heart diseases, asthma, cancer, rheumatism, thyroid gland diseases, and mental illness) or cigarette smoking.

The results of the study show that older age, severity of hearing loss, and vertigo together with ISSNHL predict inferior hearing recovery. Patients without hearing recovery have poorer long-term QoL, QoH, and more tinnitus and balance problems. Poor sound localization and impaired speech perception in noise most probably have an effect on poorer QoL as well. ISSNHL-related symptoms, such as impaired working performance, anxiety about possible recurrence, and fear of hearing loss in the contralateral ear, may also affect QoL.

ISSNHL can be a dramatic incidence for a patient who has never had hearing problems before. Therefore, ISSNHL patients should be offered intensive audiological rehabilitation to cope with the complex issues that might arise after this dramatic event.

Hearing deteriorated with age in a normal manner, and ISSNHL did not appear to accelerate the hearing loss. The progression of hearing loss during the 8-year

follow-up did not differ between the groups. The hearing in the affected and the healthy ear deteriorated on average by 7 dB and 6 dB in both groups. Wiley et al. have calculated the rate of change in hearing thresholds for 48 to 59-year old men to be about 0.4 dB per year at 0.5 kHz and about 1.6 dB at 8 kHz (Wiley, Chappell, Carmichael, Nondahl, & Cruickshanks, 2008). In our study, the change in the affected ear was 0.4 dB per year at 0.5 kHz and 1.4 dB at 8 kHz.

5.4 Hybrid cochlear implantation: Quality of life, quality of hearing, and working performance compared to patients with conventional unilateral or bilateral cochlear implantation (Study IV)

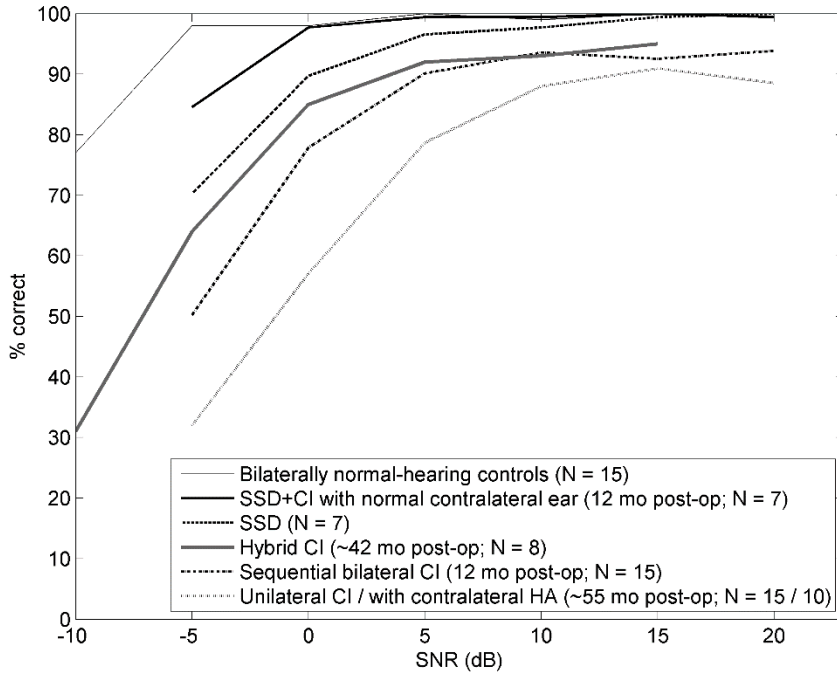
In HCI patients, QoL and working performance improved after cochlear implantation. The GBI scores showed a positive effect for CI on QoL in all groups, but the mean total GBI score was higher for HCI patients than for SSD patients. (Table 3).

Table 3. The mean long-term Glasgow Benefit Inventory scores and working performance change after cochlear implantation.

	hCI	unilat. CI	bilat.CI	SSD + CI
Total (SD)	+44 (9)	+43 (19)	+39 (17)	+28 (10)
General	+68 (12)	+60 (26)	+56 (27)	+42 (18)
Social support	+2 (19)	+12 (20)	+6 (12)	+7 (9)
Physical health	-10 (25)	+8 (19)	+8 (23)	-5 (13)
How much has the CI helped you to do your work?	moderately	NA	moderately	moderately
How much has the CI positively influenced your career development or planning?	moderately	NA	a little	a little
How much more active have you been in your working environment after the CI?	a little	NA	moderately	a little
Has the CI decreased your fatigue after the workday?	a little	NA	moderately	a little
Is it easier to communicate with your co-workers after the CI?	moderately	NA	moderately	a little
Is it easier to speak on the phone after the CI?	moderately	NA	a little	no change

CI = cochlear implant, hCI = hybrid cochlear implant, NA = not applicable, SSD = single-sided deafness, SD = standard deviation. Range in last questions: very much, moderately, a little, no change, worsened

Figure 3 demonstrates the speech perception in noise in all CI groups and in normal hearing controls. SSD patients had better speech perception scores than the other CI groups. The scores were clearly worst in patients with a unilateral CI. The mean sound localization accuracy was equal in HCI, bilateral CI, and SSD+CI patients.



SNR = signal-to-noise ratio, SSD = single-sided deafness

Figure 3. The mean best-aided speech perception in noise.

At the end of the HCI patients' follow-up, the mean decrease in hearing at 125 Hz was 11 dB HL in the implanted ear and 2 dB HL in the non-operated ear. The decrease was 14 and 10 dB HL at 250 Hz and 19 and 19 dB HL at 500 Hz, respectively (Figure 4).

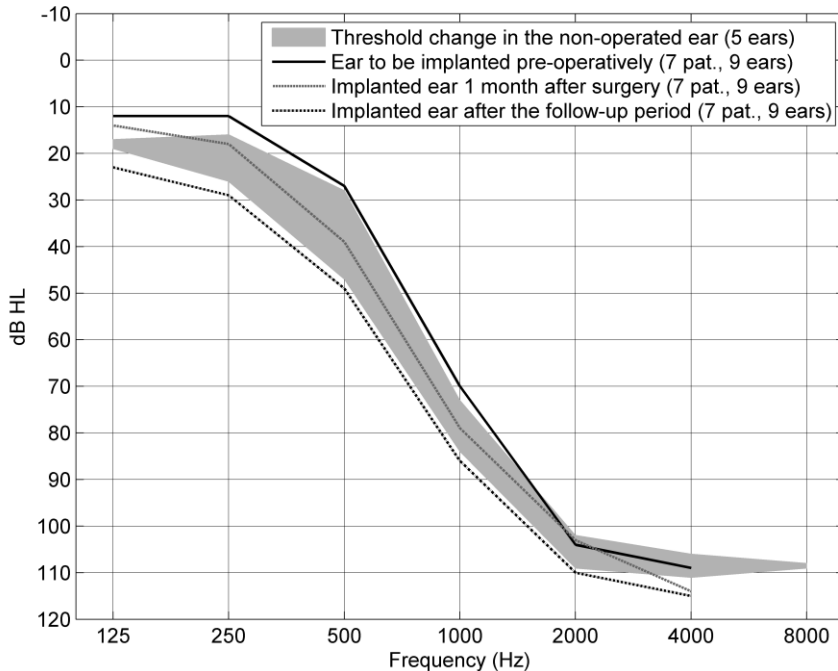


Figure 4. The mean pre- and postoperative hearing thresholds and the change in hearing thresholds in the non-operated ear in HCI patients.

This study shows that cochlear implantation with HCI and conventional CI improves QoL and working performance. Improvement in QoL was greater in HCI than in SSD patients. The reason for this is probably that SSD patients managed quite well with one normally hearing ear before the cochlear implantation.

There is always a risk that residual hearing will disappear partially or entirely after CI surgery. Every patient in our study had good hearing preservation immediately after surgery. After 3.6-year follow-up, the mean hearing threshold at 125 Hz to 500 Hz decreased on average by 15 dB HL in the implanted ear and by 10 dB HL in the non-implanted ear. This decrease exceeds Wiley's calculation about normal hearing threshold changes along with age and is probably due to the initial surgical trauma and/or unknown etiological factors (Wiley et al., 2008).

6 General discussion

This study shows that binaural hearing provides better opportunities to manage at work and in everyday life. The demands for hearing at work are nowadays different than they were some decades ago. The trade and service industries have taken over from the manufacturing industry and good speech communication skills are more important than ever before. In fact, there are not many occupations left that are suitable for people with severe bilateral sensorineural hearing loss. Therefore, healthcare professionals are under a lot of pressure to provide good binaural hearing for adult patients suffering from severe sensorineural hearing loss. If rehabilitation fails with HAs, the options are bimodal CI/HA or bilateral CIs.

Most patients with unilateral severe sensorineural hearing loss manage quite well without any rehabilitation. Although our and some other SSD studies have shown encouraging results after cochlear implantation, high-level evidence about cost-effectiveness is still lacking. Fortunately, only a few SSD patients fail to manage at their work with only one hearing ear, and therefore they should be offered CI if other rehabilitation options are unsuccessful. However, CI rehabilitation can be challenging for SSD patients. Patients need to be encouraged and motivated to use a CI because they manage quite well in easy listening conditions with one normally hearing ear. At the beginning of the CI rehabilitation, patients are told to plug their healthy ear while training the implanted ear.

New prospective indications for cochlear implantations, such as incapacitating tinnitus, newborn unilateral congenital deafness, and presbycusis have been widely studied and discussed. For example, Arndt et al., Van de Heyning and Tavora-Vieira et al. (Arndt et al., 2011; Tavora-Vieira D et al., 2015; Van de Heyning P et al., 2008) have reported significant reductions in tinnitus distress and loudness after cochlear implantation in SSD patients. Interestingly, all our SSD patients reported relief in their tinnitus perception after CI surgery. Moreover, Thomas et al. have shown that CI provides significant audiological and subjective benefits for children with congenital SSD (Thomas, Neumann, Dazert, & Voelter, 2017). Moreover, Lin et al. have reported that hearing loss associates with dementia in adults over 60 years of age (Lin et al., 2011). Therefore, cochlear implantation with HCI or conventional CI should be considered for senior citizens with presbycusis and severe high frequency

hearing loss who fail to benefit from conventional HAs. The possible reduction in the cost of CI in future may result in the indication criteria being widened. However, more multi-center studies are needed to clarify the cost-effectiveness of these new extended indications.

This study has some limitations. For example, the number of patients in each CI study was quite small. The reason for this is that we do not perform so many CI surgeries at Tampere University Hospital annually to obtain large CI series. The follow-up time was also relatively short in these studies, but still long enough to demonstrate clear changes in the assessed measures. Two questionnaires (working performance and work-related stress) were not validated, and therefore we cannot be quite sure how well these questionnaires measured the ability to work and work-related stress after the cochlear implantation. In addition, we did not have a good questionnaire for measuring hearing-related QoL before and after cochlear implantation.

The results of this study have affected the indication criteria for CI at Tampere University Hospital. The aim is now to carry out CI surgery before patients are unable to continue to work due to their hearing. Adult patients with severe sensorineural hearing loss may get two CIs if there is not enough benefit from a single CI or CI+HA. In addition, SSD patients may get CI, if they do not manage at work with only one hearing ear or they have incapacitating tinnitus in their affected ear. The working environment of the patient is now taken into account more closely when considering CI.

7 Conclusions

The specific conclusions of the individual studies were as follows:

1. Bilateral CIs provide better opportunities to manage at work and in everyday life than unilateral CI. A second CI improves working performance, QoL, and QoH and tends to decrease work-related stress.
2. Cochlear implantation in SSD patients improves working performance, QoL, and QoH and decreases tinnitus perception in the implanted ear.
3. Older age, severity of hearing loss, and vertigo together with ISSNHL predict inferior hearing recovery. Patients without hearing recovery have poorer long-term QoL, QoH, and more tinnitus and balance problems. Hearing deteriorates as a function of age similarly in both the affected and healthy ear.
4. Hybrid cochlear implantation improves QoL, QoH, and working performance in patients with severe sensorineural high frequency hearing loss, and the results are comparable with SSD patients with CI and patients with bilateral CIs.

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Appendices

1. Glasgow Benefit Inventory questionnaire
2. 15D health-related QoL questionnaire
3. Speech, Spatial and Qualities questionnaire
4. Work-related stress questionnaire
5. Working performance questionnaire

Glasgow Benefit Inventory Questionnaire

1. Has the result of the <i>cochlear implantation</i> affected the things you do?				
Much worse 1	A little or somewhat worse 2	No change 3	A little or somewhat better 4	Much better 5
2. Have the results of the <i>cochlear implantation</i> made your overall life better or worse?				
Much better 5	A little or somewhat better 4	No change 3	A little or somewhat worse 2	Much worse 1
3. Since your <i>cochlear implantation</i>, have you felt more or less optimistic about the future?				
Much more optimistic 5	More optimistic 4	No change 3	Less optimistic 2	Much less optimistic 1
4. Since your <i>cochlear implantation</i>, do you feel more or less embarrassed when with a group of people?				
Much more embarrassed 1	More embarrassed 2	No change 3	Less embarrassed 4	Much less embarrassed 5
5. Since your <i>cochlear implantation</i>, do you have more or less self-confidence?				
Much more self-confidence 5	More self-confidence 4	No change 3	Less self-confidence 2	Much less self-confidence 1
6. Since your <i>cochlear implantation</i>, have you found it easier or harder to deal with company?				
Much easier 5	Easier 4	No change 3	Harder 2	Much harder 1
7. Since your <i>cochlear implantation</i>, do you feel that you have more or less support from your friends?				
Much more support 5	More support 4	No change 3	Less support 2	Much less support 1
8. Have you been to your family doctor, for any reason, more or less often, since your <i>cochlear implantation</i>?				
Much more often 1	More often 2	No change 3	Less often 4	Much less often 5
9. Since your <i>cochlear implantation</i>, do you feel more or less confident about job opportunities?				
Much more confident 5	More confident 4	No change 3	Less confident 2	Much less confident 1
10. Since your <i>cochlear implantation</i>, do you feel more or less self-conscious?				
Much more self-conscious 1	More self-conscious 2	No change 3	Less self-conscious 4	Much less self-conscious 5
11. Since your <i>cochlear implantation</i>, are there more or fewer people who really care about you?				
Many more people 5	More people 4	No change 3	Fewer people 2	Many fewer people 1
12. Since you had the <i>cochlear implantation</i>, do you catch colds or infections more or less often?				
Much more often 1	More often 2	No change 3	Less often 4	Much less often 5

13. Have you had to take more or less medicine for any reason, since your <i>cochlear implantation</i> ?				
Much more medicine 1	More medicine 2	No change 3	Less medicine 4	Much less medicine 5

14. Since your <i>cochlear implantation</i> , do you feel better or worse about yourself?				
Much better 5	Better 4	No change 3	Worse 2	Much worse 1

15. Since your <i>cochlear implantation</i> , do you feel that you have had more or less support from your family?				
Much more support 5	More support 4	No change 3	Less support 2	Much less support 1

16. Since your <i>cochlear implantation</i> , are you more or less inconvenienced by your <i>hearing</i> problem?				
Much more inconvenienced 1	More inconvenienced 2	No change 3	Less inconvenienced 4	Much less inconvenienced 5

17. Since your <i>cochlear implantation</i> , have you been able to participate in more or fewer social activities?				
Many more activities 5	More activities 4	No change 3	Fewer activities 2	Many fewer activities 1

18. Since your <i>cochlear implantation</i> , have you been more or less inclined to withdraw from social situations?				
Much more inclined 1	More inclined 2	No change 3	Less inclined 4	Much less inclined 5

15D health-related QoL questionnaire

Elämänlaatu kysely (15 D)

Ympyröi kunkin osa-alueen kohdalla terveydentilaasi ja toimintakykyäsi tällä hetkellä parhaiten kuvaavin kohta. Valitse aina vain yksi vaihtoehto. Lomakkeeseen ei laiteta mitään tunnistetietoja.

