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Cochlear Implant

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Abstract: **As the most successful neural prosthesis, cochlear implants have provided partial hearing to more than 120000 persons worldwide. First, the cochlear implants are system designed and specifications are laid out. Second, the design goals, principles, and methods of subsystem components are identified from the external speech processor and radio frequency transmission link to the internal receiver, stimulator, and electrode arrays. Third, the system integration and functional evaluation are presented with respect to safety, reliability, and challenges facing the present and future cochlear implant designers and users. Finally, issues beyond cochlear implants are discussed to address treatment option for the entire spectrum of hearing impairment as well as to use the cochlear implant as a model to design and evaluate other similar neural prosthesis such as vestibular and retinal implants.**

Key words: Cochlear implant, external speech processor, radio frequency, internal receiver, stimulator, electrode array, hearing impairment, neural prosthesis.

I. INTRODUCTION

A cochlear implant (CI) is a surgically implanted neuroprosthetic device that provides a sense of sound to a person with moderate to profound hearing loss. Andre Journo and Charles Eyries invented the original CI in 1975. This original design distributed stimulation using a single channel. The first cochlear implant was invented by William Have, in 1961. In 1964 Blair Simmons and Robert J.White implanted a single channel electrode in a patient's cochlea at a standard university. In 1970's the research at the University of Melbourne focused at first on behavioral experiment in the alert animal to confirm the acute physiological findings. The research showed the limitations of using rate of electrical stimulation to code speech and other frequencies. This research commenced in 1971, and was essential for making sure that a multiple-rather than a single electrode implant should be developed. Cochlear implant research, industries development and clinical studies made considerable advances in 1980's. In October 1982, Melbourne Man Graham Carrick made history when a remarkable invention, implanted in his cochlea was switched on and 15 min later he could hear for the first time in 17 years. There are three main phase of development of the cochlear implant, as shown in Fig 1. The figure shows the conceptualization phases demonstrate the feasibility of electric stimulation. The research and development phase legitimized the utility and safety of electric stimulation. The commercialization phase saw a wide spread use of electric stimulation in treating sensorineural hearing loss. The cochlear implants bypass the normal acoustic hearing process, instead replacing it with electric hearing. Namely, the second sensation comes from the sound that is converted to electric signal which directly stimulate the auditory never. The brain adapts to the new mode of hearing, and eventually can interpret the electric signal as sound and speech.

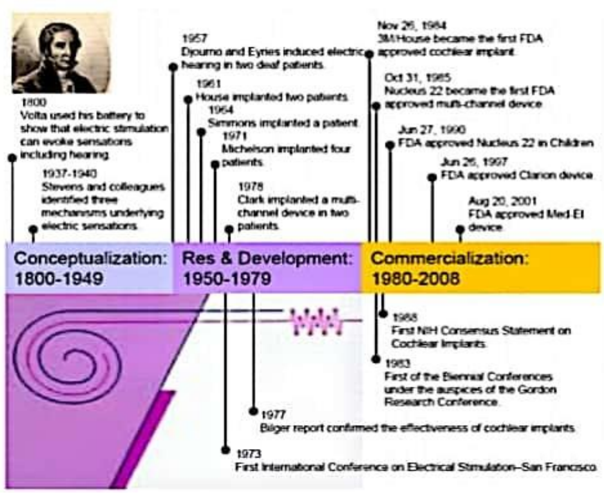

Fig 1: Three phase defining the major events in cochlear implants

II LITERATURE REVIEW

[1] Authors here discussed about the challenges deaf people had in communicating. Nevertheless, prior to the 18th century, deafness was a serious sensory disability. Apart from the ear trumpet there was title to help with communication. Children were particularly disadvantaged. They led sheltered, restricted lives in institutions, and were referred to as being deaf and dumb.

[2] Auditory prostheses use electric currents on multiple Electrodes to stimulate auditory neurons and recreate auditory sensations in deaf people. Cochlear implants have restored hearing in more than 200,000 deaf adults and children to a level that allows most to understand speech. Here we review the reason underlying these results and describe new direction in restoring hearing to additional patient population and the design of new devices.

[3] In this paper, the author discussed about the pressing need to reassess and reevaluate the current narratives about CIs - where the field is right now and where basic and clinical research needs to go in the future. While enormous advances have been made over the last 25 years in the medical and the surgical management of profound SNHL in both adults and children using CIs, it is now becoming necessary to rethink and reconsider the agenda and narrative for the future and move beyond the focus on hearing, audibility and the early registration and encoding of sensory input provided by a CI.

[4] This paper is all about use of a cochlear implant has had a dramatic impact on the linguistic competence of profoundly hearing-impairment children. More than half of the children in this sample with average learning ability produces and understood English level at a level of comparable with that of their hearing age mates. Such mature language outcomes were not typical of children with profound hearing loss who used hearing aids.

[5] This book covers basic techniques as well as new concepts and areas of expansion, making it appropriate for beginners as well as experience practitioners. Includes information on the latest advancement in cochlear implant programming concepts. Written by experts in the field who are spearheading advancement in cochlear implant technology.

