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Review Article

Intracochlear electrode insertion of cochlear implant: a scoping review

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ABSTRACT

Cochlear implant currently shows remarkable speech understanding performance despite use of non-optimized coding strategies for transmission of tonal information. Certain features of cochlear implant electrode arrays enable the preservation of intracochlear structures when the devices are inserted into the scala tympani. The standard location for insertion of electrode of cochlear implant is into the scala tympani. The failure of insertion of the electrode into scala tympani has been seen in clinical practice. Minimal or no insertion trauma, deep insertion to the apex of the scala tympani is possible using recently developed flexible long straight electrodes. Misplacement of cochlear implant electrode array is considered as a major complication during cochlear implantation. If there is any malformed cochlea, it needs to be diagnosed, and the right electrodes should be selected for each individual cochlea. The aim of this review article is to discuss on the current knowledge about the intracochlear electrode insertion of cochlear implant.

Keywords: Cochlear implant, Electrode array, Scala tympani, Electrode insertion

INTRODUCTION

Patients with bilateral profound sensorineural hearing loss are being treated with cochlear implantation.[1] With the expansion of cochlear implantation indications to include younger patients and those with greater residual hearing, atraumatic surgery and intracochlear structure preservation have become more important.[2] An advanced implantable device that aids in the restoration of functional hearing is a cochlear implant (CI). Since the CI's electrodes make direct touch with the intra-cochlear tissues that surround the neuronal components, they are a crucial part.[3]

Along a significant part of the cochlear length, the electrode electrically stimulates neuronal components like spiral ganglion cells.[4] Neural stimulations at specific points along the spiral ganglion's length, spanning a variety of tonotopically arranged positions, aid in the production of place-pitch spectral signals that are crucial for speech recognition.[5] The electrode array is typically inserted into the scala tympani via the round window or a small cochleostomy made nearby, using a proper surgical technique that reduces the intracochlear injury. The electrode insertion is an important step in the CI surgery for giving maximum outcome to the patients for hearing and speech.[5] The suboptimal electrode placement may compromise the outcome of the cochlear implantation. Placing all of the stimulating contacts inside the cochlea without inflicting any kind of intracochlear damage is the goal of electrode placement.

METHODS OF LITERATURE SEARCH

Different systematic approaches were employed to locate recent research articles on the intracochlear electrode insertion in cochlear implants. Online search was done across the Scopus, PubMed, Medline, and Google Scholar databases. In addition to searching other papers through citation references, our search strategy focused on identifying the abstracts of published studies. PRISMA (preferred reporting items for systematic reviews and meta-analysis) criteria were used to design a search strategy. The eligibility of randomized controlled trials, observational studies, comparative studies, case series, and case reports was evaluated. There were a total number of articles 52 (15 case reports, 18 cases series, 19 original articles) (Figure 1). This paper focuses only on the intracochlear electrode insertion of cochlear implant. The search articles other than intracochlear electrode insertion of cochlear implant are excluded from this review article. Review articles with no primary research data were also excluded. This paper examines the prevalence, anatomical perspectives, electrode array design, principles of electrode insertion, types of electrodes, complications of electrode insertion, and atraumatic way of electrode insertion during cochlear implant surgery. This analysis provides a foundation for future prospective trials for the intracochlear electrode insertion of cochlear implant. It will also catalyze additional studies of intracochlear electrode insertion of cochlear implant.

PREVALENCE

The prevalence of permanent bilateral childhood hearing loss (>40 dB Hl) ranges from 1 to 1.2 per 1000 for newborns and increases to 1.62 to 1.68 per 1000 at the age of 16.[6] The newborns with bilateral hearing loss, 25 to 30% have a profound hearing loss (>90 dB Hl) and 20 to 25% a severe hearing loss (71 to 90 dB Hl).[7] Cochlear implantation is the choice of surgery for bilateral profound hearing loss. A cochlear implant is an implantable medical device that is helpful to restore the hearing functionality. The insertion of the cochlear implant is an important part of the surgery that affect the hearing outcome of the patient. The electrode of cochlear implant malposition has been considered as the cause for cochlear implant revision in up to 13% to 16% cases.[8] In majority of cases, there is intracochlear malposition in case of dysplastic cochleae or cochlear ossification. The true incidence of electrode misplacement into extracochlear sites is unknown.

