

Review

Safety and outcomes of cochlear implantation in the elderly: A review of recent literature

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Abstract

Global demographic changes related to longevity are leading to increasing numbers of the elderly, for whom hearing loss is a significant cause of morbidity and disability. Once met with reticence, severely hearing impaired older adults are increasingly being considered for cochlear implantation (CI). Significant data indicate that CI in the elderly population is safe, well-tolerated, and effective. Risks from CI surgery and anesthesia are low and generally comparable to rates in other age groups. Outcomes studies regarding CI in older adults have shown excellent improvements to speech perception, quality of life, and even cognition. Overall, currently available data suggests that advanced age should not, in itself, be considered a barrier to implantation. This review paper will highlight selected articles from recent medical literature regarding the safety and efficacy of CI in the elderly population.

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Keywords: Cochlear implants; Elderly; Hearing loss; Safety; Efficacy

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1. Introduction

1.1. Epidemiology

The global prevalence and impact of hearing loss on health and function is becoming increasingly recognized. According to the World Health Organization, hearing impairment is the third-highest cause of years lived with disability (YLD) in adults worldwide (Cruikshanks et al., 2003). This is a particularly crucial health concern for the geriatric population. Incidence of hearing loss increases with age, with more than 70% of adults older than 75 experiencing some degree of loss (Cruikshanks et al., 2003; Sprinzl and Riechelmann, 2010). Many of these individuals experience hearing loss too severe to be adequately treated with conventional amplification or hearing aids. Individuals with severe to profound sensorineural hearing loss (SNHL) are candidates for cochlear implantation (CI).

Unlike a hearing aid, a CI bypasses the inner hair cells through a surgically implanted intra-cochlear electrode and provides electric signals directly to the spiral ganglion cells of the cochlear nerve. Sound perception with CI requires the remainder of the auditory pathway, from the spiral ganglion cells to the auditory cortex, to be intact and uncompromised. Age-related degeneration of the peripheral and central auditory pathways, long-term auditory deprivation, cognition, and neural plasticity were once considered barriers to implantation in this population, but are now areas of active, multidisciplinary investigation. Robust data are now available to calm historical concerns over peri-operative morbidity in older adults and suggest that CI candidacy evaluation in elderly hearing-impaired patients should not depend on age alone. Reports in the United States indicate that only 5–10% of adult CI candidates receive implants, thereby underscoring the need for greater understanding of the barriers to, and benefits of, CI in this population (Sorkin, 2013).

This paper will review the data from recent literature on cochlear implantation in the elderly population. Recent data on the negative effects on hearing loss in older adults and the potential mitigating impact of CI will be reviewed. Issues of peri-operative safety, specifically surgical and anesthetic-related complications, will be addressed. Finally, available literature examining post-CI outcomes in this population, including speech understanding in quiet and noise, quality of life and cognition, are reviewed.

1.2. Significance

Historically, attitudes regarding treatment of the elderly with CI ranged from reluctant to cautiously optimistic for multiple reasons, many of which pertain to age-related changes in the auditory pathway. Cadaveric studies have demonstrated age-related effects on the peripheral auditory system, specifically, decreased spiral ganglion cell counts within the cochlea (Nadol et al., 1989). On a cellular level, the aging brain is associated with decreased synaptic density and dendritic cell numbers, which may have implications for neural plasticity (Dickstein

et al., 2007). Centrally, changes to neuron number and composition within the cochlear nuclei have been observed (Dickstein et al., 2007; Mahncke et al., 2006).

In addition to degradation of the peripheral and central auditory pathways, the overall cognitive decline associated with aging may have an impact on auditory processing in the elderly (Mahncke et al., 2006). Elderly patients with hearing loss may face unique issues related to listening effort and attention. Tun et al. (2009) suggest that older adults require additional effort and attention to achieve meaningful listening.