[6] This book provides "comprehensive coverage of the Audiological principles and practices pertaining to cochlear implant and other implantable Hearing technologies," according to an announcement by Plural Publishing. Written specifically for the audiologist, it addresses the details involved with assessment and management of cochlear implant technology. Additionally this book is described as providing an overview of hybrid cochlear implant, implantable bone conduction hearing technology, middle ear implantable devices, and auditory brainstem.

[7] This book revels Programming Cochlear Implants; Second Edition introduces the basics of the cochlear implant hardware and programming and continues through advances programming techniques, with manufacturer-specific information and case studies.

III. SYSTEM DESIGN AND SPECIFICATION

The implant has two main components. The outside component is generally worn behind the ear, but could also be attached to clothing, for example, the sound processor, contains microphone, electronics that include DSP chips, battery, and a coil which transmit a single to the implant across the skin. The inside component, the actual implant, has a coil to receive signal, electronics, and an array of electrode which is placed into the cochlea, which stimulate cochlear nerve.

The surgical procedure is performed under general anesthesia. Surgical risks are minimal but can include tinnitus and dizziness.

The over-arching goal of a cochlear implant is to use electric stimulation safely to provide or restore functional hearing. Figure 2 shows graphically a typically modern cochlear implant system. System That Converts Sound To Electric Impulses Delivered to The Auditory Nerve. The behind-the-ear external processor with ear hook and a battery case (2) uses a microphone to pick up sound, converts the sound in digital signal, processed and encodes the digital signal into a radio frequency (RF) signal, and send it to the antenna inside a headpiece (3). The headpiece is held in place by a magnet attracted to an internal receiver (4) placed under the skin behind the ear. A hermetically sealed stimulator (5) contains active electronic circuits that derive power from the RF signal, decode the signal, convert it into electric current, and send them along wires (6) threaded into the cochlea. The electrode (7) at the end of the wire stimulate the auditory nerve (8) connected to the central nervous system, where the electrical impulses are interpreted as sound.

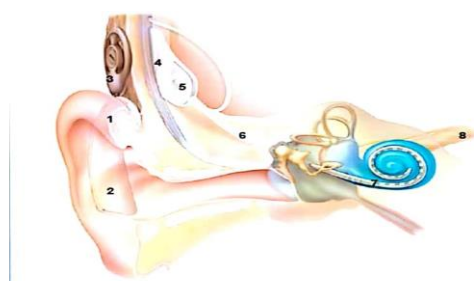

Fig. 2. A Typical Modern Cochlear Implant

All modern cochlear implant system has the following architecture and functional blocks (Figure 3). The single-electrode systems had an analog external unit and contained no internal active circuits. The Utahsix-electrode, four-channel system had a percutaneous plug and contained no internal circuits. The Nucleus 22 device had essentially all

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components of a modern system, except forth back telemetry circuits

An external unit, also known as speech processor, consists of a digital signal processing (DSP) unit, a power amplifier, and an RF transmitter. The DSP is the brain of the cochlear implant system that receives sounds, extracts features in the sound, and converts the features into a stream of bits that can be transmitted by the RF link. The DSP also contains memory units or "maps" that store patient specific information. The maps and other speech processing parameters can be set or modified by a PC fitting program.

An external unit contains of the RF receiver had a hermetically sealed stimulator. Because the internal unit has no battery, the stimulator must first derive power from the RF signal. The charged up stimulator will then decode the RF bit stream and converts it into electric current to be delivered to appropriate electrode. All modern system also contains a feedback loop that can monitor critical and neural activities in the implants and transmit these activities back to the external unit.

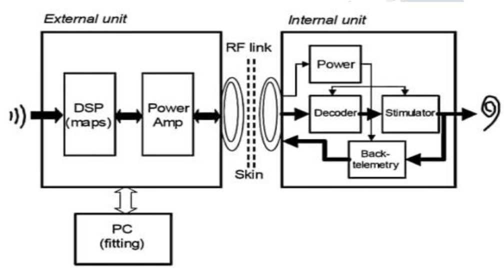

Fig. 3.Architecture and functional block diagram of a modern cochlear implant.

3.1 Signal processing

Except for the paradigm shift from the single electrode device to the multi-electrode device in the early 1980s, advances in signal processing are largely responsible for the continuous and Steady improvement by cochlear implant users.

Figure 4A shows the functional block diagram of the continuous-interleaved-sampling (CIS) strategy, which has been implemented by all major manufacturers and is still available in their latest devices. The sound is first subject to a number of band pass filters with the number being as few as 5 in the original CIS implementation and as many as 20 in the Nucleus Freedom device. The temporal envelope from each band is extracted by either half-wave (shown in the figure) or full-wave rectification followed by a low-pass filter; or more recently by the Hilbert transform. The envelope is then logarithmically compressed to match the widely varying acoustic amplitudes to the narrow electric dynamic range .The compressed envelope amplitude modulates a fixed-rate biphasic carrier, whose rate can vary from several hundred to several thousand per second. To avoid simultaneous electrical field interference, a problem that apparently bothered early devices such as the analog Ineraidimplant, the biphasic carriers are time interleaved between the bands so that no simultaneous stimulation occurs between the bands at any time. In practice, a single current source is needed in a CIS strategy. The CIS strategy can avoid simultaneous channel interaction while preserving the temporal envelope samples for each band as long as the carrier rate is sufficiently high. Typically the cutoff-frequency of the low-pass envelope filter is set between400 Hz or slightly lower, requiring at least 800 Hz carrier for faithful representation of these envelopes.