1. Liikuntakyky

1. Pystyn kävelemään normaalisti (vaikeuksitta) sisällä, ulkona ja portaissa
2. Pystyn kävelemään normaalisti (vaikeuksitta) sisällä, mutta ulkona ja/tai portaissa on pieniä vaikeuksia
3. Pystyn kävelemään ilman apua sisällä (apuvälinein tai ilman), mutta ulkona ja/tai portaissa melkoisin vaikeuksin tai toisen avustamana
4. Pystyn kävelemään sisälläkin vain toisen avustamana
5. Olen täysin liikuntakyvytön ja vuoteenoma

2. Näkö

1. Näen normaalisti lukea lehteä ja tv:n tekstejä vaikeuksitta (silmälaseilla tai ilman)
2. Näen lukea lehteä ja/tai tv:n tekstejä pienin vaikeuksin (silmälaseilla tai ilman)
3. Näen lukea lehteä ja/tai tv:n tekstejä huomattavin vaikeuksin (silmälaseilla tai ilman)
4. En näe lukea lehteä enkä tv:n tekstejä ilman silmälasia tai niiden kanssa, mutta näen (näkisin) kulkea ilman opasta
5. En näe (näkisi) kulkea ilman opasta, eli olen lähes tai täysin sokea

3. Kuulo

1. Kuulen normaalisti, eli kuulen hyvin normaalia puheääntä (kuulokojeen kanssa tai ilman)
2. Kuulen normaalia puheääntä pienin vaikeuksin
3. Kuulen normaalia puheääntä melkoisin vaikeuksin, keskustelussa on käytettävä normaalia kovempaa puheääntä
4. Kuulen kovaakin puheääntä heikosti; olen melkein kuuro
5. Olen täysin kuuro

4. Hengitys

1. Pystyn hengittämään normaalisti, eli minulla ei ole hengenahdistusta tai muita hengitysvaikeuksia
2. Minulla on hengenahdistusta raskaassa työssä tai lievässä ylämäessä
3. Minulla on hengenahdistusta kävellessä muiden samanikäisten vauhtia tasamaalla
4. Minulla on hengenahdistusta pienenkin rasituksen jälkeen, esim. peseytyessä tai pukeutuessa
5. Minulla on hengenahdistusta lähes koko ajan, myös levossa

5. Nukkuminen

1. Nukun normaalisti, eli minulla ei ole mitään ongelmia unen suhteen
2. Minulla on lieviä uniongelmia, esim. nukahtamisvaikeuksia tai heräilen satunnaisesti yöllä
3. Minulla on melkoisia uniongelmia, esim. nukun levottomasti, uni ei tunnu riittävältä
4. Minulla on suuria uniongelmia, esim. joudun käyttämään usein tai säännöllisesti unilääkettä, herään säännöllisesti yöllä ja/tai aamuisin liian varhain
5. Kärsin vaikeasta unettomuudesta, esim. unilääkkeiden runsaasta käytöstä huolimatta nukkuminen on lähes mahdotonta, valvon suurimman osan yöstä

6. Syöminen

1. Pystyn syömään normaalisti, eli ilman mitään vaikeuksia
2. Pystyn syömään itse pienin vaikeuksin (esim. hitaasti, kömpelösti, vavisten tai erityisapuneuvoin)
3. Tarvitsen hieman toisen apua syömisessä
4. En pysty syömään itse lainkaan, vaan minua pitää syöttää
5. En pysty syömään itse lainkaan, vaan minua pitää syöttää joko letkulla tai suonensisäisellä ravintoliuksella

7. Puhuminen

1. Pystyn puhumaan normaalisti eli selvästi kuuluvasti ja sujuvasti
2. Puhuminen tuottaa minulle pieniä vaikeuksia, esim. sanoja on etsittävä tai ääni ei ole riittävän kuuluva tai se vaihtaa korkeutta
3. Pystyn puhumaan ymmärrettävästi, mutta katkonaisesti, ääni vavisten, sammaltaen tai änkyttäen
4. Minulla on vaikeuksia ymmärtää puhettani
5. Pystyn ilmaisemaan itseäni vain elein

8. Eritystoiminta

1. Virtsarakkoni ja suolistoni toimivat normaalisti ja ongelmitta
2. Virtsarakkoni ja/tai suolistoni toiminnassa on lieviä ongelmia, esim. minulla on virtsaamisvaikeuksia tai kova tai löysä vatsa
3. Virtsarakkoni ja/tai suolistoni toiminnassa on melkoisia ongelmia, esim. minulla on satunnaisia virtsanpidätysvaikeuksia tai vaikea ummetus tai ripuli
4. Virtsarakkoni ja/tai suolistoni toiminnassa on suuria ongelmia, esim. minulla on säännöllisesti ”vahinkoja” tai peräruiskeiden tai katetroinnin tarvetta
5. En hallitse lainkaan virtsaamista ja/tai ulostamista

9. Tavanomaiset toiminnot (päivittäiset toiminnot)

1. Pystyn suoriutumaan normaalisti tavanomaisista toiminnoista (esim. pyykinpesu, ruuanlaitto, kaupassa käynti, henkilökohtainen hygienia)
 2. Pystyn suoriutumaan tavanomaisista toiminnoista hieman alentuneella teholla tai pienin vaikeuksin
 3. Pystyn suoriutumaan tavanomaisista toiminnoista huomattavasti alentuneella teholla tai huomattavin vaikeuksin tai vain osaksi
 4. Pystyn suoriutumaan tavanomaisista toiminnoista vain pieneltä osin
 5. En pysty suoriutumaan lainkaan tavanomaisista toiminnoista
- Missä tarvitsen apua _____

10. Henkinen toiminta

1. Pystyn ajattelemaan selkeästi ja johdonmukaisesti ja muistini toimii moitteettomasti
2. Minulla on lieviä vaikeuksia ajatella selkeästi ja johdonmukaisesti ja muistini ei toimi täysin moitteettomasti
3. Minulla on melkoisia vaikeuksia ajatella selkeästi ja johdonmukaisesti ja minulla on jonkin verran muistinmenetystä
4. Minulla on suuria vaikeuksia ajatella selkeästi ja johdonmukaisesti, tai minulla on huomattavaa muistinmenetystä
5. Olen koko ajan sekaisin tai vailla ajan ja paikan tajua

11. Vaivat tai oireet

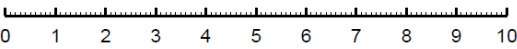
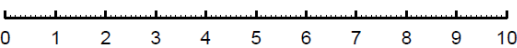
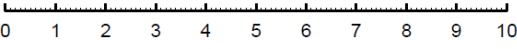
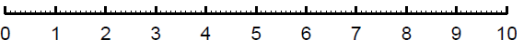
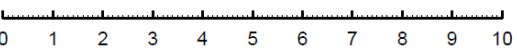
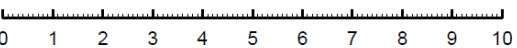
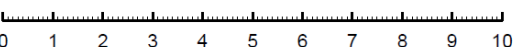

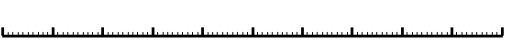
1. Minulla ei ole mitään vaivoja tai oireita, esim. kipua, särkyä, pahoinvointia, kutinaa jne.
2. Minulla on lieviä vaivoja tai oireita, esim. lievää kipua, särkyä, pahoinvointia, kutinaa jne.
3. Minulla on melkoisia vaivoja tai oireita, esim. melkoista kipua, särkyä,

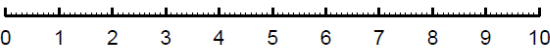
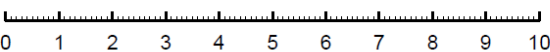
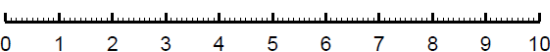
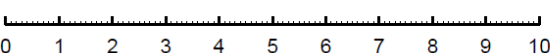
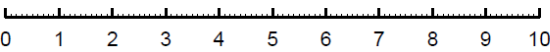
- pahoinvointia, kutinaa jne.
4. Minulla on voimakkaita vaivoja tai oireita, esim. voimakasta kipua, särkyä, pahoinvointia, kutinaa jne.
5. Minulla on sietämättömiä vaivoja tai oireita, esim. sietämätöntä kipua, särkyä, pahoinvointia, kutinaa jne.
12. Masentuneisuus
1. En tunne itseäni lainkaan surulliseksi, alakuloiseksi tai masentuneeksi
 2. Tunnen itseni hieman surulliseksi, alakuloiseksi tai masentuneeksi
 3. Tunnen itseni melko surulliseksi, alakuloiseksi tai masentuneeksi
 4. Tunnen itseni hyvin surulliseksi, alakuloiseksi tai masentuneeksi
 5. Tunnen itseni äärimmäisen surulliseksi, alakuloiseksi tai masentuneeksi
13. Ahdistuneisuus
1. En tunne itseäni lainkaan ahdistuneeksi, hermostuneeksi tai jännittyneeksi
 2. Tunnen itseni hieman ahdistuneeksi, hermostuneeksi tai jännittyneeksi
 3. Tunnen itseni melko ahdistuneeksi, hermostuneeksi tai jännittyneeksi
 4. Tunnen itseni hyvin ahdistuneeksi, hermostuneeksi tai jännittyneeksi
 5. Tunnen itseni äärimmäisen ahdistuneeksi, hermostuneeksi tai jännittyneeksi
14. Elinvoimaisuus
1. Tunnen itseni terveeksi ja elinvoimaiseksi
 2. Tunnen itseni hieman uupuneeksi, väsyneeksi ja voimattomaksi
 3. Tunnen itseni melko uupuneeksi, väsyneeksi ja voimattomaksi
 4. Tunnen itseni hyvin uupuneeksi, väsyneeksi ja voimattomaksi, lähes ”loppuun palaneeksi”
 5. Tunnen itseni äärimmäisen uupuneeksi, väsyneeksi ja voimattomaksi, täysin ”loppuun palaneeksi”
15. Sukupuolielämä
1. Terveystilani ei vaikeuta mitenkään sukupuolielämääni
 2. Terveystilani vaikeuttaa hieman sukupuolielämääni
 3. Terveystilani vaikeuttaa huomattavasti sukupuolielämääni
 4. Terveystilani tekee sukupuolielämääni lähes mahdottomaksi
 5. Terveystilani tekee sukupuolielämääni mahdottomaksi

Puheen kuulemisen arviointi

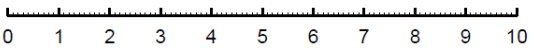
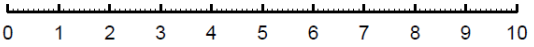
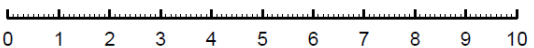
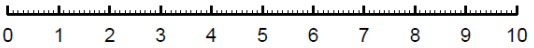
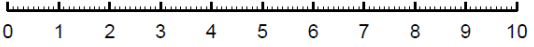
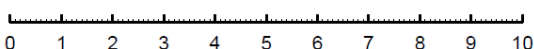
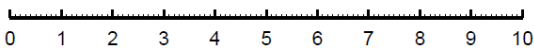
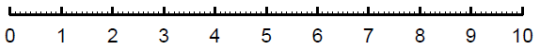
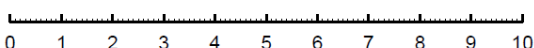
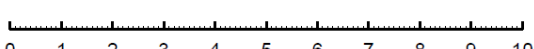
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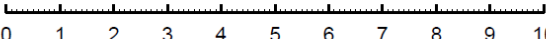

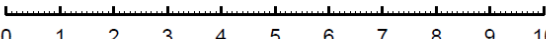
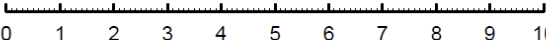


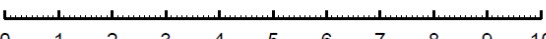
Henkilötunnus: _____ Päivämäärä: _____

<p>1. Keskustelet henkilön kanssa huoneessa ja televisio on auki. Sujuuko keskustelu normaalisti ilman television sulkemista tai sen hiljentämistä?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>2. Keskustelet henkilön kanssa hälyttömässä huoneessa. Sujuuko keskustelu normaalisti?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>3. Istut pöydän ympärillä hälyttömässä huoneessa neljän henkilön kanssa. Näet jokaisen heistä ympärilläsi. Pystytkö seuraamaan keskustelua?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>4. Olet viiden hengen seurassa hälyisessä ravintolassa. Näet jokaisen heistä ympärilläsi. Pystytkö seuraamaan keskustelua?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
16-Jun-17	
<p>5. Keskustelet henkilön kanssa. Taustalla on jatkuva tuulettimen tai juoksevan veden ääni. Sujuuko keskustelu normaalisti?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>6. Olet viiden hengen seurassa hälyisessä ravintolassa. Et näe jokaista heistä ympärilläsi. Pystytkö seuraamaan keskustelua?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>7. Keskustelet henkilön kanssa paikassa, jossa kuuluu runsaasti (kirkko, rautatieasema tms). Pystytkö seuraamaan keskustelua?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>8. Pystytkö keskustelemaan henkilön A kanssa, jos henkilö B puhuu vieressäsi samalla äänensävyllä kuin henkilö A?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>9. Pystytkö keskustelemaan henkilön A kanssa, jos henkilö B puhuu vieressäsi eri äänensävyllä kuin henkilö A?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>

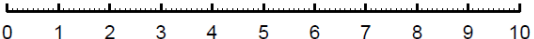
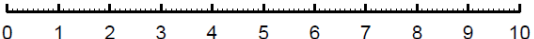
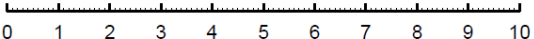
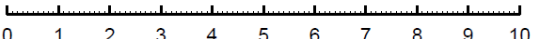
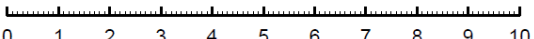
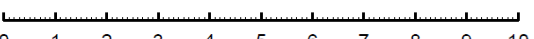
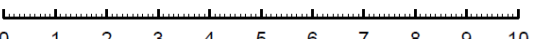


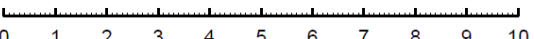
<p>10. Puhut kaverisi kanssa ja samanaikaisesti kuuntelet uutisia televisiosta. Pystytkö seuraamaan puhetta molemmista lähteistä?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>11. Keskustelet henkilön A kanssa huoneessa jossa on paljon muita puhuvia henkilöitä. Pystytkö seuraamaan henkilön A puhetta?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>12. Olet ryhmässä ja keskustelu vaihtelee henkilöltä toiselle. Pystytkö helposti seuraamaan keskustelua ilman että menetät jotain uuden puhujan alkusanoista?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>13. Pystytkö keskustelemaan puhelimesta normaalisti?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>14. Keskustelet puhelimesta ja henkilö A alkaa puhua vieressäsi. Pystytkö seuraamaan puhetta molemmista lähteistä?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>