In recent years, a growing body of knowledge has formalized and quantified the negative effects of hearing loss on health and function. Hearing loss has been associated with lower quality of life (QOL), social isolation, depression, personality changes, and reduced functional status (Mulrow et al., 1990; Carabellese et al., 1993; Cacciatore et al., 1999). In addition, recent data underscore the relationship between hearing loss and age-related cognitive decline. Lin et al. (2011) found that hearing loss is independently associated with higher rates of dementia in the elderly. A cohort of 639 older adults without dementia was followed prospectively, and those with hearing loss were more likely to develop dementia. Additionally, the incidence of dementia increased proportionately to the degree of hearing loss, with nearly five times higher rates of dementia in elderly patients with severe hearing loss when compared to those with normal hearing (Lin et al., 2011). In a separate study, Lin (2011) showed an association between hearing loss and cognitive decline in another large cohort of elderly patients. Of 605 patients, those with poor hearing performed worse on the Digit Symbol Substitution Test (DSST), a test of cognitive function. In this study, auditory rehabilitation using traditional amplification (hearing aids) was associated with better DSST performance (Lin, 2011). While a complete discussion of outcomes with traditional amplification is outside this review, data suggests that use of hearing aids can have significant effects on the lives of older adults. For individuals who not receive adequate rehabilitation from hearing aids, a cochlear implant may be considered. Interventions for hearing loss, such as cochlear implantation, have the potential to mitigate the widespread impact of hearing loss in this population. Available literature on the impact of cochlear implantation in older adults is reviewed in detail below.

2. Safety

2.1. Complications

Examination of the safety profile of CI and peri-operative morbidity is imperative when considering implantation in the elderly, who have more comorbidities and inherently poorer outcomes with many surgical treatments than younger adults. Multiple studies have shown that CI in the elderly population is well-tolerated and that risks of major and minor surgical complications are equivalent with rates in younger adults (Wong et al., 2016; Chen et al., 2013; Roberts et al., 2013; Carlson et al., 2010; Schwab et al., 2015).

Major complications of CI include meningitis, permanent post-operative facial nerve paralysis, device failure, flap dehiscence or wound breakdown, implant migration, or extracochlear insertion (Wong et al., 2016; Chen et al., 2013). Minor complications include dizziness or imbalance, temporary facial nerve palsy, facial nerve stimulation, tinnitus, and dysgeusia. None of the major or minor complications listed are unique to elderly patients. Roughly 5% of older CI patients experience a major complication, and minor complications total to 9.2%–16.7% (Wong et al., 2016; Chen et al., 2013). While a discussion of peri-operative complications, overall, is beyond the scope of this review, these rates are comparable to the available literature in younger aged patients (Wong et al., 2016; Chen et al., 2013; Roberts et al., 2013; Carlson et al., 2010; Schwab et al., 2015). The most common post-operative surgical complication of CI is dizziness, imbalance, or vertigo, which occurs in up to 20% of all patients regardless of age and is usually transient (Wong et al., 2016; Roberts et al., 2013; Carlson et al., 2010). Chen et al. (2013) have suggested that increased rates of cognitive decline and neurologic impairment may predispose the elderly to greater risk of post-operative imbalance. In their retrospective cohort of 445 patients older than 60 at a single institution, 3.8% (n = 17) required implant removal for reasons such as nonuse or secondary to other major complications, such as infection, device failure, and flap dehiscence. Of these patients, 88.2% underwent subsequent re-implantation. At 5 and 10 years post-implantation, 95.4% and 93.1% of all elderly CI patients retained their original implant, respectively (Chen et al., 2013).

Thinning skin and decreased vascularization with age have made flap surveillance a concern in the elderly. Spitzer et al. (2013) found that 13% of elderly CI patients experience flap thinning over long-term follow up, although this is rarely significant enough to require implant removal. Meningitis in the post-surgical CI patient is rare and compliance with CI vaccination protocols, specifically against *Streptococcus pneumoniae*, is crucial at all ages (Wei et al., 2010).

2.2. Risk of anesthesia

General anesthesia for CI is well tolerated and carries a low risk of complications, even within the elderly population. In a retrospective cohort of 70 patients over the age of 70 undergoing CI, Coelho et al. (2009) demonstrated that increased age alone does not confer an increased risk of anesthesia. Instead, overall medical well-being and physical status as measured by American Society of Anesthesiologists (ASA) classification is more strongly associated with risk due to anesthesia in patients receiving CI. Patients who are ASA class I or II have significantly fewer post-operative complications of anesthesia when compared with patients who are ASA class III or IV. Such complications include delayed extubation, post-operative transient congestive heart failure, and urinary retention, which in their study occurred in 12% of patients who were ASA class III and IV. These patients were also more likely to require intraoperative vasopressors. However, CI is still well

tolerated in both cohorts, as no patients developed long-term morbidity or mortality secondary to complications of anesthesia (Coelho et al., 2009).