ANATOMICAL PERSPECTIVES FOR ELECTRODE INSERTION

The electrode array of the cochlear implant is designed to be positioned along the length of the scala tympani as it provides a close proximity to the spiral ganglion cells along the Rosenthal's canal.[9] Scala tympani insertion reduces the intracochlear trauma and so widely acceptable as preferred site for electrode placement.[10] In contrast, the electrode array insertion that translocate into site other than scala tympani such as scala vestibuli are associated with injury to the basilar membrane, Reissner's membrane, and organ of corti.[11]

There are many factors that has impact on scalar electrode placement. Electrode design is seen as an important factor, with lateral wall electrodes entering scala vestibuli less commonly than peri-modiolar electrodes.[12] The surgical approach also influences scalar position of electrode. The round window and extended round window insertions are often associated with lower chance of scala vestibuli insertion in comparison to cochleostomy insertions.[13] The cochlear size also influences the intracochlear electrode insertion. As cochlear morphology is variable, it follows that smaller volume cochlea and/or greater depth of electrode insertion may cause interscalar electrode translocation. The maintenance of the residual hearing has been shown to be better among patients with electrodes placed completely within the scala tympani (Figure 2).[14] The deeper insertion of the electrodes has impact on the scalar position and intracochlear injury.

The deeper insertion of the electrodes may not cause increased chance of injury of the cochlea. The current clinical practice such as surgeons aim to prevent the electrodes from buckling by insertion and not further than the point of first resistance. A study showed that interscalar trans location into the scala vestibuli is associated with higher angular insertion depths for peri-modiolar electrodes inserted through cochleostomy approaches.[15] The misplacement of electrode array may be due to unidentified ear malformations such as possibility of anatomical variation of the basal turn of the cochlea. The preoperative radiographic examination should be done to avoid such complications.

Electrodes of cochlear implant

Straight lateral wall (LW) electrode arrays and pre-curved modiolar hugging (MH) electrode arrays are two types of electrodes of cochlear implant available commercially.[16] Another type of electrode array is the mid-scala (MS) electrode, which is placed in the center of the scala tympani and is commonly known as the MH type of electrode.[16] The section of the electrode array that contains all the stimulating channels is referred to as the active insertion or stimulation length.

This differs from the overall insertion length, which is measured from the tip of the electrode to the stopper marker. The distance between the most basal stimulating contact and the stopper is called the buffer length. When the electrode is fully inserted to the buffer length, it ensures that the stimulating currents remain entirely within the cochlea, allowing them to effectively stimulate the neural elements and preventing any pain sensation at the cochlea entrance. In some cases, however, the electrode may shift or extrude out of the cochlea after insertion.[17]

A flexible electrode, which applies less pressure on the intra-cochlear blood vessels, may enhance the likelihood of preserving hearing in the long term.[18] A still electrode may exert more pressure on the surrounding blood vessels, potentially restricting the blood supply to the neural elements extending into the apical region of the cochlea, where residual hearing is typically observed.[19] A larger electrode can occupy more space in the perilymph, leading to higher intra-cochlear pressure, depending on the speed at which the electrode is inserted into the cochlea.[20] However, a larger electrode array results in stimulating contacts being positioned closer to the neural elements, while a thinner electrode has the opposite effect. Therefore, a balance must be struck in determining the optimal distance between the stimulating contacts and the neural elements.

PRINCIPLES OF ELECTRODE INSERTION

The position of cochleostomy is important for atraumatic and optimal electrode placement of cochlear implant in the scala tympani.[21] The use of 1.5 mm or 1.0 mm diamond burr and removal of round window niche is helpful to get proper visualization of the round window membrane so correct estimation of cochleostomy location.[21] The ideal cochleostomy is usually inferior and slight anterior to the round window membrane. If the cochleostomy is placed in a more superior location, there is a risk of the electrode being inserted into the scala vestibuli and damage to the spiral ligament and basilar membrane.

On the down side, hypotympanic air cells may be misinterpreted as seeing a round window niche, which could lead to a disastrous misjudgment of the jugular bulb or a major misplacement of the electrode outside the cochlea entirely. It is impossible to overstate the significance of maximizing visibility through a well-made facial recess. When the cochlea's dome is properly drilled anteriorly and inferiorly to the round window membrane, it is saucerised till the scala tympani's endosteum is found.[22]

If blood and bone dust are present, they should be eliminated with careful suctioning and irrigation. A little pick or rasp is next used to carefully open the cochlear endosteum, revealing the scala tympani lumen.[23] Sharp edges can be removed with a little rasp, and if necessary, the cochleostomy can be widened until the outside wall of the basal turn is visible. Lubricants like sodium hyaluronate or 50% glycerine help ensure a smooth electrode insertion and stop blood and bone dust from getting in.[24]