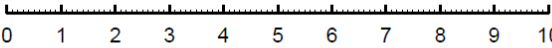
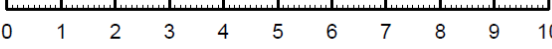
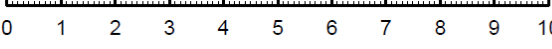
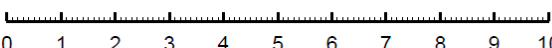

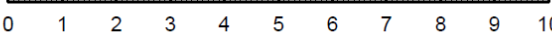
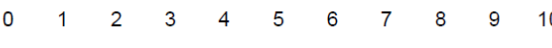
Suuntakuulon arviointi

<p>1. Olet ulkona ja oudossa paikassa. Kuulet jonkun käyttävän ruohonleikkuukonetta, mutta et näe missä. Osaatko välittömästi paikallistaa äänen suunnan?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>2. Istut pöydän ääressä kokouksessa muutaman henkilön kanssa etkä näe kaikkia osallistujia. Osaatko paikallistaa henkilön heti kun hän aloittaa puhumisen?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>3. Istut kahden henkilön välissä ja toinen heistä alkaa puhua. Osaatko ilman katsomista kertoa puheen tulevan oikealta tai vasemmalta?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>4. Olet hiljaisessa ja oudossa talossa. Kuulet oven sulkeutuvan. Osaatko välittömästi kertoa mistä suunnasta ääni kuului?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>5. Olet kerrostalon rappukäytävässä ja ylä- ja alapuolellasi on kerroksia. Kuulet ääniä jostain kerroksesta. Osaatko sanoa välittömästi mistä suunnasta (alhaalta/ylhäältä)?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>6. Olet ulkona ja kuulet koiran haukkuvan äänekkäästi. Osaatko välittömästi ja katsomatta kertoa mistä suunnasta ääni kuuluu?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>7. Seisot vilkkaan kadun varrella. Osaatko kuulon perusteella kertoa mistä suunnasta bussi tai kuorma-auto lähestyy ennen kuin näet sen?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>8. Seisot jalkakäytävällä. Osaatko arvioida kuulemasi puhe- tai askelääniä perusteella kuinka kaukana henkilö on?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>9. Osaatko kuulemasi äänen perusteella arvioida kuinka kaukana bussi tai kuorma-auto on?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min or wouldn't hear it Max</p>
<p>10. Osaatko kuulemasi äänen perusteella kertoa bussin tai kuorma-auton kulkusuunnan, esim. vasemmalta oikealle tai päinvastoin?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min or wouldn't hear it Max</p>

<p>11. Osaatko kuulemasi puhe- tai askelääniä perusteella kertoa henkilön kulkusuunnan, esim. vasemmalta oikealle tai päinvastoin?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>12. Osaatko kuulemasi puhe- tai askelääniä perusteella kertoa onko henkilö tulossa sinua kohti vai menossa pois päin?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>13. Osaatko kuulemasi äänen perusteella kertoa onko bussi tai kuorma-auto tulossa sinua kohti vai menossa pois päin?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>14. Koetko että kuulemasi äänet tulevat paremminkin pään sisältä kuin kohteesta pään ulkopuolelta?</p>	<p>Pään sisältä Ulkopuolelta</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>15. Onko äänilähde (ihminen, auto tms) yleensä lähempänä kuin oletit jos et aluksi näe kyseistä äänilähdettä?</p>	<p>Paljon lähempänä Ei lähempänä</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>16. Onko äänilähde (ihminen, auto tms) yleensä kauempana kuin oletit jos et aluksi näe kyseistä äänilähdettä?</p>	<p>Paljon kauempana Ei kauempana</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
<p>17. Tuntuuko sinusta että äänet tulevat juuri sieltä mistä oletatkin niiden tulevan?</p>	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>

Äänen laadun arviointi

1. Kun kuulet useampia ääniä samanaikaisesti, tuntuuko että ne sekoittuvat yhdeksi epäselväksi ääneksi	<p>Epäselvä Ei epäselvä</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
2. Olet huoneessa ja radiosta tulee musiikkia. Henkilö A puhuu myös huoneessa. Erotatko puheäänen ja musiikin toisistaan?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
3. Tunnistatko helposti tuntemasi henkilöt äänen perusteella?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
4. Tunnistatko helposti tunut musiikkiesitykset?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
5. Erotatko erilaiset äänet toisistaan, esim., henkilöauto vai bussi: kiehuva vesi kattilassa vai paistinpannulla tirisevä pihvi?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
6. Kun kuuntelet musiikkia erotatko mitä instrumenttia soitetaan (esim piano, kitara)?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
7. Kuuluuko musiikki luonnolliselta ja selkeältä?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
8. Kuuluvatko helposti kuultavat arkipäivän äänet selkeästi?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
9. Kuuluuko muiden ihmisten puhe selkeältä ja luonnolliselta?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
10. Kuuluuko arkipäivän äänet keinotekoisilta ja luonnottomilta?	<p>Luonnoton Luonnollinen</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>

11. Kuuluuko oma äänesi luonnolliselta?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
12. Voitko helposti määritellä toisen henkilön mielialan hänen äänensä perusteella?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
13. Täytyykö sinun keskittyä erittäin kovasti kuunnellessasi jotain henkilöä tai asiaa?	<p>Keskittyä kovasti Ei tarvetta</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
14. Autoa ajaessasi kuuletko helposti mitä vieressä istuva matkustaja puhuu?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
15. Kun olet matkustajana autossa kuuletko helposti mitä vieressä istuva kuski puhuu?	<p>Ei ollenkaan Täydellisesti</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
16. Joudutko kovasti "tsemppaamaan" keskustellessasi ihmisten kanssa?	<p>Kovasti Ei tarvetta</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>
17. Onko sinun helppoa olla huomioimatta muita ääniä kun yrität kuunnella jotain tai jotakuta?	<p>Ei helppo olla huomioimatta Helppo olla huomioimatta</p>  <p>0 1 2 3 4 5 6 7 8 9 10</p> <p>Min Max</p>

Work-related stress questionnaire

TYÖSTRESSIN ITSEARVIOINTILOMAKE

Anna seuraaville väittämille niitä mielestäsi parhaiten kuvaava pistemäärä
Vastausvaihtoehdot

1. Täysin eri mieltä
2. Eri mieltä
3. Hieman eri mieltä
4. Hieman samaa mieltä
5. Samaa mieltä
6. Täysin samaa mieltä

Kysymykset

1. Minua vaivaa usein unettomuus työasioiden vuoksi ___
2. En saa unta, kun työasiat pyörivät mielessäni ___
3. Heräilen yöllä työasiat mielessäni ___
4. Herään aikaisin aamuyöstä pohdiskelemaan työasioita ___
5. Kärsin työssä erilaisista kivuista / särystistä ___
6. Minulla on niska- ja hartiakipuja ___
7. Minulla on selkäkipuja ___
8. Minulla on nivelsärkyä ___
9. Kärsin päänsärystä ___
10. Minulla on vatsakipuja ___
11. Rintaani koskee tai puristaa usein ___
12. Työni on ruumiillisesti erittäin tai liian raskasta ___
13. Työasentoni tuntuu hankalalta ___
14. Minun on vaikea ulottua kaikkiin työvälineisiin ja tavaroihin, joita tarvitsen työssäni ___
15. Työympäristöni tuntuu epämiellyttävältä ___
16. Työympäristöni on rauhaton ___
17. Työpaikkani valaistus on sopimaton ___
18. Lämpötila työpaikallani on sopimaton ___
19. Työpaikallani tuntuu vetoa ___
20. Työympäristössäni on epämiellyttäviä hajuja tai pölyjä ___
21. Työympäristöni on epämiellyttävän meluinen ___
22. Olen ahdistunut ajatellessani aamuisin töihin lähtöä ___
23. Työasiat pyörivät mielessäni jatkuvasti vapaa-aikanakin ___
24. Minun on vaikea keskittyä työhöni ___
25. Minun on vaikea irtautua työstäni, vaikka siihen olisi mahdollisuuskin ___
26. Olen turhautunut työssäni ___
27. Minusta tuntuu, etten osaa työtäni kunnolla ___
28. Minusta tuntuu, etten ehdi tehdä kaikkia työtehtäviäni ___

29. Minusta tuntuu, etten jaksakaan työssäni, voimani ovat lopussa ___
30. Teen päivittäin ylityötä vähintään kaksi tuntia tai olen kuukaudessa vähintään kahtena viikonloppuna töissä ___
31. Tunnen itseni ärtyisäksi työssäni ___
32. Olen ahdistunut työssäni ___
33. Olen joutunut ruumiillisen tai henkisen väkivallan kohteeksi työssäni ___
34. Minua kiusataan työssäni ___
35. Minun väitetään kiusaavan muita työssäni ___
36. En saa esimieheltäni tai työtovereilta sellaista palautetta, arvostusta tai apua, jota toivoisin saavani ___
37. Esimiehelläni ei ole aikaa tai hän ei halua kuunnella minua ___
38. En tule toimeen toisten kanssa tai he eivät tule toimeen minun kanssani ___
39. Minusta tuntuu, etten olisi kykenevä kehittämään työolojani tai työyhteisöäni ___
40. Minusta tuntuu, etten saa aikaiseksi, työni ei suju ___
41. Työni ei kiinnosta tai innosta minua ___
42. En voi vaikuttaa haluamallani tavalla työssäni ___
43. En voi vaikuttaa haluamallani tavalla tulostavoitteisiin ___
44. En voi vaikuttaa työni sisältöön ___
45. En voi vaikuttaa tapaani tehdä työtä ___
46. En voi vaikuttaa työni määrään ___
47. En tiedä, miten oma työsuoritukseni liittyy kokonaisuuteen / toisten työhön ___
48. Työlläni ei ole merkitystä toisten ihmisten kannalta ___
49. Työtä tehdessäni en pysty näkemään miten hyvin tai huonosti tein työni ___
50. En pysty työssäni käyttämään kaikkia kykyjäni niin monipuolisesti kuin haluaisin ___
51. Työni ei ole riittävän itsenäistä ___
52. Joudun työssäni käyttämään alkoholia turhan paljon ___
53. Olen tyytymätön työehtoihini ja / tai kehitysmahdollisuuksiini ___

Working performance questionnaire

Työkyky istuteleikkauksen jälkeen.

1. Nimi:

Ammatti:

Ole hyvä ja ympyröi sopiva vaihtoehto

2. Työn luonne (ympyröi yksi tai useampi vaihtoehto)
a) puhelintyö b) asiakaspalvelu c) melutyö d) muu
3. Miten paljon sisäkorvaistute on helpottanut selviytymistä nykyisessä työssäsi?
a) erittäin paljon b) paljon c) vähän d) ei muutosta e) huonontanut
4. Onko sisäkorvaistute vaikuttanut positiivisesti urakehitykseesi tai urasuunnitelmiisi?
a) erittäin paljon b) paljon c) vähän d) ei muutosta e) huonontanut
5. Oletko osallistunut aktiivisemmin työyhteisösi toimintaan sisäkorvaistuteleikkauksen jälkeen?
a) erittäin paljon b) paljon c) vähän d) ei muutosta e) vähentänyt aktiivisuutta
6. Onko sisäkorvaistute vähentänyt työpäiväsi jälkeistä uupumusta?
a) erittäin paljon b) paljon c) vähän d) ei muutosta e) lisännyt uupumusta
7. Onko kommunikointi työkavereiden kanssa helpottunut sisäkorvaistuteleikkauksen jälkeen?
a) erittäin paljon b) paljon c) vähän d) ei muutosta e) huonontunut
8. Onko puhelintyöskentely helpottunut sisäkorvaistuteleikkauksen jälkeen?
a) erittäin paljon b) paljon c) vähän d) ei muutosta e) huonontunut
9. Onko istutteen käytössä ilmennyt haittoja tai vaikeuksia (esim puhelimen käyttö tms)? Ole ystävällinen ja nimeä myös pienet ja mielestäsi merkityksettömätkin haitat ja vaikeudet.

Original publications

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Sequential Bilateral Cochlear Implantation Improves Working Performance, Quality of Life and Quality of Hearing

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Abstract

Conclusions: This prospective study shows that working performance, quality of life (QoL) and quality of hearing (QoH) is better with two compared to single cochlear implant (CI). The impact of second CI on the patients' QoL is as significant as the impact of the first CI.

Objectives: To evaluate the benefits of sequential bilateral cochlear implantation in working, QoL and QoH.

Methods: We studied working performance, work-related stress, QoL and QoH with specific questionnaires in 15 patients with unilateral CI scheduled for sequential CI of another ear. Sound localization performance and speech perception in noise were measured with specific tests. All questionnaires and tests were performed before the second CI surgery and 6 and 12 months after its activation.

Results: Bilateral CIs increased patients' working performance and their work-related stress and fatigue decreased. Communication with co-workers was easier and patients were more active in their working environment. Sequential bilateral cochlear implantation improved QoL, QoH, sound localization and speech perception in noise statistically significantly.

Keywords: Ability to work, quality of life, quality of hearing.

Introduction

Cochlear implantation (CI) is a routine practice to rehabilitate severe bilateral hearing loss. In Finland, adults have been traditionally implanted unilaterally, whereas children will have CIs to both ears. The importance of hearing at work and in everyday life increases invariably, and nowadays patients are well aware of the benefits of bilateral cochlear implantation. This has put a lot of pressure on public healthcare to provide bilateral CIs for adult patients as well.

The advantages of unilateral CI in adults are well known. Although single CI offers significant benefits, binaural hearing is not restored. With two CIs, sound localization and speech perception in noise are significantly enhanced. For example, Nopp et al. [1] found that sound localization accuracy improved by 30% in the bilateral condition compared to the better ear alone. Laszig et al. [2] demonstrated 8% better speech perception in noise in bilateral than in unilateral CI mode. Dunn et al. [3] reported that patients with bilateral CIs were able to listen 9 dB higher noise levels than patients with single CI to identify 50% of the presented words. Hearing with single CI may cause remarkable problems in certain professions, such as in trading and customer service.

Bilateral CIs enhance quality of life (QoL). Summerfield et al. [4] have reported improved hearing-related QoL and Olze et al. [5] health-related QoL in patients after sequential bilateral cochlear implantation. Moreover, patients with two CIs have less social restriction, better emotional well-being and cognition [6,7]. Sparreboom et al. [8] found that sequential bilateral cochlear implantation in children is associated mainly with an improvement in disease-related (speech perception and directional hearing) aspects of QoL. King et al. [9] with their new QoL questionnaire that assesses the physical and psychosocial benefits of sequential bilateral cochlear implantation showed subjective improvement in all measured domains - hearing and balance, psychological and social.

In this study, we explored the effect of sequential bilateral cochlear implantation on patient's ability to work in his/her current workplace and on QoL and QoH.

Materials and Methods

We invited all currently working adult patients with unilateral CI to participate in the study. Fifteen out of 24 patients (9 females, 6 males) with an average age of 41 years (range 19–58 years) replied and were included. The etiology was bilateral progressive postlingual sensorineural hearing loss in

14 patients, and 1 patient had severe bilateral hearing impairment since birth. Ten patients used a hearing aid (HA) in the contralateral ear before the second CI surgery (detailed patient data are shown in **Table I**). The first CI had been implanted, on average, 4.7 years (range 1–14 years) earlier. The study was conducted at Tampere University Hospital, Tampere, Finland and approved by the Ethics Committee of Pirkanmaa Hospital District, Tampere University Hospital.