Other data have indicated that age alone is associated with increased risk of peri-operative anesthetic complications. Carlson et al. (2010) found in their study of 232 CI patients that patients older than 80 were more likely than younger adults to have cerebrovascular events (4%, n = 2) and cardiac arrhythmia (4%, n = 2) secondary to anesthesia. Eshraghi et al. (2009) found no permanent complications in their cohort of 21 elderly CI patients, though one patient developed peri-operative urinary retention and another had acute delirium. Both were temporary. Overall, these complications are uncommon, occurring in less than 5% of patients, indicating that overall risk of anesthesia is still low in geriatric patients (Carlson et al., 2010).

For individuals deemed unfit for general anesthesia, cochlear implantation under local anesthesia (LA) with conscious sedation may be considered. While this has not been specifically evaluated in an elderly cohort, the few published reports on this technique have included some elderly patients. Toner et al. (2013) reported on 16 patients aged 29–92 years (mean 68 years) who underwent successful, uncomplicated unilateral CI under LA with intravenous sedation. Using an anesthesia risk assessment scale (Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity or POSSUM), the authors retrospectively calculate the preoperative POSSUM score of each patient and compare it to post-operative scores (Toner et al., 2013). Although specific peri-operative complications are not reported, the authors suggest that LA avoided a 9% mortality as predicted by the pre-operative POSSUM scale (Toner et al., 2013). More recently, Pateron et al. (2016) compared 20 patients implanted under LA (average age 69.5 years, range 36–87 years) with a 40 individuals implanted under general anesthesia (average age 59.1, 31–82 years). There were no significant differences in peri-operative morbidity between groups. Mean surgical time was less in the LA group, however 40% of LA patients reported intra-operative vertigo and pain (Pateron et al., 2016). Age as an independent variable was not examined in either of the above reports on LA.

3. Outcomes

3.1. Speech perception

Multiple studies have examined speech perception outcomes in elderly CI recipients by comparing their performance to younger adults. These results vary, with some showing that improvements seen in older adults are similar to that of other age groups (Wong et al., 2016; Carlson et al., 2010; Schwab et al., 2015; Dillon et al., 2015; Djalilian et al., 2002; Hast et al., 2015; Lenarz et al., 2012; Olze et al., 2012; Zwolan et al., 2014). Other findings are contradictory, indicating that the geriatric population has a less or slower improvement to speech understanding following CI (Roberts et al., 2013; Budenz et al., 2011; Friedland et al., 2010; Vermeire et al., 2005).

Budenz et al. (2011) have suggested that differences in speech perception improvement between older and younger adults following CI are confounded by duration of deafness, which negatively affects improvement to speech perception. Duration of deafness is a well-established predictor of post-implantation speech understanding and is often directly correlated with age at implantation. Specifically, implanted older patients have likely experienced longer durations of hearing loss prior to receiving CI, both as a function of age and as a result of historic reticence to implantation in elderly individuals. In their comparison between adult CI patients older and younger than 70, older patients did not perform as well at 2-year post-implantation follow-up as their younger counterparts in City University of New York sentence (CUNY) test and Consonant-Nucleus-Consonant word (CNCw) and phoneme (CNCp) scores. This difference was no longer sustained after controlling for duration of deafness, suggesting that duration of deafness, and not age alone, may account for differences in improvement to speech perception following CI (Budenz et al., 2011). In an attempt to address the confounding relationship between duration of deafness and age at implantation, Schwab et al. (2015) retrospectively compared speech understanding in 119 patients implanted between ages 21–64 years (mean age 46 years) and 121 patients over the age of 65 years (mean age 72 years, range 65–88 years.). Using CNC words presented in quiet, they found no difference in speech perception at 3, 12 or 24 months post-operatively. A very weak correlation was found between age, duration of deafness and CNCw at 24 months (multiple regression coefficient of 0.27), with no relationship at the other time points (Schwab et al., 2015).

