Surgical Techniques and The Benefits of Cochlear Implantation

Subjects: Otorhinolaryngology
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As selection criteria for CI are continuously evolving and more patients are eligible for implantation, the preservation of residual hearing is becoming increasingly studied. Sustained trauma to the cochlea during the advancement of the electrode array was identified as a critical factor that can deteriorate residual hearing; therefore, in recent years, increasing attention has been directed towards surgical principles.

Keywords: cochlear implant ; hearing loss ; deafness ; review ; nanomaterials ; dexamethasone

1. Soft Surgery

The aim of preserving residual hearing led to an emphasis on avoiding mechanical trauma to the cochlea, leading to the use of the term ‘‘soft’’ surgical technique. After the first mention of the soft-surgery concept by Lehnhardt in 1993 [1], several researchers have attempted to systemize the basic principles of this concept. The intention of soft surgery is to reduce the mechanical stress transmitted to the cochlea by using drills judiciously and limiting the trauma caused by electrode advancement, as well as by limiting the accidental introduction of autologous materials (blood, bone dust, etc.) in the inner ear that could cause an intracochlear reaction [2].

Cochlear implantation most commonly begins with cortical mastoidectomy followed by posterior tympanotomy and preparation of the device well. Non-mastoidectomy approaches, such as the pericanal approach, the suprameatal approach, and the transcanal approach, still require drilling to create the groove that shelters the electrode [3]. One principle of soft surgery principles is to avoid bone dust entering the cochlea. Bone dust can trigger an inflammatory response within the scala media and alter residual hearing.

Noise and vibration during surgical drilling has become a concern for the potential reduction in residual hearing. Pau et al. determined that drilling at the level of the promontory exceeds 100 dB SPL, with further increased SPL when the endosteal layer is exposed, and exceeding 130 dB SPL when the round window membrane is touched by the drill [4]. Vibration generated by the burr during mastoidectomy or inadvertent contact with the ossicular chain is considered to induce an auditory threshold shift, possibly due to cellular and stria vascularis damage [5] Blood, similarly to bone dust, is regarded as a foreign body; hence, avoiding its entry into the vestibule is critical in preventing further sensorineural hearing loss. Although one of the core soft-surgery principles is to avoid contamination of the vestibule, there is little evidence to suggest that cochlear blood contamination can cause neurosensorial hearing loss. Avoiding perilymph suctioning or leakage is a primary concern during surgery, as it can contribute to possible cochlear damage due to changes in the endocochlear potential [6] or even lead to mechanical damage to the basilar membrane [7].

The use of hyaluronic acid (HA) in cochlear implantation is not a new concept, as Donnelly demonstrated it in 1995 by using HA to facilitate electrode insertion into fresh human temporal bone specimens [8]. In the same year, Roland et al. assessed the toxicity of HA in vivo by injecting it into the ears of guinea pigs. The authors found that HA did not affect the spiral ganglion neurons, which had even preserved the dendrite and axon histology [9]. Other articles also noted that HA lacks any toxic effects on the inner ear [2][10]. Given the safety profile, many studies have used HA to reduce friction forces during electrode insertion and to keep a seal on the perilymph inside the cochlea following electrode insertion [10][11][12][13]. Although HA reduces friction and seals off the perilymph, some studies revealed no significant benefit with respect to hearing preservation [14]. Other lubricants mentioned in the literature are oxycellulose (hydroxypropyl methylcellulose) and glycerin. The former is not metabolized, leading to a foreign body reaction inside the cochlea, whereas the latter has a high impedance, which interferes with the electrode’s electric stimulation properties. Both arguments are strong enough that each substance loses its clinical utility [9].

Another emerging surgical concept is that of partial electrode insertion in patients with residual hearing who are candidates for electric–acoustic stimulation. Lenarz et al. hypothesize that partial electrode insertion could offer protection for the lower frequencies, and if hearing loss progresses postoperatively, the electrode can be further inserted [15].

Intraoperative electrocochleography (ECochG) has been utilized during CI surgery and can provide the surgeon objective feedback during electrode insertion. Although it is not a method used to reduce inflammatory reaction by itself, whenever ECochG amplitude or phase responses are modified, the surgeon can adjust the course of the electrode in order to obtain normal intracochlear potentials and limit potential physical trauma to the cochlea [16].