Table I. Patient demographics.

No	sex	Age	HA use	Interimplant time (years)	Implant/processor for CI 1	Implant/processor for CI 2
1	F	51	+	2	CI512/CP810	CI24RE (CA)/CP810
2	F	28	+	11	CI24M/Freedom	CI24RE (CA)/CP810
3	F	58	+	4	CI24RE (CA) /Freedom	CI24RE (CA)/CP810
4	M	19	+	5	CI24RE (CA)/Freedom	CI24RE (CA)/CP810
5	M	40	+	2	CI512/CP810	CI24RE (CA)/CP810
6	F	29	-	2	CI512/CP810	CI24RE (CA)/CP810
7	M	52	+	2	CI512/CP810	CI 24RE (CA) /CP810
8	F	33	+	9	CI24R/Freedom	CI24RE (CA)/CP810
9	F	25	-	4	CI24RE (CA)/Freedom	CI24RE (CA)/CP810
10	M	46	+	10	CI24M/3G	CI24RE (CA)/CP810
11	M	41	-	14	CI24M/3G	CI24RE (CA)/CP810
12	F	53	+	1	CI24RE (CA)/Freedom	CI24RE (CA)/CP810
13	F	46	-	5	CI24RE (CA)/Freedom	CI24RE (CA)/CP810
14	F	52	-	2	CI512/CP810	CI24RE (CA)/CP810
15	M	51	+	2	Sonata/Opus 2	Concerto/Opus 2

CI24M, CI24R, CI24RE (CA) and CI512 are from Cochlear Corp, and Sonata and Concerto from Med-El Corp. CI, cochlear implant; F, female; HA, hearing aid; M, male

Preoperative hearing tests on the non-implanted ear included pure tone average (PTA, the mean of 0.5, 1, 2 and 4 kHz) and speech discrimination (SD) with recorded bisyllabic, phonetically balanced words in the Finnish language, which were validated for adult [10]. Binaural hearing (PTA and SD) was tested in sound field before the second CI surgery (with a hearing aid if used) and 6 and 12 months after the second CI's activation.

The patients' working performance, work-related stress, QoL and quality of hearing (QoH) were surveyed using specific questionnaires. The patients completed questionnaires for work-related stress, QoL and QoH before and after (6 and 12 months post activation) the second CI surgery. The questionnaire for working performance was filled out once, 24 months after the second CI. Work-

related stress was measured using the Occupational Stress Questionnaire from the Finnish Institute of Occupational Health. The test contains 53 negative claims to respond to; each response is placed on a 6-point scale ranging from a total disagreement to total agreement. The questionnaires to measure working performance and work-related stress are not validated.

The patients' QoL was measured by the Glasgow Benefit Inventory (GBI) and the 15D health-related QoL questionnaire [11,12]. The GBI scores before the second CI surgery represent the effect of the first CI on the patients' QoL. The GBI scores after the second CI depict the positive or negative impact of the CI on the patient's QoL compared with the former best-aided condition (CI \pm HA). The test contains 18 questions and the response to each question is placed on a 5-point scale ranging from a large deterioration to a large improvement in health status. The GBI consists of a total score and 3 subscores (general, social support and physical health). The total score is transposed onto a benefit scale ranging from -100 (maximal negative benefit), through 0 (no benefit), to +100 (maximal positive benefit) [13]. The 15D questionnaire is a standardized, self-administered instrument for measuring health-related QoL in adults. The test consists of 15 dimensions: moving, seeing, hearing, breathing, sleeping, eating, speaking, eliminating, usual activities, mental function, discomfort and symptoms, depression, distress, vitality and sexual activity. The respondent chooses the alternative which best describes his/her present health status (best = 1; worst = 5). The maximum score is 1 (no problems on any dimension) and the minimum score is 0 (equal to being dead).

The QoH was measured with the Speech, Spatial and Qualities (SSQ version 3.1.2) questionnaire, where patients use a visual analog scale (VAS, from 0 to 10) to evaluate their current hearing. The SSQ test is divided into three categories: speech intelligibility, spatial perception and sound quality. The speech-in-noise and the sound localization tests were performed in a sound field before the second CI surgery and at 6 and 12 months after its activation. The preoperative tests were accomplished with the best-aided condition (CI \pm HA). Five active loudspeakers (Genelec 8040A)

were used at a one-meter distance from the test participant and positioned at 0° , $\pm 45^\circ$ and $\pm 90^\circ$ of azimuth on the horizontal plane. The participant's responses were collected via a microphone connected to an audiometer (Madsen Aurical) outside the room by the audiologist performing the test over headphones.

Phonetically balanced bisyllabic Finnish words were used as speech material for the speech-in-noise test [10]. The speech signal was played back at a fixed level (65 dB SPL) from the loudspeaker in front of the participant (0°). The noise signal was an unmodulated artificial noise signal with a long-term spectrum that corresponded to human speech [14], and it was fed to the other four loudspeakers by delaying the signal to each loudspeaker by increments of 100 milliseconds to avoid problems with coherence. The level of the noise signal was varied at 5 dB steps to achieve various signal-to-noise ratios (SNRs). The speech material consisted of six lists of 25 words. The order of the words in each list was randomized and each participant listened to the word lists with six different SNRs: -5, 0, +5, +10, +15 and +20 dB. The presentation order of the SNRs, as well as which word list was presented with a given SNR, were randomized across the participants to minimize the effect on the results of potential differences in the speech reception threshold in noise between each list.

For the localization test, short speech segments were played back randomly from each of the five loudspeakers. The overall presentation level was 65 dB SPL and it was roved within ± 5 dB to avoid the participants using loudness as a cue to localize sound. The overall sound localization accuracy was quantified by an error index (EI) as a measure of variance [15]. The scale of the EI is from 0 to 1, as, for example, in the study by Asp et al. [16]. The EI is calculated as the sum of all azimuth errors during the test, where the azimuth error is the number of loudspeakers (0 to 4 in the current setup) between the perceived and presented loudspeaker (0 corresponds to coinciding perceived and presented sound-source azimuth), divided by the average random error (16 in the current setup).

EI=0 means a perfect match between all perceived and presented sound source azimuths, while EI=1.0 corresponds to chance performance.

The participants were instructed to face the loudspeaker at 0° azimuth in front of them and to not move their heads during the test. Depending on the test, they were instructed either to repeat the word they heard or to name the loudspeaker from which they thought the sound signal was emanating. Fifteen healthy volunteers (9 females and 6 males, mean age 43 years, range 20–59 years) with normal hearing ($PTA \leq 20$ dB HL) served as controls in the sound localization and speech-in-noise tests.

The data were analysed with SPSS for Windows statistical software, version 19.0. The comparison between the pre- and postoperative data was performed using a nonparametric test (Wilcoxon Signed Rank Test). Bonferroni corrections used in Wilcoxon Test in the SSQ analysis. The differences were considered statistically significant at a value of $p < 0.05$.

Results

The working performance improved after the second CI. The patients managed much better at work and were more alert after their workday. Communication with co-workers was easier and speaking on the phone was slightly easier. The patients were also more active in their working environment and the second CI had a slight positive influence on their career development or planning (**Table II**). The mean work-related stress score did not change statistically significantly after the second CI. However, the score tended to decrease during the 1-year follow-up.

Table II. Questionnaire on working performance with bilateral cochlear implants (CIs).

1. How much has the second CI helped you to do your work?				
a) very much	b) moderately	c) a little	d) no change	e) worsened
2. How much has the second CI positively influenced your career development or planning?				
a) very much	b) moderately	c) a little	d) no change	e) worsened
3. How much more active have you been in your working environment after the second CI?				
a) very much	b) moderately	c) a little	d) no change	e) decreased activity
4. Has the second CI decreased your fatigue after the workday?				
a) very much	b) moderately	c) a little	d) no change	e) increased fatigue
5. Is it easier to communicate with your co-workers after the second CI?				
a) very much	b) moderately	c) a little	d) no change	e) worsened
6. Is it easier to speak on the phone after second CI?				
a) very much	b) moderately	c) a little	d) no change	e) worsened

The questionnaire was conducted after two years of bilateral CI use. The most common answer for each question is given in bold type.

The GBI scores showed the positive effect of implantation on QoL both after the first and second CI. The mean total GBI score with single CI was +43 ($p < 0.001$). The mean subscore was +60 ($p < 0.001$) for general health, +12 ($p = 0.031$) for social support and +8 (*ns*) for physical health. At 6 months after second CI activation, the mean score for total GBI was +35 ($p < 0.001$). The mean subscore was +50 ($p < 0.001$) for general health, +1 (*ns*) for social support and +6 (*ns*) for physical health. After the 1-year follow-up, the mean score for total GBI was +39 ($p < 0.001$). The mean subscore was +56 ($p < 0.001$) for general health, +6 (*ns*) for social support and +8 (*ns*) for physical health (**Table III**). The mean 15D score was 0.93 with single CI and improved to 0.95 (*ns*) and then to 0.96 ($p = 0.046$) 6 and 12 months after second CI activation. The dimension of depression improved from 0.84 to 0.91 (*ns*) and then to 0.94 ($p = 0.023$), and the dimension of distress improved from 0.91 to 0.93 (*ns*) and then to 0.98 ($p = 0.046$) correspondingly.

Table III. The mean scores for the Glasgow Benefit Inventory.

	Preoperative with CI 1	6 months after CI 2 activation	12 months after CI 2 activation
Total (SD)	+43 (19)*	+35 (19)*	+39 (17)*
General	+60 (26)*	+50 (25)*	+56 (27)*
Social support	+12 (20)**	+1 (20)	+6 (12)
Physical health	+8 (19)	+6 (31)	+8 (23)

CI, cochlear implant; SD, standard deviation.

* $p < 0.001$. ** $p < 0.05$.

The mean VAS scores of all SSQ categories improved statistically significantly during the 1-year follow-up. In the spatial perception category, the mean VAS score was 3.0 with single CI and improved to 5.2 ($p < 0.001$) and then to 6.3 ($p < 0.001$) 6 and 12 months after the second CI activation. In the category of sound quality, the mean VAS score was 6.7 with single CI. At 6 and 12 months after the second CI activation, the score improved to 7.1 ($p = 0.035$) and then to 7.6 ($p = 0.003$) correspondingly. In the speech intelligibility category, the corresponding VAS scores were 5.7 for single CI and 6.7 ($p = 0.005$) and 7.0 ($p < 0.001$) after the second CI (**Table IV**).

Table IV. Mean scores for the SSQ test.

	Preoperative 1 CI	Postoperative 2 CI 6 months	Postoperative 2 CI 12 months
Spatial perception (SD)	3.0 (1.5)	5.2 (1.7)**	6.3 (1.4)**
Sound quality	6.7 (1.3)	7.1 (1.0)*	7.6 (1.1)**
Speech intelligibility	5.7 (1.3)	6.7 (1.5)**	7.0 (1.6)**

CI, cochlear implant; SD, standard deviation; SSQ, Speech, Spatial and Qualities questionnaire.

* $p < 0.05$. ** $p < 0.01$.

Sound localization was statistically significantly better with bilateral CIs. With single CI, the EI score was 0.73. At 6 months after the activation of the second CI, the EI score had decreased to 0.32 ($p < 0.001$), and after 1 year to 0.31 ($p < 0.001$). The EI was 58% better with bilateral CIs than with the best-aided condition with single CI (CI \pm HA). In the control group, the EI was 0.

Speech perception in noise improved statistically significantly. Compared to the best-aided measurements before the second CI, the mean percentage of correct words increased from 57 to 78 ($p < 0.001$) at 0 SNR and from 32 to 50 ($p = 0.002$) at -5 SNR during the follow-up. However, one patient (nro10) had significantly worse scores after the second CI compared to others. This patient

had had severe hearing impairment since birth and the interval between the implantations was 10 years. In the control group, the speech perception in noise was 98 % at 0 and 98 % at -5 SNR (**Figure 1**).

Before the second CI, the mean best-aided sound field PTA was 27 dB HL. At 6 months after the second CI activation the PTA was 23 dB HL ($p = 0.023$) and after 1 year 23 dB HL ($p = 0.008$). The mean best-aided sound field SD was 91% with single CI. After the second CI it improved to 93% (*ns*) during 1-year follow-up.

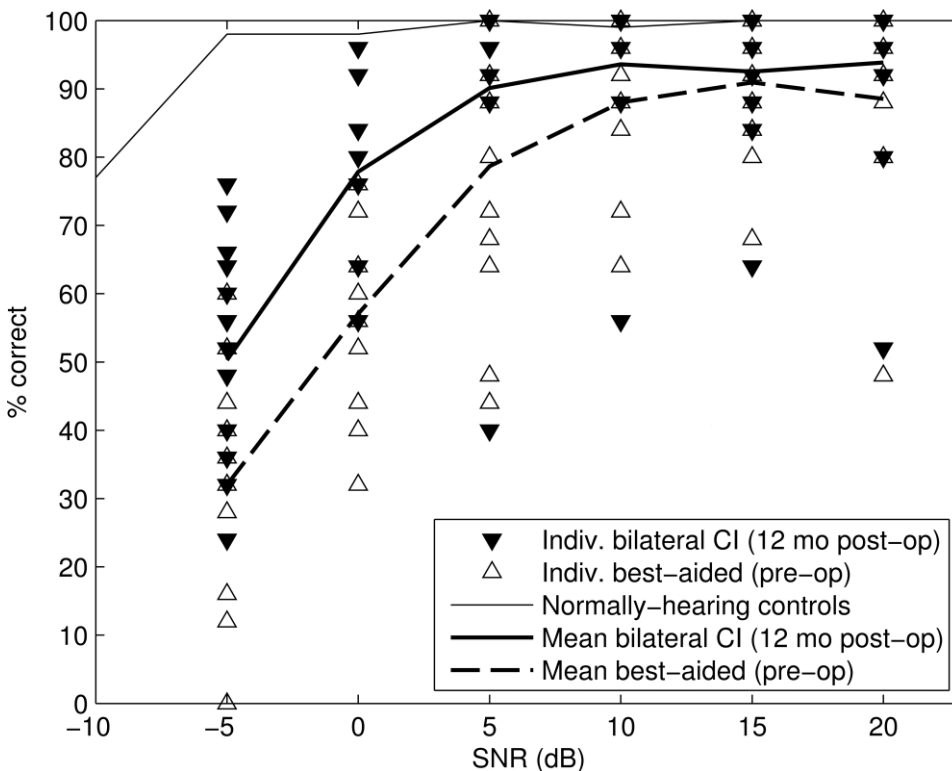


Figure 1. Speech perception in noise. Individual and mean best-aided results before and 12 months after activation of the second cochlear implant (CI). SNR, signal-to-noise ratio.

Discussion

This study demonstrated that bilateral CIs provide better opportunities to manage at work than unilateral CI. The second CI improved working performance, tended to decrease work-related stress and improved QoL and QoH. The second CI increased the patients' ability to manage at work and reduced their fatigue after the workday. In addition, ease of communicating with co-workers and

clients made them more active in their working environment. These factors are very important so that workers with severe hearing impairment will not take early retirement. When disadvantages and problems with two CIs at work were asked, the most common and quite unexpected disadvantage was background noise when speaking on the phone. This is probably due to collected sounds by the CI in the non-phone ear. Direct workplace effects are hard to measure and, therefore, we need more studies about how patients with CIs manage in different working environments.