Others have suggested additional considerations impacting performance in this age group. Roberts et al. (2013) found that differences in speech perception became particularly pronounced in patients older than 80, with elderly patients obtaining outcomes equivalent to younger adults up to that age. Specifically, they found that CI patients older than 65 did not perform as well on CNC scores. However, when stratified by decade of life at implantation, only patients in their 80s performed significantly poorer. In their study of more than 1000 CI recipients, Lenarz et al. (2012) found that all age groups had equivalent outcomes in multiple speech perception tests, including the Freiburger Monosyllabic Test, Speech Tracking Test, and Hochmair–Schulz–Moser Test (HSM) in quiet. However, older patients performed worse with HSM testing in noise (Lenarz et al., 2012).

Explanations for the observed age-related decline in speech understanding in complex listening situations, such as hearing in noise, are multi-fold and deserve further study. Some authors have suggested that speech perception in noise requires greater cognitive complexity, which may favor younger patients (Lenarz et al., 2012; Wong et al., 2010). Studies on hearing preservation and electro-acoustic stimulation (EAS) suggest that hearing in noise is improved when there is preservation of residual hearing. In these cases, an intracochlear electrode is partially or atraumatically inserted into the basal turn of the cochlea without damaging the apical

cochlear architecture. Post-operatively, these patients utilize both electrical stimulation through the CI electrode (for amplification of high-frequency in the basal cochlea) and acoustic amplification for the preserved lower frequencies in the apex. While no studies have specifically examined EAS in an elderly cohort, data have suggested the hearing preservation may be affected by age at implantation (Anagnostos et al., 2015). Future studies may allow a better understanding of the relationship between age, hearing preservation, and hearing in noise.

Most of the aforementioned studies comparing post-implantation speech understanding between older and younger adults are retrospective and limited to single institutions. Many studies used different age criteria, varying lengths of follow-up, and a mixture of speech perception tests, which may partially explain differences in findings. Regardless, all studies agree that elderly CI recipients demonstrate significant gains in speech understanding following CI.

Elderly patients continue to benefit from CI during long-term use. Dillon et al. (2013) showed that speech perception in geriatric patients continues to improve for up to five years following CI. CNCw and Hearing in Noise Test (HINT) sentence scores increase significantly from the one year to five year marks following CI in patients older than 65, then subsequently plateau and remain stable between five and ten years (Dillon et al., 2013). The persistent benefit of CI is further illustrated by the longevity of device usage in the implanted elderly. Over 90% of CI patients implanted between 60 and 74 years of age are users for over 8 h per day, even at 13.5 years following implantation (Choi et al., 2014). In elderly CI patients who are not regularly compliant with device usage, poor hearing benefit, pain or discomfort, and lack of daily necessity are leading reasons for non-use.

3.2. Quality of life (QOL)

CI has been shown to significantly improve health-related QOL in elderly CI patients. This has been validated using both general and disease-specific measurement scales, including the Medical Outcome Study 36 Short Form (SF36), Glasgow Benefit Inventory (GBI), Hearing Handicap Index for Adults (HHIA), and Nijmegen Cochlear Implant Questionnaire (NCIQ) (Olze et al., 2012; Vermeire et al., 2005; Cloutier et al., 2014). QOL improvements are long lasting, and the degree of increase to QOL is often associated with the amount of improvement in speech perception (Mosnier et al., 2015).

The GBI is a scale designed for otolaryngology procedures ranging from –100 to +100, where +100 represents the best possible QOL outcome following an intervention (Robinson et al., 1996). CI has been shown to have a GBI of +35.2 to +37.5 in the elderly, which is similar to post-implantation QOL benefits seen in other age groups (Vermeire et al., 2005; Cloutier et al., 2014; Robinson et al., 1996). In one study, 40% of returned GBI questionnaires were accompanied by unsolicited, personalized letters expressing gratitude from elderly patients and patient families for their QOL improvements secondary to CI (Cloutier et al., 2014).

Vermeire et al. (2005) found a significant improvement to HHIA in the elderly following CI, with no effect of age on the degree of improvement. Olze et al. (2012) have also shown that CI improves disease-specific QOL in elderly patients, as measured by the NCIQ. Specifically, elderly patients have benefits to speech production, self-esteem, activity, and social interaction to an even greater extent than in younger patients. In this study, CI also improved tinnitus and perceived stress, as well as social and psychological health as measured by the SF36 survey (Olze et al., 2012).

