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Recent Advances in Cochlear Implant Technology: Past, Now and Future Directions

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Abstract – The hearing loss occurred due to damage in the inner cochlea layer. The cochlear implant (CI) technology is an invasive neuromodulator that provides substantial auditory perception to those with severe or profound impaired hearing. There are significant improvements in CIs technology using various systems including robotic and optical communication systems. In this study, the evolution of the CIs was summarized and new technologies that are alternatively considered were highlighted. It was suggested that the development of cochlear implant technology has gone through a complicated process. Although many scientists from various disciplines have made joint efforts and achieved success, there are still many problems to be further studied to develop an optimal CIs system for people who suffer from hearing loss.

Keywords – Cochlea Implant, Hearing Loss, Optical Communication, Robotic Guided System

I. INTRODUCTION

The function of the cochlea is to generate a sense of hearing. It transforms the sound waves into mechanical vibrations of the hair cells and subsequently into electrical pulses [1]. The pulses are transmitted to the brain through the auditory nerve to provide hearing sensation. Hearing loss occurred due to damage in this layer. This is a global socioeconomic burden. It has been shown that more than 1.5 billion people in the world have hearing loss, of which 430 million have moderate hearing loss or above. This number is expected to double by 2050 [2]. Also, this disorder is an economic burden. It has been analyzed that analyses that the middle ear implants market to account for $69.69 million by 2028 and grow in the forecast period of 2021-2028 [3]

Cochlear impalement (CI) is a successful technology in clinical medicine, and it is a gold standard of treatment for patients with severe hearing loss or deafness as shown in Fig. 1. This neuromodulator device is constantly being improved and adapted to patients' actual needs

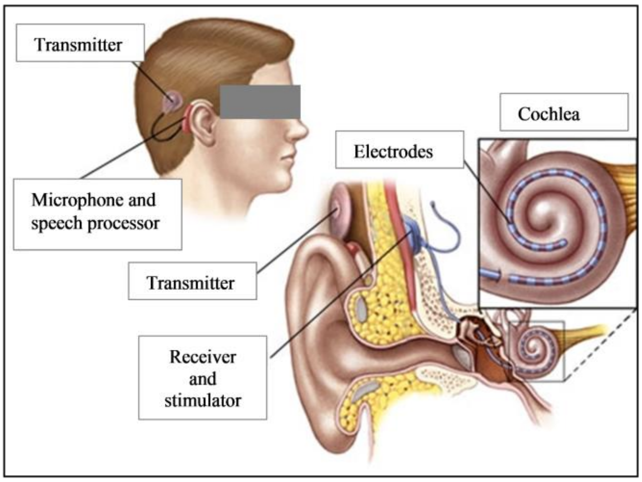

Fig.1. Components of the cochlear implant. A cochlear implant uses a sound processor that's worn behind the ear. A transmitter sends sound signals to a receiver and stimulator implanted under the skin. They stimulate the auditory nerve with electrodes that have been threaded into the cochlea [13] .

regarding patient selection, device size, adapting hearing aid noise reduction algorithms, electrode design, and speech processing strategies. Thus, to design and develop optimal parameters for CI,

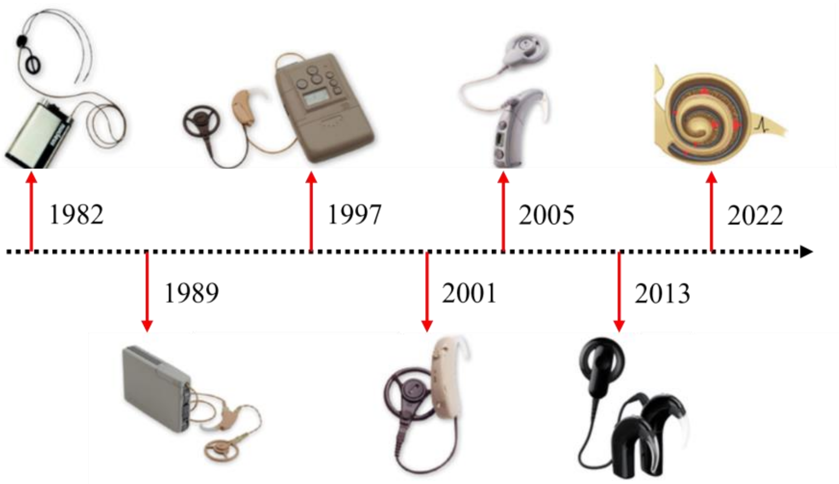

Fig. 2. The evolution of CIs from 1982 to 2022. The development of each CI is highlighted based on defined year.

multidisciplinary efforts from various professionals in different fields are required including engineering, otology, audiology, auditory neurophysiology, and acoustic psychology [4], [5].

It has been shown that more than 700,000 cochlear implant operations have been carried out in the world, and more than 10,000 deaf children meeting the indications of cochlear implant operations are added every year [4], [5]. Thus, it was aimed to summarize the development in CI technology based on existing studies by analyzing current technology expansion and looking forward to the possible and presumable future development trend.