Unilateral CI clearly ameliorates QoL. In our study, the sequential bilateral cochlear implantation enabled us to make individual QoL-comparison between uni- and bilateral CI condition. The GBI results showed a statistically significant positive effect of cochlear implantation on QoL after the second CI. Interestingly, the impact of second CI on the patients' QoL was almost as significant as was the impact of the first CI. It is probable that the improved working performance and QoH (spatial hearing and hearing in noise) with two CIs are as remarkable to the patient as was the restored hearing with the first CI. Furthermore, our patients had distinctly less depression and distress after the second CI. This might be explained by the gain in self-confidence as well as the hearing improvement.

The hearing was better with two CIs. The mean sound field PTA with two CIs was, on average, 15% better than the preoperative best-aided (CI \pm HA) PTA. The SD improved from 91% to 93%, correspondingly. All our patients had their poorest hearing ear been implanted first. Interestingly, the SD improved to its best level in the second ear roughly in the same timetable as in the first ear. Because of longer history of hearing and HA rehabilitation, we would have expected the second ear to reach the best SD level sooner. Our finding is in line with the study by Zeitler et al. [17], which found no association between performance and the time between sequential cochlear implantations in 22 adults. The QoH was statistically significantly better with two CIs. The speech intelligibility, spatial perception and sound quality increased, on average, by 36 % after the second CI. This correlates well with an improved performance and efficacy at work since, for example, all questions

in the speech intelligibility category can be related to different listening conditions in the working environment.

The patients' spatial hearing was statistically significantly better with two CIs. The EI score increased, on average, by 58% compared to best-aided situation with single CI. Nopp et al. [1] had similar results with 20 bilaterally implanted adults. They found that sound localization accuracy improved by 30% in the bilateral condition. Two CIs are capable of providing the majority of the known binaural hearing mechanisms. For example, Litovsky et al. [18] have shown that the largest benefit for speech understanding in noise was when the patient was able to take advantage of the head shadow effect with bilateral CIs. Moreover, Schleich et al. [19] showed a significant binaural summation effect in 21 adults with bilateral CIs. Our patients' speech perception in noise increased, on average, by 56% after the second CI. This may reflect enrichment of the binaural hearing mechanisms.

The one aim of this study was to collect evidence on adult bilateral cochlear implantation to help us working in a public health care to cope with forthcoming CI indications and increasing expenses. Healthcare costs grow habitually and resource allocation decisions are necessary. The importance of hearing at work is now entirely different than it was decades ago. Thus, we have a lot of pressure to provide bilateral CIs to adult patients as well to children. Interestingly, sequential bilateral cochlear implantation has been found to be cost-effective compared to unilateral cochlear implantation in long-term gains or cost-saving measures [20].

The present study demonstrated that bilateral sequential cochlear implantation improved the patients' working performance and efficacy and decreased work-related stress. Furthermore, it improved the patients' QoL and QoH.

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Declaration of interest:

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Original Paper

Single-Sided Deafness: The Effect of Cochlear Implantation on Quality of Life, Quality of Hearing, and Working Performance

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Key Words

Cochlear implant · Single-sided deafness · Working performance · Quality of life · Quality of hearing

Abstract

Aims: To evaluate the effect of a cochlear implant (CI) on quality of life (QoL), quality of hearing (QoH), and working performance in patients with single-sided deafness (SSD). **Methods:** Using specific questionnaires, we measured QoL, QoH, and working performance in 7 SSD patients scheduled for CI surgery of the affected ear. Sound localization and speech perception in noise were also assessed. All questionnaires and tests were performed before the CI surgery and at 6 and 12 months after CI activation. **Results:** The QoL, QoH, sound localization, and speech perception in noise had improved statistically significantly after CI surgery. Communication with co-workers became easier, and the patients were less fatigued after the working day. **Conclusions:** CI clearly improves QoL, QoH, and working performance in patients with SSD.

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Introduction

In most cases, postlingual single-sided deafness (SSD) is caused by Ménière's disease, trauma, or sudden sensorineural hearing loss of unknown origin. SSD causes difficulties in determining the direction of sound and separating background noise from target sounds, such as speech. Moreover, many patients may suffer from incapacitating tinnitus in their affected ear. In some patients, SSD may lead to remarkable problems in managing at work, for

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example, in business negotiations, customer service, and meetings. A hearing deficit may result in progressive absences from work and early retirement. To our knowledge, there are no studies about the impact of SSD on work performance. However, most SSD patients manage with their hearing loss and do not want or need any hearing rehabilitation.

Current rehabilitation options for SSD include the contralateral routing of signal (CROS) or bone conduction devices (BCD). However, only a few patients benefit from these options, and even the best rehabilitation conditions do not compensate for the lack of binaural hearing [1, 2]. In previous studies, only 25–40% of SSD patients chose an implantable BCD or CROS hearing aid after a short trial period [2, 3]. Most patients found it unpleasant to have an earmold with partial occlusion in their hearing ear or to have an abutment in their skull that required diligent care.

The latest rehabilitation option in SSD is the cochlear implant (CI). Recent review studies have shown that cochlear implantation in SSD leads to improved sound localization performance and speech perception in noise [4, 5]. Moreover, Arndt et al. [6] found that cochlear implantation is superior to implantable BCD or CROS hearing aids in patients with SSD. Their results showed significant improvement in localization ability as well as in speech comprehension in most presentation configurations with the CI. Interestingly, unilateral tinnitus resulting from SSD can be alleviated with electrical stimulation via the CI. Tinnitus loudness and distress decreased significantly after cochlear implantation in 21 SSD patients with intractable tinnitus [7].

Cochlear implantation in SSD is not a routine practice in Finland. However, the importance of hearing at work and in everyday life is invariably increasing, and patients are well aware of the benefits of cochlear implantation. This has put a lot of pressure on public health care to provide CIs for SSD patients. The purpose of our study was to evaluate the effect of CI on quality of life (QoL), quality of hearing (QoH), and working performance in adult patients with SSD.

Subjects and Methods

Seven consecutive patients (5 women and 2 men, mean age 48 years, range 36–61) with SSD who were referred to audiological consultation because of difficulties in managing at work were included in the study. The etiology of SSD was sudden deafness of unknown origin in 5 patients and stapes surgery in 2 patients. The average time between deafness and cochlear implantation was 2.5 years (range 1–7). All patients had normal contralateral hearing with a pure tone average (PTA; mean of 0.5, 1, 2, and 4 kHz) of ≤ 20 dB hearing level (dB HL). None of the patients had used a CROS hearing aid or BCD before the CI surgery. Preoperatively, 6 patients had moderate tinnitus in their affected ear. All patients were implanted with a Cochlear™ Nucleus® CI 24 RE (CA) implant with a Nucleus® CP810 processor. The study was conducted at Tampere University Hospital, Tampere, Finland, and approved by the Ethics Committee of Pirkanmaa Hospital District, Tampere University Hospital.

Preoperative hearing tests included PTA and speech discrimination (SD) with recorded bisyllabic, phonetically balanced words in the Finnish language in quiet, which have been validated for adults [8]. Binaural hearing (PTA and SD) was tested in a sound field before the CI surgery, and then at 6 and 12 months after CI activation.

The patients' QoL, QoH, tinnitus perception, working performance, and work-related stress were evaluated using specific questionnaires. Work-related stress and QoH questionnaires were completed before the CI and at 6 and 12 months after CI activation. The QoL questionnaire was completed 6 and 12 months after CI activation, and the working performance questionnaire was completed, on average, 22 months after CI activation. The possible change in tinnitus perception was evaluated, on average, 28 months after CI activation. Work-related stress was measured using the Occupational Stress Questionnaire from the Finnish Institute of Occupational Health. The questionnaire contains 53 negative claims to respond to; each response is placed on a 6-point scale, ranging from total disagreement to total agreement. The questionnaires measuring working performance and work-related stress have not been validated.

The patients' QoL was measured by the Glasgow Benefit Inventory (GBI) [9]. The GBI scores after the CI surgery depict the positive or negative impact of the CI on the patient's QoL compared to the former condition. The test contains 18 questions, and the response to each question is placed on a 5-point scale, ranging from marked deterioration to great improvement in health status. The GBI consists of a total score and 3 subscores (general, social support, and physical health). The total score is transposed onto a benefit scale ranging from -100 (maximal negative benefit), through 0 (no benefit), to +100 (maximal positive benefit) [10].

QoH was measured with the Speech, Spatial and Qualities of Hearing Scale (SSQ, version 3.1.2) questionnaire, where patients use a visual analogue scale (VAS, from 0 to 10) to evaluate their current hearing. The SSQ questionnaire is divided into 3 categories: speech intelligibility, spatial perception, and sound quality.

Speech recognition in noise and localization performance were assessed in an acoustically shielded room for sound field audiometry, as described in an earlier study on sequential bilateral cochlear implantation in the clinic [11]. In the present study, speech-in-noise and localization tests were performed over loudspeakers preoperatively without amplification in the SSD condition (SSD + normal hearing), and postoperatively at 6 and 12 months after the activation of the CI in the deafened ear (CI + normal hearing).

The setup for the speech-in-noise and the localization tests consisted of 5 loudspeakers at 0, ±45, and ±90° of azimuth in the horizontal plane. For the speech-in-noise test, phonetically balanced bisyllabic Finnish words [8] were presented at 65 dB sound pressure level from the frontal loudspeaker (0° of azimuth), while uncorrelated, unmodulated noise with a long-term spectrum that corresponded to human speech [12] was presented from the other 4 loudspeakers. The level of the noise signal was varied in 5-dB steps to achieve a psychometric function for 6 different signal-to-noise ratios (SNRs) ranging from -5 to +20 dB. For the localization test, short speech segments were played back randomly from each of the 5 loudspeakers. The presentation level was 65 dB sound pressure level, and it was roved within ±5 dB to avoid the participants using loudness as a cue to localize sound. Sound localization accuracy was quantified by an error index (EI) ranging from 0 to 1, with 0 corresponding to perfect localization accuracy and 1 being chance performance. For more details on the setup, see Härkönen et al. [11].

At each assessment, the participants first listened to the word lists in noise, with the 6 SNRs in a random order, and then, they took the localization test. The participants were instructed to face the loudspeaker at 0° azimuth in front of them and to not move their heads during the test. Depending on the test, they were instructed either to repeat the word they heard or to name the loudspeaker from which they thought the sound signal was emanating. The participants' responses were collected via a microphone in the test room by an audiologist performing the test. Speech-in-noise and localization data for a normally hearing control group were collected in connection with the earlier study by Härkönen et al. [11].

The data were analyzed with SPSS for Windows statistical software, version 19.0. The comparison between the pre- and postoperative data was performed using a nonparametric test (Wilcoxon signed-rank test). Bonferroni corrections were used in the SSQ analysis. The differences were considered statistically significant at a value of $p < 0.05$.

Results

The GBI scores showed a statistically significant positive effect of CI on QoL. The mean total GBI score was +23 ($p = 0.028$) 6 months after CI activation. The mean subscore was +35 ($p = 0.018$) for general health, +2 (not significant; n.s.) for social support, and -5 (n.s.) for physical health. After the 1-year follow-up, the mean score for total GBI was +28 ($p = 0.018$). The mean subscore was +42 ($p = 0.018$) for general health, +7 (n.s.) for social support, and -5 (n.s.) for physical health (table 1).

The mean VAS scores of the SSQ categories (spatial perception and speech intelligibility) had improved statistically significantly after the cochlear implantation. In the spatial perception category, the mean VAS score was 3.4 before the CI surgery; this improved to 5.1 ($p = 0.018$) 6 months after CI activation, and the score was maintained 12 months (VAS 5.1; $p = 0.043$) after CI activation. In the speech intelligibility category, the corresponding VAS score was 4.0 preoperatively, 5.9 ($p = 0.018$) at the 6-month follow-up, and 5.7 ($p = 0.034$) at the 12-month follow-up. In the category of sound quality, the mean VAS score was 6.2 with

Table 1. Mean scores for the GBI

	6 months after CI activation	12 months after CI activation
Total	+23 (15)*	+28 (10)*
General	+35 (22)*	+42 (18)*
Social support	+2 (12)	+7 (9)
Physical health	-5 (21)	-5 (13)

Values in parentheses are standard deviations. * p < 0.05.

Table 2. Mean scores for the SSQ test

	Preoperative	Postoperative 6 months	Postoperative 12 months
Spatial perception	3.4 (1.5)	5.1 (1.7)*	5.1 (1.4)*
Speech intelligibility	4.0 (1.3)	5.9 (1.5)*	5.7 (1.6)*
Sound quality	6.2 (1.3)	6.7 (1.0)	7.0 (1.1)

Values in parentheses are standard deviations. * p < 0.05.

unilateral hearing. After the CI surgery, the score had improved to 6.7 (n.s.) at the 6-month follow-up and then to 7.0 (n.s.) at the 12-month follow-up (table 2). The mean pre- and post-operative VAS scores for tinnitus perception in the affected ear were obtained 28 months after CI activation. Before the surgery, the score was 6.1; this decreased to 1.2 during the follow-up (p = 0.027).

Sound localization with the CI improved statistically significantly during the follow-up. The EI score was 0.94 without the CI. Six months after CI activation, the score had decreased to 0.41 (p = 0.017), and after 1 year to 0.31 (p = 0.018). In the control group, the EI was 0.

During the follow-up, speech perception in noise was statistically significantly better with the CI, at -5 SNR. Compared to measurements before the CI, the percentage of correct words increased from 70 to 85% (p = 0.027). At 0 SNR, the percentage increased from 90 to 98% (n.s.). In the control group, the speech perception in noise was 98% at 0 SNR and 98% at -5 SNR (fig. 1).

The mean preoperative PTA in the affected ear was 96 dB HL (range 78–118). One year after CI surgery, the sound field PTA was, on average, 22 dB HL (range 18–25). The preoperative SD was 0% in 6 patients and 44% in 1 patient. After 1 year of CI use, the mean sound field SD was 82% (range 68–92) and the speech reception threshold was 28 dB HL (range 20–32).

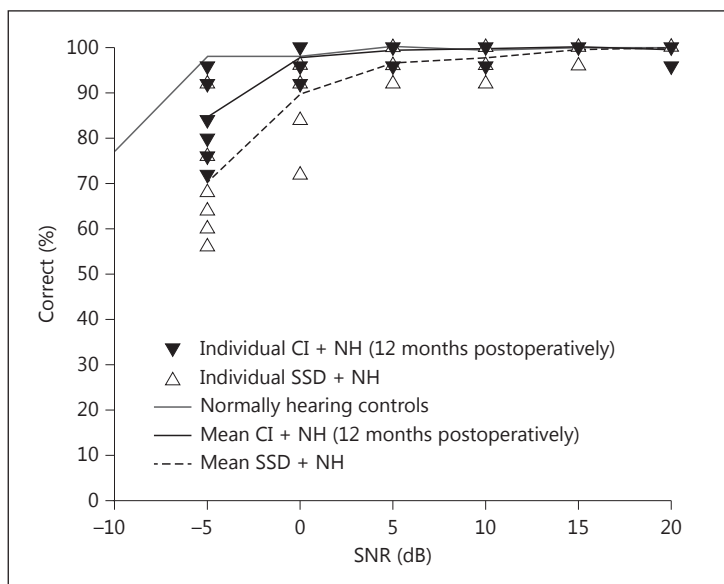
The most prominent work-related hearing difficulty with SSD was communication with co-workers and customers, especially in noisy conditions when the speech came from the patient’s deaf side. Cochlear implantation clearly improved the working performance. Communication with co-workers was easier, and the patients were more active in their working environment. Fatigue after the working day decreased, and the CI had a positive influence on the patients’ career development or planning (table 3). The mean work-related stress score did not change statistically significantly after the CI surgery.