3.3. Cognition

As previously discussed, hearing loss in the elderly is associated with higher rates of dementia and faster cognitive decline (Lin et al., 2011; Lin, 2011). Recent data have suggested that this trend may be influenced by CI. In a multi-institutional study, Mosnier et al. (2015) prospectively examined 94 patients between 65 and 85 years old and assessed for cognitive function prior to CI and at multiple follow up intervals. Using a battery of cognitive testing, the average cognitive performance of all patients improved at 6 months following CI. In patients with poorer cognitive performance prior to implantation, 81% had improvement to cognitive scores at 1 year following CI and none worsened. Additionally, the proportion of elderly patients with depression within this cohort decreased significantly, with an absolute reduction of 17% at 1 year following implantation (Mosnier et al., 2015).

Cosetti et al. (accepted, 2016) found similar evidence of improved cognitive function following CI in a longitudinal study of 7 elderly females. These patients underwent a comprehensive neurocognitive battery prior to implantation and then again 2–4 years following CI. The neurocognitive assessment included 20 tests over a variety of domains, including intellectual function, learning, short and long term memory, verbal fluency, attention, mental flexibility, and processing speed. Speech perception, as measured by CNCw, was performed pre-operatively and at regular intervals post-operatively. Improvements after CI were observed in 14 (70%) of all subtests administered. Overall, improvements were largest in the verbal and memory domains. Linear regression demonstrated a significant relationship between speech perception and cognitive function over time. Five neurocognitive tests were predictive of improved speech perception following implantation (Cosetti et al., 2016).

While the underlying mechanisms for cognitive improvement following CI remain an active area of current investigation, there are data to suggest that changes may be mediated by some degree of neural plasticity. Modification of neural response patterns and cortical re-organization of the central auditory system have been shown in both animals and humans following peripheral electrical stimulation with CI (Fallon et al., 2008; Petersen et al., 2013). Improvement following auditory training in hearing impaired older adults appears to provide evidence for neural plasticity, even in the aging brain (Anderson and Kraus, 2013). In addition, post-implantation

improvements in speech perception over time, as detailed above, provide additional clinical evidence for neural plasticity in this population.

4. Conclusion

CI is a safe, well-tolerated, and effective treatment for geriatric patients with hearing loss, when satisfactory audiologic outcomes cannot be achieved with hearing aids. Risks from CI surgery and anesthesia are low and generally comparable to rates in other age groups. Outcomes studies examining CI in older adults have shown excellent improvements to speech perception, often equivalent to benefits gained in younger patients, especially in quiet. Despite a large bulk of data on CI in older adults, many issues remain unresolved and are ripe for further study. For example, future research is needed to better understand elderly CI speech perception in noise and the potential for electro-acoustic stimulation in this population. Relationships between aging, cognition, hearing loss and cochlear implantation have just begun to emerge in present literature and deserve further investigation. Given the vast potential for improvement to hearing, quality of life, and potentially even cognition that CI offers in elderly hearing impaired individuals, it is clear that age alone should not be considered a barrier to implantation.

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References

- Anagiotos, A., Hamdan, N., Lang-Roth, R., et al., 2015. Young age is a positive prognostic factor for residual hearing preservation in conventional cochlear implantation. *Otol. Neurotol.* 36, 28–33.
- Anderson, S., Kraus, N., 2013. Auditory training: evidence for neural plasticity in older adults. *Perspect. Hear. Hear. Disord. Res. Res. Diagnostics* 17, 37–57.
- Budenz, C.L., Cosetti, M.K., Coelho, D.H., et al., 2011. The effects of cochlear implantation on speech perception in older adults. *J. Am. Geriatr. Soc.* 59, 446–453.
- Cacciatore, F., Napoli, C., Abete, P., Marciano, E., Triassi, M., Rengo, F., 1999. Quality of life determinants and hearing function in an elderly population: osservatorio Geriatrico Campano Study Group. *Gerontology* 45, 323–328.
- Carabellese, C., Appollonio, I., Rozzini, R., et al., 1993. Sensory impairment and quality of life in a community elderly population. *J. Am. Geriatr. Soc.* 41, 401–407.
- Carlson, M.L., Breen, J.T., Gifford, R.H., et al., 2010. Cochlear implantation in the octogenarian and nonagenarian. *Otol. Neurotol.* 31, 1343–1349.
- Chen, D.S., Clarrett, D.M., Li, L., Bowditch, S.P., Niparko, J.K., Lin, F.R., 2013. Cochlear implantation in older adults: long-term analysis of