In addition to the soft surgery principles, it has been hypothesized that applying hypothermia to the surgical site has the potential to reduce immediate and delay secondary hearing loss. In preclinical studies, local application of controlled hypothermia rendered a protective effect by decreasing the auditory function loss associated with electrode insertion [17][18]. Taking into consideration existing knowledge regarding hypothermia, ongoing studies on human temporal bones consider cooling probes and iced irrigation, with temperature distribution measurements at the level of the round window and different cochlear levels [19][20][21].

2. Cochleostomy vs. Round Window Insertion

The cochlear implant electrode array is positioned in the scala tympani when normal anatomy is present. The round window membrane or a basal turn cochleostomy are the two most common ways to access the scala tympani in order to insert the electrode array [2]. Each has its own set of benefits and limitations.

The round window membrane (RWM) is a natural boundary of the scala tympani. It has become an increasingly popular route for electrode insertion in cochlear implantation, particularly for hearing preservation. Preliminary comparisons revealed that the round window approach causes much less traumatic than insertion through a cochleostomy [22]. Drilling is usually not required to reach the scala tympani; therefore, noise exposure and the risk of bone dust entering the cochlea are limited [23]. Even when drilling is involved in eliminating the bony overhang of the round window niche, it takes less time and surface exposure than performing a cochleostomy. A cochleostomy requires drilling of an overlying segment of the promontory. The procedure is more likely associated with perilymph loss, acoustic trauma, bone dust-related inflammatory reaction followed by osteoneogenesis, or spiral lamina damage than in the case of round window insertion [22]. Conflicting results regarding residual hearing preservation with each approach concede no clear benefit of a particular surgical approach for cochlear implantation [14][24][25]. An ongoing clinical randomized controlled trial (CIPRES) is being conducted with the aim of clarifying this aspect by comparing hearing preservation following cochlear implantation, considering four frequent combinations of surgical approaches (round window and cochleostomy) and electrode array designs (straight and pre-curved) [26].

3. Robot-Assisted Insertion System

Robotics in neurotology is a relatively recent subject is intended to help with various aspects of cochlear implant surgery, such as drilling a keyhole route to the middle ear for implants, inner ear access, and electrode insertion into the cochlea [27]. Insertion speeds are proportionately correlated with insertion forces, and force peaks appear to be linked to interrupted insertions [28]. Robot-assisted electrode insertion seeks to limit human involuntary tremors and augment accuracy during micromanipulation of the electrode array.

Early experimental studies on cadaveric cochleae revealed that robotic-assisted insertion systems reduced cochlear trauma associated with CI electrode insertions compared to manual insertions [29][30]. Comparative X-ray microscopy (XRM) allowed for direct measurement of the insertion trauma by identifying the cochlear lesions present after the insertion and categorizing them according to a scale of severity first described by Roland and Wright [31].

Following the first reports of cochlear implantations using robot-assisted electrode insertion, the results obtained after a radiological and audiological evaluation showed that this technique is less traumatic [27][32][33]. As was expected, different electrode array (EA) designs delivered different results. Daoudi et al. considered straight and pre-curved EA in their study. Cochlear reconstructions using 3D computed tomography imaging detected that in the case of a straight EA, scalar translocations occurred in 19% of the robot-assisted electrode insertion group and 31% of the manually inserted electrode group. With a pre-curved EA, scalar translocation was present in 50% of the robot-assisted group compared to 38% in the manually inserted electrode group. This comparison offers helpful information to consider when deciding which surgical approach is most advantageous to achieve the desired electrode array design [34].

Torres et al. also described their experience using straight and pre-curved electrodes but did not correlate the electrode type results, instead emphasizing the electrode array's scalar translocation and functional outcomes. They observed no differences in speech perception in a sound-isolated room between manual electrode array insertion and robot-assisted techniques. However, they did observe that robot-assisted insertion reduced the number of translocated electrodes compared with manual insertion [35] but lacked statistical correlation with an improved speech performance.

As this new technique is promising, studies are still needed to determine safety, utility recommendations, and cost effectiveness. Further developments in robotic technologies and more clinical evidence may convert this surgical approach into a feasible, affordable option. Meanwhile, using intraoperative ECochG during CI surgery can offer the surgeon objective feedback during electrode insertion.

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