Table 3. Working performance questionnaire

1. How much has the CI helped you to do your work? (a) very much <i>(b) moderately</i> (c) a little (d) no change (e) worsened
2. How much has the CI positively influenced your career development or planning? (a) very much (b) moderately <i>(c) a little</i> (d) no change (e) worsened
3. How much more active have you been in your working environment after the CI? (a) very much (b) moderately <i>(c) a little</i> (d) no change (e) decreased activity
4. Has the CI decreased your fatigue after the working day? (a) very much (b) moderately <i>(c) a little</i> (d) no change (e) increased fatigue
5. Is it easier to communicate with your co-workers after the CI? (a) very much (b) moderately <i>(c) a little</i> (d) no change (e) worsened
6. Is it easier to speak on the phone after the CI? (a) very much (b) moderately (c) a little <i>(d) no change</i> (e) worsened

The questionnaire was conducted after 22 months of CI use. The most common answer is given in italics.

Fig. 1. Speech perception in noise: individual and mean results before and 12 months after the cochlear implantation. NH = Normally hearing ear.



Discussion

This study demonstrated that cochlear implantation raises QoL and QoH in patients with SSD and improves their working performance. The GBI results show the statistically significantly positive benefits of CI on QoL. It is probable that better QoH (spatial hearing and hearing in noise) leads to better working performance and explains the improvement in QoL. This is in line with our study in sequentially bilaterally implanted adult patients, where the benefit of a second CI was almost as eminent as that of the first [11]. Binaural hearing diminished environmental difficulties in speech perception and sound localization at work.

Cochlear implantation enhanced SSD patients’ working performance. With CI, it was easier to cope with one’s work, and there was less fatigue after the working day. Furthermore, the ease of communication with co-workers or clients made the patients more active in their

working environment. These factors definitely reduce the risk of burnout or sick leave in professions dependent on hearing.

Patients with SSD become aware of the importance of binaural hearing in their daily life in terms of social interaction and communication [13]. In our study, the patients' spatial hearing was statistically significantly better after cochlear implantation. The EI score increased by an average of 67% compared to the situation before the CI surgery. The patients' speech perception in noise had also improved, on average by 21%, after the CI surgery. Our finding is in line with the study by Arndt et al. [6], who found that localization error reduced significantly after cochlear implantation compared to the pre-implant condition with either a CROS device, an implantable BCD, or an unaided condition.

Tinnitus is often related to sensorineural hearing loss, and the CI has been successfully utilized to treat incapacitating tinnitus in SSD patients. Arndt et al. [6], Van de Heyning et al. [7], and Tavora-Vieira et al. [14] reported significant reductions in tinnitus distress and loudness after cochlear implantation. In our study, 6 out of 7 patients suffered from tinnitus before the cochlear implantation, and they all reported relief in their tinnitus perception after the CI surgery.

Despite modest results, the current practice to rehabilitate SSD is to use an implantable BCD or a CROS device. Niparko et al. [1] demonstrated that sound localization was poor with both devices, and speech perception in noise was better only in selected tasks. Peters et al. [15] showed that neither a CROS device nor an implantable BCD provided a benefit regarding speech perception in noise, sound localization, or QoL. However, subjective speech communication improved moderately.

Even though cochlear implantation offers more benefits than conventional devices in SSD, it is difficult to predict its place as a routine rehabilitation mode in the near future. High-level-of-evidence studies concerning CI in patients with SSD are sparse, although the current literature suggests important benefits regarding sound localization, QoL, and tinnitus [16]. Furthermore, its cost-effectiveness may be questionable, since most SSD patients manage well without any rehabilitation. At our institute, cochlear implantation is provided to the SSD patient if his/her hearing is unexpectedly lost due to ear surgery, the patient has incapacitating tinnitus, or his/her working ability is threatened.

Conclusion

This prospective study showed that working performance, QoL, and QoH improved and tinnitus perception decreased after cochlear implantation in patients with SSD.

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Disclosure Statement

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Quality of Life and Hearing Eight Years After Sudden Sensorineural Hearing Loss

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Objectives/Hypothesis: To explore long-term hearing results, quality of life (QoL), quality of hearing (QoH), work-related stress, tinnitus, and balance problems after idiopathic sudden sensorineural hearing loss (ISSNHL).

Study Design: Cross-sectional study.

Methods: We reviewed the audiograms of 680 patients with unilateral ISSNHL on average 8 years after the hearing impairment, and then divided the patients into two study groups based on whether their ISSNHL had recovered to normal (pure tone average [PTA] \leq 30 dB) or not (PTA $>$ 30 dB). The inclusion criteria were a hearing threshold decrease of 30 dB or more in at least three contiguous frequencies occurring within 72 hours in the affected ear and normal hearing in the contralateral ear. Audiograms of 217 patients fulfilled the criteria. We reviewed their medical records; measured present QoL, QoH, and work-related stress with specific questionnaires; and updated the hearing status.

Results: Poor hearing outcome after ISSNHL was correlated with age, severity of hearing loss, and vertigo together with ISSNHL. Quality of life and QoH were statistically significantly better in patients with recovered hearing, and the patients had statistically significantly less tinnitus and balance problems. During the 8-year follow-up, the PTA of the affected ear deteriorated on average 7 dB, and healthy ear deteriorated 6 dB.

Conclusion: Idiopathic sudden sensorineural hearing loss that failed to recover had a negative impact on long-term QoL and QoH. The hearing deteriorated as a function of age similarly both in the affected and the healthy ear, and there were no differences between the groups. The cumulative recurrence rate for ISSNHL was 3.5%.

Key Words: Unilateral, sudden sensorineural hearing loss, quality of life, hearing, prognosis.

Level of Evidence: 4

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INTRODUCTION

Idiopathic sudden sensorineural hearing loss (ISSNHL) is defined as a decrease in hearing of \geq 30 decibels (dB) in at least three adjacent frequencies occurring within 72 hours (American Academy of Otolaryngology–Head and Neck Surgery Foundation [AAO-HNO]).¹ The lesion is most often cochlear in origin, and the hearing loss may be associated with tinnitus, vertigo, and a sensation of pressure in the ear. The probable causes of ISSNHL are viral infections, vascular disorders, genetics, labyrinthine membrane ruptures, autoimmune processes, or combinations of such factors.²⁻⁴ Idiopathic sudden sensorineural hearing loss has an estimated incidence of five to 20 persons per 100,000 per year.¹

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Reported prognostic factors for hearing recovery include severity of hearing loss, presence of tinnitus or vertigo, duration of symptoms before diagnosis, age, shape of audiogram, and presence of metabolic diseases.⁵⁻⁸ Natural history and placebo-controlled studies have shown hearing recovery rates of 32% to 65% without any medical treatment, typically within 2 weeks of onset.^{9,10}

Permanent unilateral deafness affects quality of life (QoL). Wie et al.¹¹ reported that unilaterally profoundly deaf patients experienced a significant disability in auditory function, which affected their speech perception, communication, and social interaction. Carlsson et al.¹² found that annoying tinnitus and vertigo after ISSNHL were the strongest predictors of negative effects on QoL, and these correlated with sick leave directly after ISSNHL and over time. Chen et al.¹³ demonstrated that ISSNHL patients with continuous tinnitus had more emotional distress and depressive symptoms. Sano et al.¹⁴ found that social life and daily activities were particularly affected in ISSNHL patients from the mental and physical perspectives. Unilateral ISSNHL may cause difficulties in sound localization and hearing in noise, which in some patients may lead to remarkable problems in managing at work (e.g., in meetings or customer service).

The aims of this study were to find predictors for poor hearing outcome after unilateral ISSNHL; to compare long-term hearing results in the affected and healthy ear

TABLE I.
Patient Data at the Time of ISSNHL Diagnosis.

	Group 1	Group 2
Patients	100	72
Male/female	54 of 46	31 of 41
Mean age (years)	43	48*
PTA/WRS (mean), affected ear	50 of 75	79 of 29*
PTA/WRS, healthy ear	8 of 100	10 of 100
Tinnitus, affected ear (%)	82	88
Vertigo (%)	23	54*

* $P < 0.05$.

ISSNHL = idiopathic sudden sensorineural hearing loss; PTA = pure tone average; WRS = word recognition score.

between ISSNHL patients with and without hearing recovery; and to evaluate the long-term effects of unilateral ISSNHL on QoL, quality of hearing (QoH), and work-related stress.

MATERIALS AND METHODS

We reviewed audiograms of 680 patients with unilateral ISSNHL who were referred to Tampere University Hospital (Tampere, Finland) for audiological consultation between 2000 and 2009. All the patients whose initial audiogram passed the AAO-HNO criteria (decrease in hearing ≥ 30 dB in at least three contiguous frequencies occurring within 72 hours in the affected ear and normal hearing in the contralateral ear) were selected for the study. The patients were divided into two groups based on whether their ISSNHL had recovered to normal (pure tone average [PTA] mean of 0.5, 1, 2, 4 kHz ≤ 30 dB HL) or not (PTA > 30 dB HL) during the short (1–2-month) follow-up period. The patient was excluded from the study if the etiology was clear at the onset of the hearing loss or at 1 to 2 months control. The audiograms of 217 patients (32%) fulfilled the AAO-HNO criteria, and 172 out of 217 (79%) patients replied to the invitation and participated in the study. Group 1 (recovered hearing) consisted of 100 patients (46 females and 54 males, mean age 51 years, age range 26–65 years). Group 2 (no hearing recovery) consisted of 72 patients (41 females and 31 males, mean age 56 years, age range 23–66 years). The interval between the onset of ISSNHL and the study was, on average, 8 years (range 3–13 years). An initial pure tone audiogram was available from all the patients, but word recognition (WRS) were only available from 60 patients in group 1 and from 52 patients in group 2. The patients' ISSNHL treatment had included systemic steroids, betahistidine, and carbogen inhalation separately or in different combinations. Magnetic resonance imaging had been performed in 17 of 100 patients in group 1 and 58 of 72 patients in group 2. Brainstem auditory-evoked responses had been recorded from 68 of 100 patients in group 1 and 14 of 72 patients in group 2. The study was conducted at Tampere University Hospital and approved by the Ethics Committee of Pirkanmaa Hospital District, Tampere University Hospital.

All patients were invited to a pure tone audiometry and WR test with recorded bisyllabic, phonetically balanced words in the Finnish language, which had been validated for adults.¹⁵ Of the 172 patients, 147 participated in the hearing tests. The remaining 25 patients (17 in group 1 and 8 in group 2) skipped the hearing tests due to their distance from the hospital.

Quality of life, QoH, and work-related stress were evaluated with specific questionnaires for all patients. Tinnitus and

balance problems in the daylight and in the dark were evaluated by visual analogue scale (VAS) (VAS 0–10; 0 = no tinnitus, no balance problems). The patients' QoL was measured by the 15 dimensions (D) health-related questionnaire.¹⁶ The test consists of 15 dimensions: moving, seeing, hearing, breathing, sleeping, eating, speaking, eliminating, usual activities, mental function, discomfort and symptoms, depression, distress, vitality, and sexual activity. Respondent chooses the alternatives that best describe their present health status (best = 1; worst = 5). The maximum score is 1 (no problems on any dimension), and the minimum score is 0 (equal to being dead).

The QoH was measured with the Speech, Spatial and Qualities of Hearing Scale (SSQ; version 3.1.2) questionnaire, for which patients use a visual analogue scale (VAS 0–10) to evaluate their current hearing. The SSQ questionnaire is divided into three categories: speech intelligibility, spatial perception, and sound quality.

Work-related stress was measured using the Occupational Stress Questionnaire from the Finnish Institute of Occupational Health. The test contains 53 negative claims to respond to; each response is placed on a 6-point scale ranging from total disagreement to total agreement. The questionnaire to measure work-related stress has not been validated. Of the 172 patients, 43 were retired (15 in group 1 and 28 in group 2); therefore, they did not fill out the questionnaires.

The data were analyzed with SPSS for Windows statistical software, version 19.0 (IBM Corp., Armonk, NY). We used the Mann–Whitney U test and Fisher's exact test to compare the two groups regarding the categorical variables belonging to the study. A repeated-measures analysis of variance test was used to compare vertigo, hearing loss, and age in both groups. In all the analysis, the significance level was 5% ($P < 0.05$).

RESULTS

Table I presents the patient data at the time of ISSNHL diagnosis. The patients in group 1 were, on average, 5 years younger than patients in group 2 ($P < 0.05$). The mean PTA in the affected ear was 50 dB HL in group 1 and 79 dB HL in group 2, and the mean value for WRS was 75% in group 1 and 29% in group 2 ($P < 0.001$). In the healthy ear, the mean PTA was 8 dB HL in group 1 and 10 dB HL in group 2, and the mean WRS was 100% in both groups. On average, tinnitus was related to ISSNHL in 85% of patients. Twenty-three percent of patients in group 1 and 54% in group 2 had concurrent vertigo, and the difference was statistically significant ($P < 0.001$). The relationship between age and vertigo was not statistically significant, but vertigo was related to greater hearing loss in group 2 ($P < 0.001$).

TABLE II.
Short- and Long-Term Hearing Results After ISSNHL.

	Group 1	Group 2
PTA/WRS 1–2 months, affected ear	12 of 99	65 of 50
PTA/WRS 8 years, affected ear	18 of 97	72 of 43
PTA/WRS 8 years, healthy ear	12 of 99	18 of 96
Recurrence (%)	3	4
ISSNHL in healthy ear (%)	1	3

ISSNHL = idiopathic sudden sensorineural hearing loss; PTA = pure tone average; WRS = word recognition score.

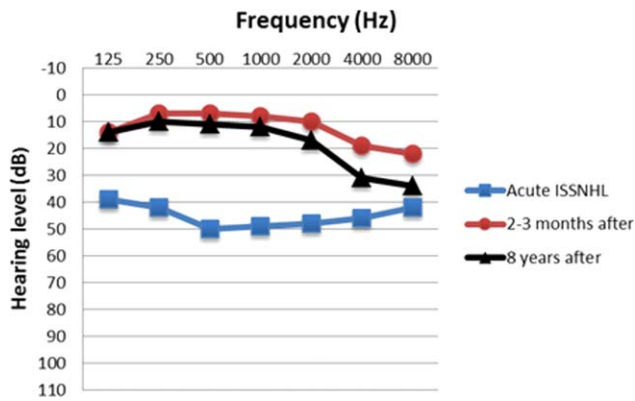


Fig. 1. Group 1 hearing results. dB = decibels; ISSNHL = idiopathic sudden sensorineural hearing loss. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Table II depicts the short- and long-term hearing results after ISSNHL and the recurrence rate. During the short-term follow-up, the mean PTA improved from 50 to 12 dB HL in group 1 and from 79 to 65 dB HL in group 2. Correspondingly, the mean WRS improved from 75% to 99% in group 1 and from 29% to 50% in group 2. After 8 years, the mean PTA in the affected ear was 18 dB HL in group 1 and 72 dB HL in group 2, and the mean WRS was 97% and 43%, respectively. In the healthy ear, the mean long-term PTA was 12 dB HL in group 1 and 18 dB HL in group 2. The mean values for WRS were 99% and 96% correspondingly (see Figs. 1 and 2).