- complications and device survival in a consecutive series. *Otol. Neurotol.* 34, 1272–1277.
- Choi, J.S., Contrera, K.J., Betz, J.F., Blake, C.R., Niparko, J.K., Lin, F.R., 2014. Long-term use of cochlear implants in older adults: results from a large consecutive case series. *Otol. Neurotol.* 35, 815–820.
- Cloutier, F., Bussières, R., Ferron, P., Cote, M., 2014. OCTO “Outcomes of cochlear implant for the octogenarians: audiologic and quality-of-life. *Otol. Neurotol.* 35, 22–28.
- Coelho, D.H., Yeh, J., Kim, J.T., Lalwani, A.K., 2009. Cochlear implantation is associated with minimal anesthetic risk in the elderly. *Laryngoscope* 119, 355–358.
- Cosetti, M.K., Pinkston, J.B., Flores, J.M., Friedmann, D.R., Jones, C.B., Roland, J.T., Waltzman, S.B., 2016. Neurocognitive testing and cochlear implantation: insights into performance in older adults. *Clin. Interv. Aging* 11, 1–11.
- Cruikshanks, K.J., Tweed, T.S., Wiley, T.L., et al., 2003. The 5-year incidence and progression of hearing loss: the epidemiology of hearing loss study. *Arch. Otolaryngol. Head. Neck Surg.* 129, 1041–1046.
- Dickstein, D.L., Kabaso, D., Rocher, A.B., Luebke, J.I., Wearne, S.L., Hof, P.R., 2007. Changes in the structural complexity of the aged brain. *Aging Cell* 6, 275–284.
- Dillon, M.T., Buss, E., Adunka, M.C., et al., 2013. Long-term speech perception in elderly cochlear implant users. *JAMA Otolaryngol. Head. Neck Surg.* 139, 279–283.
- Dillon, M.T., Adunka, O.F., Anderson, M.L., et al., 2015. Influence of age at revision cochlear implantation on speech perception outcomes. *JAMA Otolaryngol. Head. Neck Surg.* 141, 219–224.
- Djalilian, H.R., King, T.A., Smith, S.L., Levine, S.C., 2002. Cochlear implantation in the elderly: results and quality-of-life assessment. *Ann. Otol. Rhinol. Laryngol.* 111, 890–895.
- Eshraghi, A.A., Rodriguez, M., Balkany, T.J., et al., 2009. Cochlear implant surgery in patients more than seventy-nine years old. *Laryngoscope* 119, 1180–1183.
- Fallon, J.B., Irvine, D.R., Shepherd, R.K., 2008. Cochlear implants and brain plasticity. *Hear. Res.* 238, 110–117.
- Friedland, D.R., Runge-Samuels, C., Baig, H., Jensen, J., 2010. Case-control analysis of cochlear implant performance in elderly patients. *Arch. Otolaryngol. Head. Neck Surg.* 136, 432–438.
- Hast, A., Schlucker, L., Digeser, F., Liebscher, T., Hoppe, U., 2015. Speech perception of elderly cochlear implant users under different noise conditions. *Otol. Neurotol.* 36, 1638–1643.
- Lenarz, M., Sonmez, H., Joseph, G., Buchner, A., Lenarz, T., 2012. Cochlear implant performance in geriatric patients. *Laryngoscope* 122, 1361–1365.
- Lin, F.R., 2011. Hearing loss and cognition among older adults in the United States. *J. Gerontol. A Biol. Sci. Med. Sci.* 66, 1131–1136.
- Lin, F.R., Metter, E.J., O'Brien, R.J., Resnick, S.M., Zonderman, A.B., Ferrucci, L., 2011. Hearing loss and incident dementia. *Arch. Neurol.* 68, 214–220.
- Mahncke, H.W., Bronstone, A., Merzenich, M.M., 2006. Brain plasticity and functional losses in the aged: scientific bases for a novel intervention. *Prog. Brain Res.* 157, 81–109.
- Mosnier, I., Bebear, J.P., Marx, M., et al., 2015. Improvement of cognitive function after cochlear implantation in elderly patients. *JAMA Otolaryngol. Head. Neck Surg.* 141, 442–450.