Electrode array insertion depth

The insertion of electrode array of cochlear implant inside the cochlea depends on the length of cochlea accommodating the electrode.[25] A number of factors, such as the angle at which the round window opening is observed, intra-cochlear anatomical changes, or intracochlear obliteration, frequently make it impossible to fully insert the electrode array (Figure 2) inside the cochlea.[25] The insertion of electrodes into cochlea needs a significant amount of force to intracochlear structures. The amount of force required to penetrate the basilar membrane from scala tympani to scala vestibuli is 40 to 120 mN with an average value of 88 mN.[26] Such small forces can be challenging to detect during insertion. Therefore, pushing the electrode past the first significant resistance, where the electrode no longer moves further into the cochlea and causes basal buckling, is not recommended. However, with the assistance of pre-curved MH stylet electrodes, surgeons typically proceed to insert the electrode fully into the cochlea.

TYPES OF ELECTRODES

It may be difficult to achieve an ideal design of electrode because of several factors that require to achieve full benefits for cochlear implant users. Major cochlear implant manufacturers have their own electrode design for getting best hearing outcomes to the patients. In case of inexperienced cochlear implant surgeon, a smart electrode design is helpful to counter mistakes that are made by the surgeon and should aim to prevent the intracochlear structures.[27] Advanced bionics J electrode is usually inserted with an insertion tool provided by advanced bionics corporation (Sylmar, CA). The J electrode can be placed manually without tool using a claw or forceps if required in case of very narrow facial recess.[27] The contacts of the electrodes are on the modiolar (inner) surface only, and so, orientation of the electrodes towards the modiolus is needed.[27]

Better visibilities of the cochleostomy through the facial recess is made possible by the use of a thinner metal insertion tube. Before reattaching to the insertion tool and placing the electrode, it is necessary to remove it from the plastic tube it is stored in and reload it into the metal tube. The cochlear corporation K electrode is available on the Nucleus receiver stimulators (Cochlear Corp, Lane Cove, Australia). Using a claw instrument provided by the Cochlear Corporation, the electrode is placed into the scala tympani while the receiver stimulator is held in the nondominant hand.[28]

To ensure a smooth insertion, the receiver stimulator can be turned slightly clockwise on the left ear and counterclockwise on the right. An effort is made to fully insert the electrode without kinking or causing damage. 28 Access to the cochlea's speech frequency regions requires the implantation of all active electrodes as well as a minimum of five stiffening rings. The straight MED-EL electrode is inserted using modified alligator forceps or a claw.[29] On either side of this oval array are the active contact points.

Making a 1.2 mm diameter tunnel through the cochlear wall using a 1-mm diamond burr is a very practical way to perform a cochleostomy.[29] During the insertion, the electrode is supported by the tunnel walls. Of the electrodes that are currently on the market, this one is the longest. If at all possible, MED-EL advises complete insertion into the hub. In order to remain near the spiral ganglion cells in the modiolus, the peri-modiolar electrodes are made to self-coil either during or after insertion. This helps with intracochlear damage reduction, power consumption reduction, stimulation threshold reduction, and selective activation of spiral ganglion cells. Modiolar hugging electrodes result in minimal intracochlear damage, lowered evoked auditory brainstem response thresholds, and decreased evoked auditory brainstem response threshold latencies.[30]

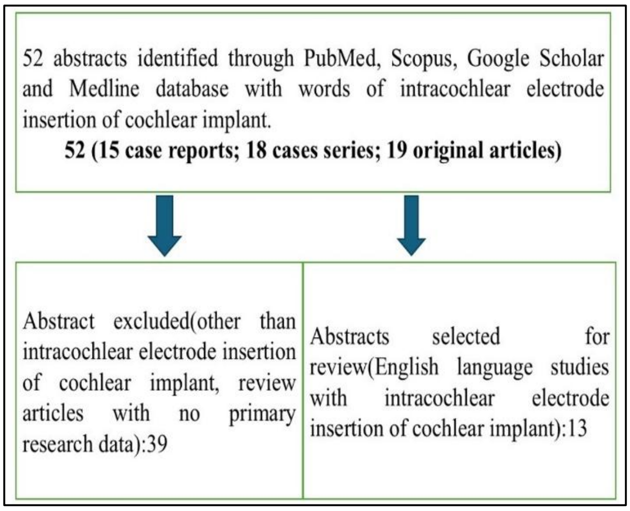

Figure 1: Method of literature search.