Figure 3 shows the scattergram of both groups pooled together. After 1 to 2 months follow-up, PTA was improved in 69% and WRS in 41% of the patients.

Three patients in group 1 (3%) and three in group 2 (4%) had had a recurrence of ISSNHL in their affected ear during the 8-year follow-up. All patients in group 1 had recovered their hearing after the recurrence. One patient in group 1 (1%) and two in group 2 (3%) had had ISSNHL in their initially healthy ear during the last 8 years. No vestibular schwannomas were detected during the 8-year follow-up. One patient had brain hemosiderosis in magnetic resonance imaging.

Quality of life was statistically significantly better in group 1. The mean 15D total score was 0.93 in group

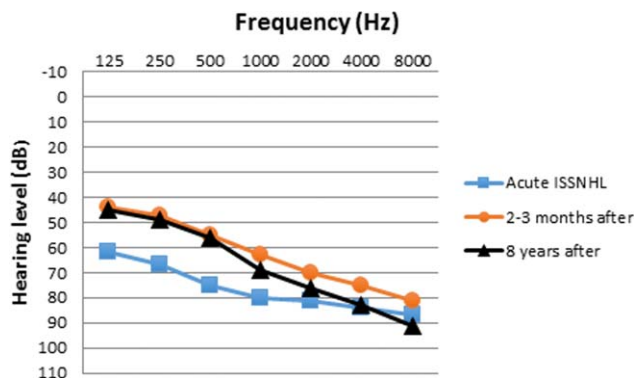


Fig. 2. Group 2 hearing results. dB = decibels; ISSNHL = idiopathic sudden sensorineural hearing loss. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

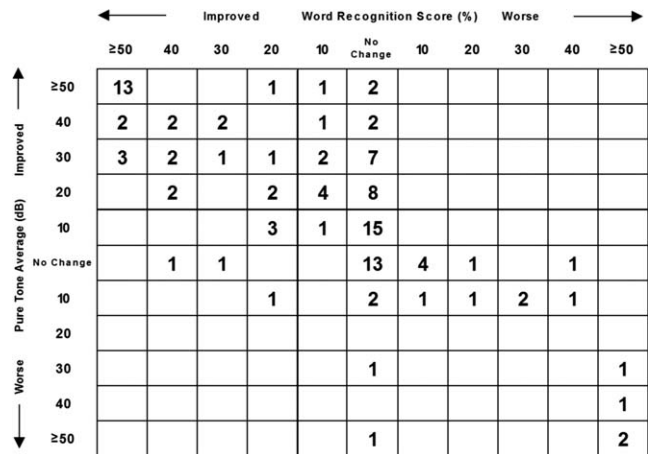


Fig. 3. Scattergram of 112 patients 1 to 2 months after idiopathic sudden sensorineural hearing loss. Pure tone averages are represented on the y-axis and word recognition scores are represented on the x-axis.

1 and 0.90 in group 2 ($P < 0.05$). The dimension of hearing and vitality were also statistically significantly better in group 1 than in group 2 ($P < 0.001$ and $P < 0.01$). There were no statistically significant differences between the groups regarding work-related stress.

Table III presents the mean long-term results for SSQ. The VAS scores of all SSQ categories were statistically significantly better in group 1. In the spatial perception category, the score was 8.2 in group 1 and 5.0 in group 2 ($P < 0.001$). In the category of sound quality, the score was 8.8 in group 1 and 6.9 in group 2 ($P < 0.001$). In the speech intelligibility category, the corresponding scores were 8.0 and 5.6 ($P < 0.001$).

Table IV shows the mean long-term VAS results for tinnitus and balance. Eight years after the ISSNHL, the mean VAS for tinnitus was 1.5 in group 1 and 4.7 in group 2 ($P < 0.001$). The VAS for balance in daylight was 1.2 in group 1 and 1.9 in group 2 ($P < 0.005$). The VAS for balance in the dark was 1.5 in group 1 and 2.4 in group 2 ($P < 0.005$).

There were no statistically significant differences between the groups concerning the prevalence of diseases (diabetes, blood pressure, heart diseases, asthma, cancer, rheum, thyroid gland diseases, and mental illness) or cigarette smoking. Diseases were confirmed from the patients' medical records at the end of the follow-up.

DISCUSSION

This study demonstrated that a poor hearing outcome after ISSNHL is correlated with the patient's age,

	Group 1	Group 2
Spatial perception (SD)	8.2 (1.7)	5.0 (2.4)*
Sound quality	8.8 (1.1)	6.9 (1.7)*
Speech intelligibility	8.0 (1.6)	5.6 (1.8)*

* $P < 0.001$.

SD = standard deviation; SSQ = Speech, Spatial and Qualities of Hearing Scale.

TABLE IV.
Mean Long-Term VAS Results for Tinnitus and Balance.

	Group 1	Group 2
Tinnitus (SD)	1.5 (2.3)	4.7 (3.1)*
Balance in daylight	1.2 (1.2)	1.9 (1.8)*
Balance in the dark	1.5 (1.4)	2.4 (2.0)*

* $P < 0.005$

SD = standard deviation; VAS = visual analogue scale.

severity of hearing loss, and vertigo in conjunction with ISSNHL. Quality of life and QoH were statistically significantly better in patients with recovered hearing, and they also had less tinnitus and fewer balance problems.

The progression of hearing loss during the 8-year follow-up did not differ statistically significantly between the groups. The mean PTA in the affected and the healthy ear deteriorated, on average, 6 dB in both groups. Wiley et al.¹⁷ have calculated the rate of change in hearing thresholds for 48- to 59-year-old men to be approximately 0.4 dB per year at 0.5 kHz and approximately 1.6 dB per year at 8 kHz. In our study, the change in affected ears was 0.4 dB per year at 0.5 kHz and 1.4 dB at 8 kHz. In the healthy ears, the change was 0.5 dB per year at 0.5 kHz and 1.6 dB at 8 kHz. The hearing deteriorated with age in a normal manner, and ISSNHL did not appear to accelerate the hearing loss.

We reviewed audiograms of 680 patients diagnosed with ISSNHL. However, only the audiograms of 217 patients fulfilled the study's audiological inclusion criteria based on the AAO-HNO recommendation. The explanation for this is that the AAO-HNO criteria are not used at our clinic, and ISSNHL diagnosis is quite liberally given to patients with sudden sensorineural hearing impairment. We excluded many patients whose hearing loss was limited to one or two frequencies or whose hearing loss was less than 30 dB. Furthermore, some patients had gradually developed a hearing impairment, and in some, the normal fluctuations in hearing of patients with Meniere's disease were wrongly interpreted as ISSNHL. By using the AAO-HNO criteria, we ensured that real ISSNHL patients were included.

Systemic diseases may influence recovery from ISSNHL because of their microvascular or autoimmune effects on the inner ear. We did not find statistically significant differences concerning hearing recovery after ISSNHL in smokers or in patients with diabetes, hypertension, heart diseases, asthma, cancer, rheum, thyroid gland diseases, or mental illness. This is in line with a study by Wen et al.,⁶ which found no significant differences in the recovery of patients with diabetes, hypertension, tinnitus, or vertigo in profound ISSNHL. On the other hand, Lin et al.¹⁸ showed that cardiovascular risk factors, such as smoking and heavy alcohol consumption, had a positive association with ISSNHL.

Meniere's disease is a notable cause for sensorineural hearing disturbances. In our study, seven patients developed Meniere's disease during the 8-year follow-up. However, none of the patients in group 2 had had vertigo during the acute phase, and three patients in group 1 had had only mild dizziness. Therefore, ISSNHL with-

out vertigo may express the first sign of the development of Meniere's disease.

In our study, the long-term cumulative recurrence rate in the affected ear was 3.5%. In some studies, the recurrence rate has been reported to vary from 0.8% to 4.99%, but none of these studies has described the severity of hearing loss.¹⁹⁻²¹

Unilateral ISSNHL may be a dramatic experience for a patient who has never had hearing problems before. If the hearing loss fails to recover, then poor sound localization skills, impaired speech perception in noise, and annoying tinnitus may have long-term effects on the patient's QoL.²² Wie et al.¹¹ found that in unilateral deafness the major challenges were communication in poor acoustic surroundings or situations with background noise, as well as limited access to speech reading or direct listening. Idiopathic sudden sensorineural hearing loss-related symptoms, such as vertigo, anxiety about possible recurrence, and fear of hearing loss in the unaffected ear, may affect QoL as well. In our study, QoL was significantly worse in the patients in group 2. Besides unilateral hearing loss, these patients had more tinnitus annoyance and balance problems. Poor sound localization and impaired speech perception in noise due to ISSNHL may affect working performance. However, we did not find any differences in work-related stress between the groups. One reason might be that group 2 consisted of older and more retired patients than group 1.

Otologists should pay more attention to unilateral ISSNHL and offer more intensively audiological rehabilitation for patients to cope with the complex issues that might arise after ISSNHL. Carlsson et al.¹² showed that 47% of ISSNHL patients who received extended audiological rehabilitation experienced good or very good benefits compared to 24% of patients who received basic audiological rehabilitation. Current rehabilitation options for permanent sensorineural hearing loss are a hearing aid, contralateral routing of signal, or a bone conduction device. However, not all patients benefit from these options in profound hearing loss, and in such cases even the best rehabilitation conditions do not compensate for the lack of binaural hearing.^{23,24} Härkönen et al.²⁵ demonstrated that cochlear implantation raises QoL and QoH in patients with single-sided deafness and improves their working performance. Tinnitus annoyance also decreased statistically significantly after cochlear implantation. Cochlear implantation is one of the rehabilitation options for patients with severe ISSNHL with incapacitating tinnitus.

CONCLUSION

This study showed that older age, severity of hearing loss, and vertigo in conjunction with ISSNHL predicted inferior hearing recovery. Patients without hearing recovery had statistically significantly poorer long-term QoL, QoH, and more tinnitus and balance problems. There were no statistically significant differences in work-related stress between the groups. Hearing deteriorated as a function of age similarly both in the affected and the healthy ear, and there were no

differences between the groups. The cumulative recurrence rate for ISSNHL was 3.5%.


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Hybrid cochlear implantation: quality of life, quality of hearing, and working performance compared to patients with conventional unilateral or bilateral cochlear implantation

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Abstract The objective of the present study is to evaluate the effect of hybrid cochlear implantation (hCI) on quality of life (QoL), quality of hearing (QoH), and working performance in adult patients, and to compare the long-term results of patients with hCI to those of patients with conventional unilateral cochlear implantation (CI), bilateral CI, and single-sided deafness (SSD) with CI. Sound localization accuracy and speech-in-noise test were also compared between these groups. Eight patients with high-frequency sensorineural hearing loss of unknown etiology were selected in the study. Patients with hCI had better long-term speech perception in noise than uni- or bilateral CI patients, but the difference was not statistically significant. The sound localization accuracy was equal in the hCI, bilateral CI, and SSD patients. QoH was statistically significantly better in bilateral CI patients than in the others. In hCI patients, residual hearing was preserved in all patients after the surgery. During the 3.6-year follow-up, the mean hearing threshold at 125–500 Hz decreased on average by 15 dB HL in the implanted ear. QoL and working performance improved significantly in all CI patients. Hearing outcomes with hCI are comparable to the results of bilateral CI or CI with SSD, but hearing in noise and sound localization are statistically significantly better than with unilateral CI. Interestingly, the impact of CI on

QoL, QoH, and working performance was similar in all groups.

Keywords Hybrid cochlear implant · Quality of life · Working ability · Quality of hearing · Residual hearing

Introduction

Cochlear implant (CI) rehabilitation can be categorized into four different types depending on the implanted condition; unilateral, bilateral, bimodal (CI and contralateral hearing aid), and hybrid. Electroacoustic stimulation with a hybrid cochlear implant (hCI) is an option for patients with severe, high-frequency sensorineural hearing impairment.

Cochlear implantation, either uni- or bilateral, has a positive effect on quality of life (QoL) and quality of hearing (QoH) [1]. Despite constantly developing processor techniques, the QoH with traditional CI may remain relatively unnatural and therefore hearing in noise is often challenging [1, 2]. Interestingly, hCIs have been shown to improve hearing in noise and even music perception over traditional CIs [3–5]. Moreover, advanced surgical techniques and less traumatic electrodes have led to better preservation of cochlear structures, providing a better basis for good speech perception with preserved residual hearing.

Sound localization with a single CI (with or without a contralateral hearing aid) is poor. Bilateral CI use improves sound localization, but it is still much poorer than in normal hearing controls [1]. Because of their relatively good low-frequency residual hearing, hCI patients are expected to have better sound localization than patients with conventional CI. Interestingly, Moteki et al. have shown that bilateral hCIs effectively improved speech perception in

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noise and sound localization in patients with high-frequency hearing loss [6]. Gifford et al. and Adunka et al. have shown that, in hCI patients, performance in complex hearing environments—for example, in restaurant noise—is better with electro-acoustic stimulation than with electric stimulation alone [3, 7]. Rader et al. found that bimodal hCIs (with a hearing aid in the contralateral ear) significantly improved speech perception in noise compared to bilateral cochlear implantation [8]. In most workplaces, the hearing environment is complex, and hearing loss may cause difficulties in working performance. Improved hearing in noise and more accurate sound localization should lead to better performance at work and in everyday life. These benefits have not been evaluated in hCI patients.

The purpose of this study was twofold: (1) to evaluate the long-term effects of hCIs on QoL, QoH, and working performance in adult patients; and (2) to compare these results to patients with conventional unilateral or bilateral CI.

Materials and methods

We invited all eight hCI patients operated in our hospital to participate in the study. All patients (5 women and 3 men) with a mean implantation age of 49 years (range 25–70 years) responded and were included. Six patients had unilateral hCIs and two patients had bilateral hCIs. Five patients with unilateral hCIs used a hearing aid (HA) in the contralateral ear. Six patients used acoustic amplification in the implanted ear (i.e., electro-acoustic stimulation) and two patients used only the electric stimulation mode. Bilateral high-frequency sensorineural hearing loss etiology was unknown in all patients. The duration between the hCI implantation and the study was, on average, 3.6 years (range 1.7–5.1 years). The study was conducted at Tampere University Hospital, Tampere, Finland, and approved by the Ethics Committee of Pirkanmaa Hospital District, Tampere University Hospital. Detailed patient data are shown in Table 1.

Comparison groups were single-sided deafness (SSD), patients with unilateral CI, and sequentially bilaterally implanted patients. The SSD group included seven patients (five women and two men, mean age 48 years, range 36–61 years) and the etiology was sudden deafness of unknown origin in five patients and stapes surgery in two patients. The average time between the deafness and cochlear implantation was 2.5 years (range 1–7 years). All patients had normal contralateral hearing. The bilateral CI group consisted of 15 patients (9 females, 6 males, mean age 41 years, range 19–58 years). The etiology was bilateral progressive postlingual sensorineural hearing loss in 14 patients, and 1 patient had severe bilateral congenital

hearing impairment. Ten patients had used an HA in the contralateral ear before the second CI surgery. The first CI had been implanted, on average, 4.7 years (range 1–14 years) before the second CI. The follow-up period after CI surgery was 1 year in both comparison groups. Detailed information about these control groups can be found in our previous studies [1, 2].