II. History and Development of Cochlear Implantation

The development of the CI based on time schedule is shown in Fig. 2. Although the idea of the electrical stimulation of hearing loss was considered in 1957, the first CI neuromodulator device was established in 1982 under the name MedEl Corporation, closely followed by Cochlear Limited in 1984, and Advanced Bionics in 1996 [5], [6]. The CI companies always update the CI design to meet the users' requirements using advanced technology tools by optimizing architecture designs, hardware, and stimulation techniques. The first generation of CIs was released in the early 1980s and included Nucleus 22 and Comfort CI with multichannel stimulation. Then, Advanced Bionics released their device which is called Clarion in 1996. This CI was designed based on eight channels and used rechargeable batteries.

With new developments, the second generation of the Clarion II, Nucleus 24 Contour, and Combi 40+ were released. There were significant improvements in the second generation of the CIs. The new version of these CIs is composed of 24 electrodes and new

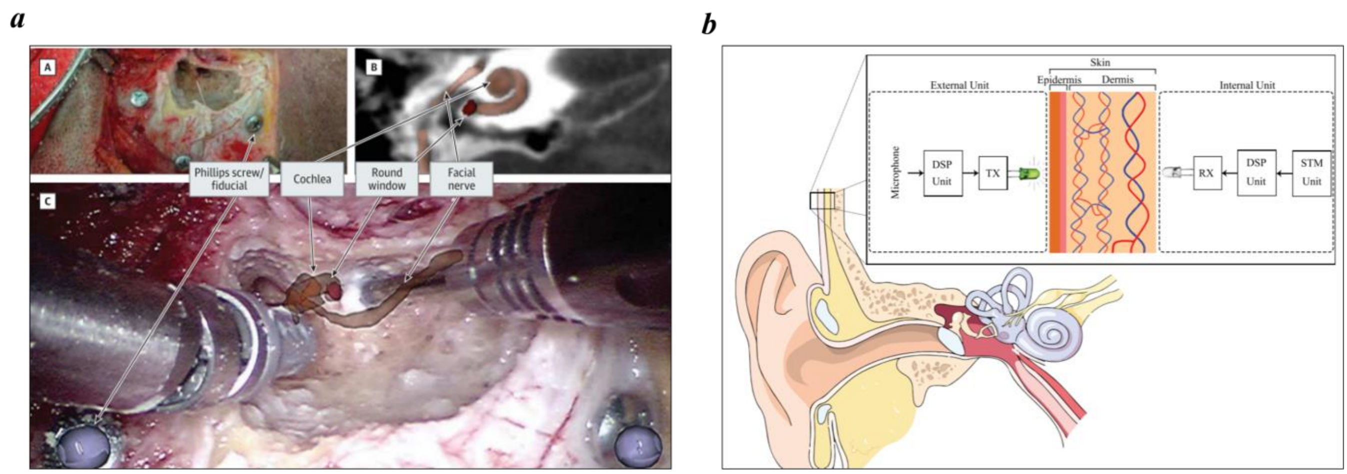

Fig. 3. (a) Shows Da Vinci robot system for CIs. (b) shows the proposed optical communication system architecture for CIs. The figuers were adopted from [10], [12].

sound processors with novel features such as pre-curved electrode arrays, backward compatibility, frequency modulation capabilities, dual electrodes, and behind-the-ear external components [7]– [9].

However, in the early 2000s, new CIs were released using technological improvements. These were Freedom, Pulsar, and HiRes90k. In the era after 2010, the latest iterations of CIs have been focused on higher fidelity sound that enhances the perception of music through state-of-the-art sound processing, wireless control, and software-enabled programmability, as well as waterproof designs.

III. Development trend of cochlear implants

Since clinicians may not be able to reach the sensitivity layer of the cochlear due to constraints, the advancements in robotic technology achieved great success in the field of minimally invasive surgery and allow clinicians to do many operations including cochlear implementation. By using this technique, the trauma due to misplacement of the electrode was significantly reduced [10]. It has been shown that Johns Hopkins University studied image-guided electrode implantation using Da Vinci robot system (as shown in Fig. 3(a)) and an ear endoscope system. Also, a robotic-based system was developed by the University of Berlin and a research team applied to a clinical trial of artificial cochlear implantation, and the French Sterkers team developed the world's first ear robot system (RobOtol) with clinical access [11]

Conventional cochlear implants rely on current stimulation and higher current levels may cause problems due to sensitive layers in the cochlea. Thus, the utilization of optical wireless communications to develop CI transdermal optical links has been recently investigated and some researchers have been working on the laser to use for the CI instead of current stimulation as the proposed system shown in Fig. 3(b) [12]. However, the study is still under research, and the animal test was successfully completed but deep investigation is required to apply this technology to the CIs.

IV. Future directions

Although there are significant improvements in the design and development of the CI system, the full insertion of the electrode array still relies on the clinician experience due to the lack of a visualization system in the current technology. Thus, the authorities should support much more projects on the cochlear implementation technology and the scientific board may have more collaborations from various disciplines (including engineering, otology, audiology, auditory neurophysiology, and acoustic psychology) to design and develop the CIs using current technologies including artificial intelligence and bio-computational modeling systems.

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