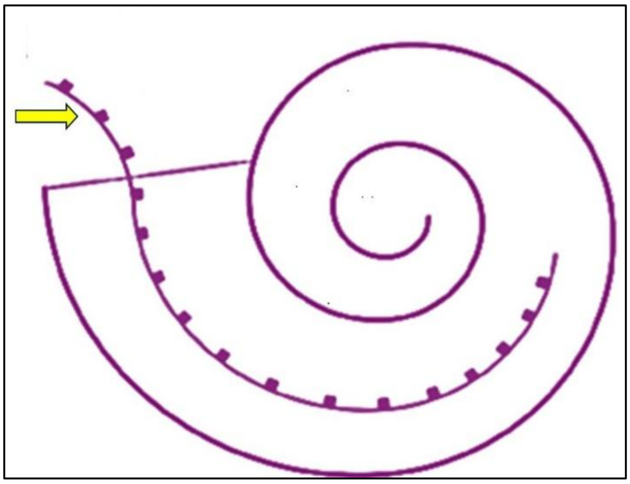

Figure 2: Line diagram showing complete insertion of the electrode array.

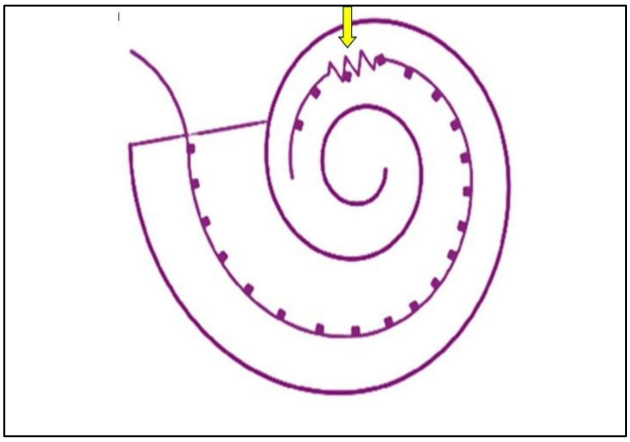

Figure 3: Line diagram showing kinking of the electrode array.

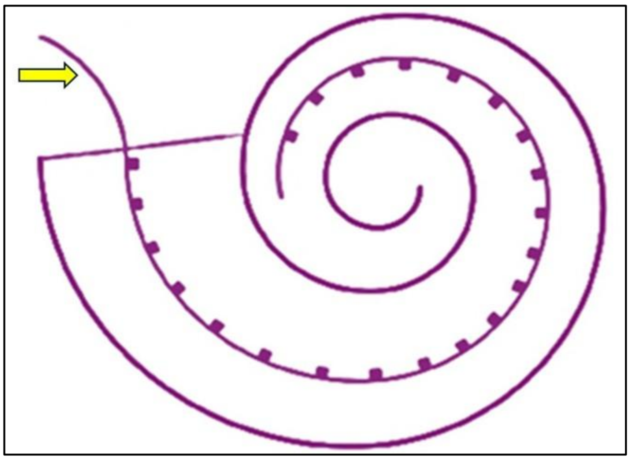

Figure 4: Line diagram showing electrode tip fold over.

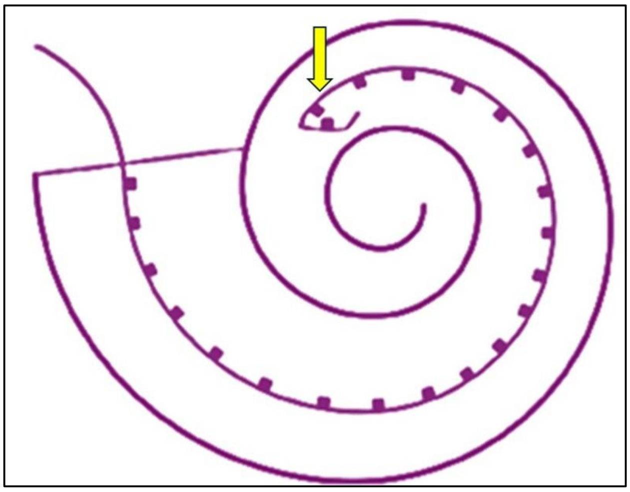

Figure 5: Line diagram showing incomplete insertion of electrode array.

COMPLICATIONS DURING ELECTRODE INSERTION

Electrode array extrusion, translocation of electrode from scala tympani to scala vestibuli, difficulties achieving complete or full insertion, not having electrode array homogenously positioned along lateral wall or modiolus wall, along with surgical difficulties are major complaints reported on the intra-cochlear electrode insertion.[31] During introduction of electrode in scala tympani, there are several anatomical regions prone for injury such as the modiolar wall, osseous spiral lamina, basilar membrane, lateral wall or spiral ligament, and neuroepithelium.[31]

Degeneration may ensue from disruption of spiral ganglion cells or their dendrites caused by direct trauma to the modiolar wall and osseous spiral lamina.[24] Sometimes, it may result in less-than-ideal electrode positioning in the upper cochlea's scala vestibuli or scala media. The scala tympani's outer wall often slopes upward, thus any force applied will be equivalent to the force perpendicular to the wall at the point of contact (less frictional forces). Histologically and fluoroscopically, this site is consistently seen in the lower midpars ascendens.[24] The resulting force vector may push the electrode out of the scala tympani to a last, less-than-ideal location in the upper cochlea as it travels superiorly towards the spiral ligament and basilar membrane.