The CochlearTM Nucleus[®] Hybrid L24 Cochlear Implant System provides electrical stimulation to the basal section of the cochlea while protecting the apical section to provide benefits from acoustic stimulation. This combination of stimulation is indicated in patients with mild to moderate hearing loss in the low frequencies and severe to profound hearing loss in the high frequencies. The implant's active array is 15 mm in length with 22 half-band electrode contacts inserted through the round window or cochleostomy into the cochlea. The typical insertion depth is 16 mm, indicated by a stopper to control the insertion depth. The electrode diameter is 0.4 mm at the basal end and 0.25 mm at the apical end. In this study, cochlear implantations were performed with a standard mastoidectomy and the facial recess approach. The round window niche was identified and the bony overhang was carefully removed to provide good access to the round window membrane. The electrode insertion was performed via an incision to the round window membrane.

Preoperative hearing and speech discrimination (SD) were measured with recorded bisyllabic, phonetically balanced words in the Finnish language that have been validated for adults [9]. Residual hearing and SD were measured 1 month after the surgery and at the end of the follow-up. Binaural hearing and hearing with an hCI alone were tested in a sound field. Hearing in the non-implanted ear with and without HA was tested after the follow-up.

The patients' QoL, QoH, and working performance were evaluated using specific questionnaires, which were completed after the follow-up. The patients' QoL was measured by the Glasgow Benefit Inventory (GBI) questionnaire [10]. The GBI scores after the implantation of an hCI depict the positive or negative impact of hCIs on the patient's QoL compared to the former condition. The test contains 18 questions and the response to each question is placed on a five-point scale ranging from a large deterioration to a large improvement in health status. The GBI consists of a total score and three subscores (general, social support, and physical health). The total score is transposed onto a benefit scale ranging from –100 (maximal negative benefit) through 0 (no benefit) to +100 (maximal positive benefit).

QoH was measured with the Speech, Spatial and Qualities of Hearing Scale (SSQ; version 3.1.2) questionnaire, where patients use a visual analog scale (VAS; from 0 to 10) to evaluate their current hearing. The SSQ

Table 1 Patient demographics

No	F/M	Age (years)	hCI (ear)	HA (other ear)	Years implanted	Processor	Acoustic stimulation
1	M	25	Right	+	5	CP910	+
2	M	46	Both		5 and 4	CP810 + CP810	–
3	M	70	Right	–	3	CP910	+
4	F	45	Right	+	3	CP910	+
5	F	51	Right	+	3	CP810	–
6	F	62	Left	+	2	CP910	+
7	F	33	Both		5 and 4	CP910 + freedom	+
8	F	57	Right	+	3	CP910	+

F female, *M* male, *hCI* hybrid cochlear implant, *HA* hearing aid

questionnaire is divided into three categories: speech intelligibility, spatial perception, and sound quality. The questionnaire measuring working performance has not been validated. One patient was retired and did not fill this questionnaire.

To assess the effect of electro-acoustic stimulation on hearing, the patients' speech recognition in noise and localization abilities were measured via five loudspeakers placed at $0^\circ \pm 45^\circ$ and $\pm 90^\circ$ of azimuth in the horizontal plane in a sound-field test room. Speech-in-noise and localization tests were carried out after the postoperative period following the implantation of the hCI.

In the speech-in-noise test, phonetically balanced bisyllabic Finnish words [9] were presented at a level of 65 dB SPL from the loudspeaker at 0° of azimuth. The noise was an unmodulated artificial signal with a long-term spectrum corresponding to human speech [11]. The noise was uncorrelated and presented from the other four loudspeakers, and its level was varied in 5 dB steps to achieve speech recognition scores as a function of signal-to-noise ratio (SNR). The six SNRs in the present study were -10 , -5 , 0 , $+5$, $+10$, and $+15$ dB. In the localization test, short speech segments were presented randomly from each of the five loudspeakers. The presentation level was 65 dB SPL and it was roved within ± 5 dB to avoid the participants using loudness as a cue to localize sound. In the analysis, sound localization accuracy was quantified by an error index (EI) ranging from 0 to 1, with 0 corresponding to perfect localization accuracy and 1 being chance performance.

In the assessment, the participants were instructed to face the frontal loudspeaker at 0° of azimuth and to not move their heads during the test. In the speech-in-noise test, they were instructed to repeat the word they heard, and in the localization test, to name the loudspeaker they thought the sound was emanating from. Similar data had earlier been collected for sequentially bilaterally implanted adults, as well as for a normally hearing control group [1]

and SSD patients implanted unilaterally with a cochlear implant [2]. Although background and etiological factors play a major role in cochlear implant outcomes, the aim of the present assessment was to arrive at a basic understanding of how well the recipients of hCIs fared in comparison to the other two groups of cochlear implantees. More details on the test setup are found in Härkönen et al. [1, 2].

The data were analyzed with SPSS for Windows statistical software, version 19.0. The comparison between the pre- and postoperative health (GBI) was performed using a nonparametric test (the Wilcoxon signed-rank test). The Mann–Whitney *U* test and the Kruskal–Wallis test were used when comparing the hCI, SSD, and unilateral and bilateral CI groups. The differences were considered statistically significant at a *p* value < 0.05 .

Results

The GBI scores showed a positive effect for CI on QoL in all groups. In hCI patients, the mean total GBI score was $+44$ at the end of the follow-up ($p = 0.012$). The mean subscore was $+68$ ($p = 0.011$) for general health, $+2$ for social support (not significant; ns), and -10 for physical health (ns). One patient was diagnosed with breast cancer during the study and this probably influenced her physical health subscore. In comparison to the other CI groups, the mean total GBI score was statistically significantly higher for the hCI patients than for the SSD patients ($p = 0.012$) (see Table 2).

Working performance clearly improved after the hCI (see Table 3). The patients managed much better at work and the implantation had a positive influence on their career planning. Communication with co-workers and speaking on the phone were also much easier. The patients were more active in their working environment and more alert after the working day. Working performance

Table 2 The mean long-term Glasgow Benefit Inventory scores

	hCI	Unilat. CI	Bilat. CI	SSD + CI
Total (SD)	+44 (9)	+43 (19)	+39 (17)	+28 (10)
General	+68 (12)	+60 (26)	+56 (27)	+42 (18)
Social support	+2 (19)	+12 (20)	+6 (12)	+7 (9)
Physical health	-10 (25)	+8 (19)	+8 (23)	-5 (13)

CI cochlear implant, hCI hybrid cochlear implant, SSD single-sided deafness, SD standard deviation

improved after cochlear implantation in all comparison groups [1, 2].

In the hCI patients, the SSQ score was 6.2 for sound quality, 5.4 for speech intelligibility, and 5.5 for spatial perception. In comparison to the other groups, speech intelligibility was statistically significantly better in bilateral CI patients than in hCI or SSD patients ($p = 0.034$) (see Table 4).

The mean EI score was 0.34 in the hCI patients. This result is in line with patients with bilateral CI (0.31) and SSD (0.31). The sound localization score was 0.73 in unilateral CI patients, which was statistically significantly worse than the other groups ($p < 0.004$).

Figure 1 demonstrates the speech perception in noise in normal hearing controls and all CI groups. SSD patients had statistically significantly better speech perception scores than the other CI groups ($p < 0.027$). The scores were clearly the worst in patients with a unilateral CI.

At the end of the follow-up, the mean decrease in hearing at 125 Hz was 11 dB HL in the implanted ear and 2 dB HL in the non-operated ear. The decrease was 14 and 10 dB HL at 250 Hz and 19 and 19 dB HL at 500 Hz, respectively. One patient was excluded from this study because she completely lost her residual hearing during chemotherapy (see Fig. 2).

Table 4 The mean long-term speech, spatial and qualities of hearing scale scores

	hCI	Unilat. CI	Bilat. CI	SSD + CI
Sound quality (SD)	6.2 (1.5)	6.7 (1.3)	7.6 (1.1)	7.0 (1.1)
Speech intelligibility	5.4 (1.1)	5.7 (1.3)	7.0 (1.6)	5.7 (1.6)
Spatial perception	5.5 (1.5)	3.0 (1.5)	6.3 (1.4)	5.1 (1.4)

hCI hybrid cochlear implant, SSD single-sided deafness, SD standard deviation

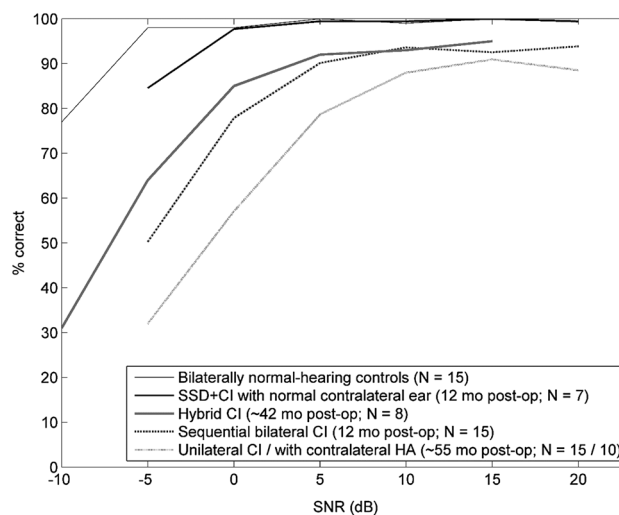


Fig. 1 The mean best-aided speech perception in noise. SNR signal-to-noise ratio, SSD single-sided deafness

After the follow-up, the mean best-aided sound-field PTA was 25 dB HL and the SD was 87%. The mean PTA with an hCI alone was 27 dB HL and the SD was 88%. In the non-implanted ear, the best-aided PTA was 64 dB HL and the SD was 56%.

Table 3 Questionnaire for working performance with hCI

1. How much has the hCI helped you to do your work?	(a) Very much	(b) Moderately	(c) A little	(d) No change	(e) Worsened
2. How much has the hCI positively influenced your career development or planning?	(a) Very much	(b) Moderately	(c) A little	(d) No change	(e) Worsened
3. How much more active have you been in your working environment after the hCI?	(a) Very much	(b) MODERATELY	(c) A little	(d) No change	(e) Decreased activity
4. Has the hCI decreased your fatigue after the workday?	(a) Very much	(b) Moderately	(c) A little	(d) No change	(e) Increased fatigue
5. Is it easier to communicate with your co-workers after the hCI?	(a) Very much	(b) Moderately	(c) A little	(d) No change	(e) Worsened
6. Is it easier to speak on the phone after the hCI?	(a) Very much	(b) Moderately	(c) A little	(d) No change	(e) Worsened

The most common answer is in bold

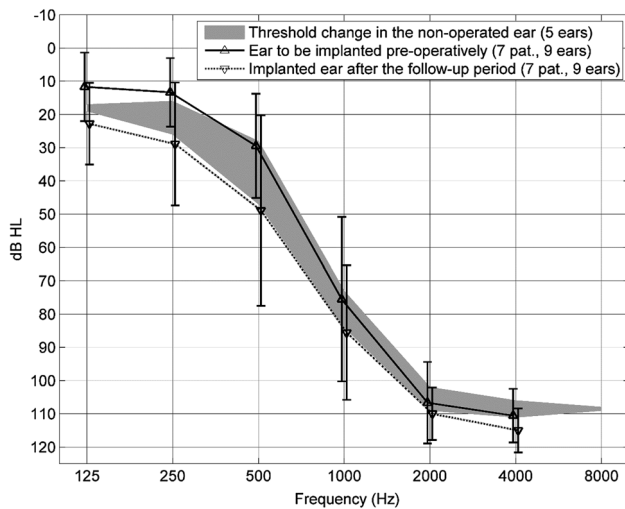


Fig. 2 The mean pre- and postoperative hearing thresholds and the change in hearing thresholds in the non-operated ear

Discussion

This study shows that patients with hybrid and conventional CIs experienced a positive impact from cochlear implantation on their well-being and working performance. QoL increased more in hCI patients than in SSD patients. The reason for this might be that, with one normally hearing ear, SSD patients managed quite well already before the cochlear implantation.

Rader et al. have shown that patients with an hCI and a contralateral HA had statistically significantly better speech perception in noise than patients with bilateral CIs, indicating that binaural interaction between the hCI in one ear and residual acoustic hearing in the opposite ear enhances speech perception in complex noise situations [8]. This is in agreement with our study, although our findings were not statistically significant. Gifford et al. and Adunka et al. found that the performance in noise of patients with hCIs was better with electro-acoustic stimulation than with electric stimulation alone [3, 7]. However, in these studies the comparison between electro-acoustic and electric stimulation was made within one ear by switching acoustic gain on/off. In our study, the comparison was performed between patients with hCIs and conventional CIs.

The mean long-term sound localization accuracy was similar in hCI, bilateral CI, and SSD patients. We have shown earlier that sound localization improved statistically significantly after sequential bilateral cochlear implantation and when the deaf ears of patients with SSD were implanted. The mean EI score decreased from 0.73 to 0.31 after the second CI and from 0.94 to 0.31 in the SSD patients [1, 2]. Unfortunately, preoperative sound

localization scores were not available for the hCI patients. However, in two patients with bilateral hCIs, the sound localization was tested before the second implant. One patient had normal localization accuracy before and after the surgery. The other patient's preoperative EI was 0.42 with a contralateral HA and 0.22 with two hCIs without acoustic stimulation. In severe uni- or bilateral hearing impairment, moderately good sound localization can only be achieved by cochlear implantation(s) that enhances binaural hearing.

There is always a risk with cochlear implantation that residual hearing will disappear partially or entirely. The new shorter electrode designs and soft surgery techniques aim at good long-term preservation of residual hearing. It is probable that the shorter the electrode, the less is the risk for hearing loss. Jurawitz et al. have shown that residual hearing was preserved for the majority of the 197 implanted patients with the Hybrid L24 and the CI422 implant [12]. Patients implanted with the Hybrid L24 implant demonstrated greater stability and less median hearing loss over time than those with the CI422 implant. Talbot et al. have shown that 13% of hCI patients had a total loss of residual low-frequency hearing after the implantation [5]. All our patients had good hearing preservation with the Hybrid L24 implant immediately after the surgery. During the 3.6-year follow-up, the mean hearing threshold at 125–500 Hz decreased on average by 15 dB HL in the implanted ear and 10 dB HL in the non-implanted ear. At 500 Hz, the mean decrease was 19 dB HL in both ears. Interestingly, Wiley et al. [13] have calculated the rate of change in hearing thresholds for 48- to 59-year-old healthy men to be approximately 0.4 dB per year at 500 Hz. The more rapid hearing deterioration in our patients clearly exceeds Wiley's findings and probably results from the initial surgical trauma and/or unknown etiological factors.

This study confirms the clinical observations that cochlear implantation improves quality of life, quality of hearing, and working performance in patients with severe sensorineural high-frequency hearing loss, and the results are comparable with patients with single-sided deafness and those with bilateral implants. Furthermore, good speech perception and sound localization cannot be achieved with unilateral CI only. Due to the small number of patients and large variation, for example, in duration of deafness, the duration of CI experience, and cause of deafness among the patients, it is difficult to create matched pairs for comparison. Therefore, our results may reflect individual experience and performance, and outcomes may not be directly derived from the CI treatment option. To uncover these differences, larger multi-center studies are needed.

Compliance with ethical standards

Conflict of interest The authors have no funding, financial relationships, or conflicts of interest to disclose.

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Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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