- Mulrow, C.D., Aguilar, C., Endicott, J.E., et al., 1990. Association between hearing impairment and the quality of life of elderly individuals. *J. Am. Geriatr. Soc.* 38, 45–50.
- Nadol Jr., J.B., Young, Y.S., Glynn, R.J., 1989. Survival of spiral ganglion cells in profound sensorineural hearing loss: implications for cochlear implantation. *Ann. Otol. Rhinol. Laryngol.* 98, 411–416.
- Olze, H., Grabel, S., Forster, U., et al., 2012. Elderly patients benefit from cochlear implantation regarding auditory rehabilitation, quality of life, tinnitus, and stress. *Laryngoscope* 122, 196–203.
- Pateron, B., Bakhos, D., LeLouarn, A., et al., 2016. Local anaesthesia and conscious sedation for cochlear implantation: experience with 20 patients. *J. Laryngol. Otol.* 130, 151–156.
- Petersen, B., Gjedde, A., Wallentin, M., Vuust, P., 2013. Cortical plasticity after cochlear implantation. *Neural plast.* 2013, 318521.
- Roberts, D.S., Lin, H.W., Herrmann, B.S., Lee, D.J., 2013. Differential cochlear implant outcomes in older adults. *Laryngoscope* 123, 1952–1956.
- Robinson, K., Gatehouse, S., Browning, G.G., 1996. Measuring patient benefit from otorhinolaryngological surgery and therapy. *Ann. Otol. Rhinol. Laryngol.* 105, 415–422.
- Schwab, B., Gandolfi, M., Lai, E., Reilly, E., Singer, L., Kim, A.H., 2015. The impact of age on cochlear implant performance. *Int. J. Otolaryngol. Head Neck Surg.* 4, 329–337.
- Sorkin, D.L., 2013. Cochlear implantation in the world's largest medical device market: utilization and awareness of cochlear implants in the United States. *Cochlear Implants Int.* 14 (Suppl 1), S4–S12.
- Spitzer, J.B., Cellum, I.P., Bosworth, C., 2013. Stability of audiometric measures and challenges in long-term management of the elderly cochlear implant patient. *Otol. Neurotol.* 34, 1636–1641.
- Sprinzi, G.M., Riechelmann, H., 2010. Current trends in treating hearing loss in elderly people: a review of the technology and treatment options - a mini-review. *Gerontology* 56, 351–358.
- Toner, F., Jackson, C.P., Toner, J.G., 2013. How we do it: local anaesthetic cochlear implantation. *Cochlear Implants Int.* 14, 232–235.
- Tun, P.A., McCoy, S., Wingfield, A., 2009. Aging, hearing acuity, and the attentional costs of effortful listening. *Psychol. Aging* 24, 761–766.
- Vermeire, K., Brox, J.P., Wuyts, F.L., Cochet, E., Hofkens, A., Van de Heyning, P.H., 2005. Quality-of-life benefit from cochlear implantation in the elderly. *Otol. Neurotol.* 26, 188–195.
- Wei, B.P., Shepherd, R.K., Robins-Browne, R.M., Clark, G.M., O'Leary, S.J., 2010. Pneumococcal meningitis post-cochlear implantation: preventative measures. *Otolaryngol. Head. Neck Surg.* 143, S9–S14.
- Wong, P.C., Ettlinger, M., Sheppard, J.P., Gunasekera, G.M., Dhar, S., 2010. Neuroanatomical characteristics and speech perception in noise in older adults. *Ear Hear* 31, 471–479.
- Wong, D.J., Moran, M., O'Leary, S.J., 2016. Outcomes after cochlear implantation in the very elderly. *Otol. Neurotol.* 37, 46–51.
- Zwolan, T.A., Henion, K., Segel, P., Runge, C., 2014. The role of age on cochlear implant performance, use, and health utility: a multicenter clinical trial. *Otol. Neurotol.* 35, 1560–1568.