The advance Off stylet (AOS) and peri-modiolar electrode are typically used for more dependable and less traumatic electrode insertion.[32] Partial insertions of the electrode may happen that is due to either intracochlear obstruction as in ossifications or fibrosis or from soft tissue friction or resistance during electrode insertion. Since the scala tympani diameter increases toward the base, there may be a greater probability of bending or kinking of the electrode array (Figure 3) if an electrode is put against resistance. This increases the risk of injury to the basilar membrane. Postoperative imaging can verify this. For many patients, slight electrode kinking has little effect.[33] If there is severe kinking, it may result in intracochlear trauma.

Another problem that can be detected in intra- or postoperative imaging is the fold over of the electrode tip (Figure 4). The fold overs have been documented in peri-modiolar and straight electrode arrays and can lead to obstruction of the cochlear duct, non-optimal electrode trajectory (Figure 5) or incorrect insertion of pre curved peri-modiolar arrays.[34] The scala media are damaged when an electrode is moved from the scala tympani to the scala vestibuli.

This causes the perilymph and endolymph to mix, which results in a loss of the endo-cochlear potential and pre-operative residual hearing.[35] Any subsequent pharmacological treatment to repair the spiral ganglion cells or the nerve fibers may be totally precluded by the irreversible mechanical and structural damage that such injury may induce.[36] Damage from electrode insertion may cause new bone to develop inside the cochlea, which seems to have a detrimental effect on hearing results.

ELECTRODE INSERTION IN SPECIAL SITUATIONS

The head of the bed is raised during surgery if a gusher of cerebrospinal fluid is observed. The electrode is inserted once the gusher stops. The surgeon frequently faces difficulties while dealing with a blocked or obstructed cochlea.[37] A cochleostomy is often done to explore the cochlea's basal turn. A scala tympani insertion is performed if there is any fibrosis or new bone seen prior to or at the cochlea's ascending turn. The cochleostomy is extended superiorly to the scala vestibuli if the lumen is obstructed. In situations of otosclerosis and post-meningitis, this lumen is typically patent, however when the scala tympani is occluded, a complete scala vestibuli insertion is observed. A second cochleostomy is performed directly in front of the oval window if the scala vestibuli are likewise blocked. To make it easier to enter this section, the incus bar has been removed. A cochleostomy is performed immediately anterior and lateral to the stapes footplate after the incus and stapes supra-structure are removed. The post geniculate region is heavily irrigated to prevent heating or harming the facial nerve. 38 The cochleariform process is utilized as a landmark for superior limit of dissection.

ATRAUMATIC ELECTRODE INSERTION

The proper understanding and reducing the forces involved in electrode insertion is necessary for both successful electroacoustic stimulation and the preservation of residual hearing.[31] The electrode of cochlear implant is ideally designed for insertion without damaging of any intra-cochlear structures. However certain degree of trauma is expected during electrode insertion. The electrode induced trauma can be classified into different grading such as grade 0: there is no trauma because the electrode array does not come into contact with any intra-cochlear structures, grade 1: lifting of the basilar membrane, grade 2: injury to the spiral ligament; grade 3: translocation from the scala tympani to the scala vestibuli grade 4: the maximum level of trauma is caused when the electrode array ruptures the spiral lamina.[39]

If cochlear implant surgeon suspects inappropriate placement of electrode array, intraoperative X-ray, or fluoroscopic imaging can be used to confirm the position. Appropriate preoperative evaluation with imaging, attention of device or electrode selection, and judicious application of intraoperative fluoroscopy can reduce intracochlear trauma during electrode insertion.

CONCLUSION

The primary goal of electrode insertion is to ensure a smooth, atraumatic process to avoid damaging any intra-cochlear structures. Achieving optimal electrode placement is essential for maximizing the success of cochlear implant surgery. Incorrect or suboptimal placement, as well as damaged or bent electrodes, can lead to poor cochlear implant function, unsatisfactory postoperative outcomes, and may require further or revision surgery. It is crucial for cochlear implant surgeons to be aware of the potential consequences of improper electrode insertion and understand the measures that can be taken to prevent, detect, and address such complications.

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