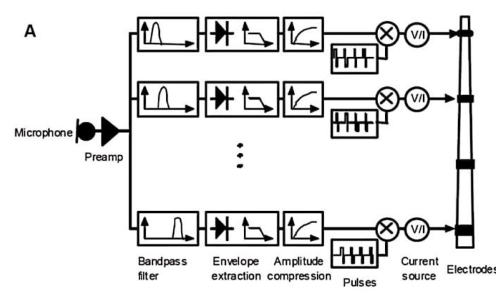

Fig. 4.A. Block diagram of Continuous-Interleaved-Sampling (CIS) strategy.

Figure 4B shows a functional block diagram of the “n-of-m” strategy, which was first described by Wilson and colleagues and had been refined in sub sequential development as the SPEAK and ACE strategies in the Nucleus devices . The pre-processing in the n-of-strategy is similar to the CIS strategy, including the bandpass filters and the envelope extraction blocks. However, there are several major differences between the two strategies. One difference is that the n-of-m strategy has a greater number of bandpass filters, e.g., m=22 in the Nucleus implementation, than the CIS strategy. The number of bandpass filters is typically set to equal the number of intra-cochlear electrodes. The second difference is that the n-of-m strategy is based on temporal frames, typically lasting 2.5 to 4 msec, whereas the CIS strategy does not have any explicit processing frames. In each frame of the n-of-m strategy, an “n” number of bands with the largest envelope amplitude are selected (by definition, n≤m). Envelopes from the selected bands are subject to the same amplitude compression and used to determine the current level of the biphasic pulse. The biphasic pulses are interleaved between the output channels, with the per channel stimulation rate being determined by the frame rate. Finally, only the corresponding "n" electrodes (dark bands in the figure) out of the "m" electrodes are stimulated in a particular frame. The SPEAK strategy selects 6-8 largest peaks and has a fixed250 Hz per channel rate. The ACE strategy has a larger range of peak selection and higher rate than the SPEAK strategy. If n=m, then the SPEAK and ACE strategies are essentially same as the CIS strategy.

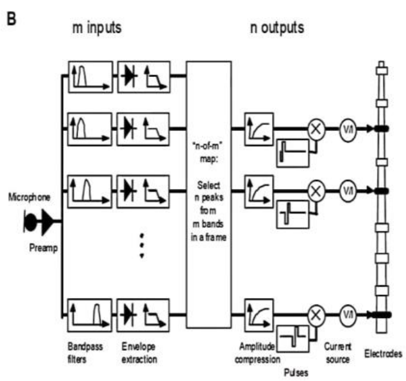

Fig. 4.B. Block diagram of the "n-of-m" strategy.

3.2 Radio Frequency (RF) Link

To ensure safety and to improve convenience, the internal unit in all modern devices is now connected to the external unit via a transcutaneous RF link. The RF link uses a pair of inductively coupled coils to transmit both power and data. The RF transmission has to address host of challenging technical issues. For example, the external unit needs to provide not only reliable communication protocols including a signal modulation method, bit coding, frame coding, synchronization and back telemetry detection, but also high efficiency RF power amplifier and immunity to electromagnetic interference (EMI). The internal unit, on the other hand, needs to harvest power with high efficiency and retrieve data with high accuracy.

3.3 Receiver and stimulator

The internal unit consists of a receiver and a stimulator, and is sometimes referred as the "engine" of a cochlear implant. Figure 5 shows the block diagram of a typical implanted receiver and stimulator. The centerpiece is an ASIC (Application Specific Integrated Circuit) chip, shown as the dotted box, which performs critical function of ensuring safe and reliable electric stimulation.

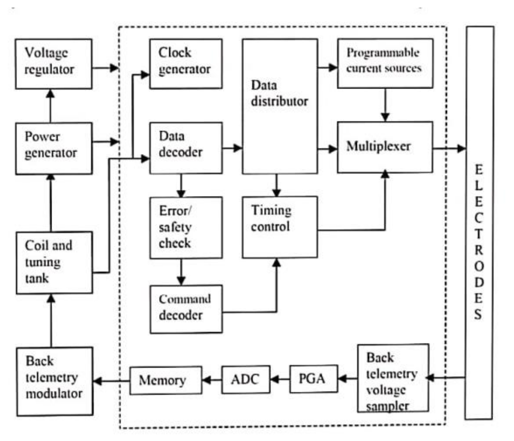

Fig. 5. Block diagram of the cochlear implant internal unit.

Inside the ASIC chip, there are a forward pathway, a backward pathway, and control units. The forward pathway usually includes a data decoder that recovers digital information from the RF signal, error and safety check that ensures proper decoding, a data distributor that sends the decoded electric stimulation parameters to the right place (i.e., the programmable current source) at the right time (i.e., by switching on and off multiplexers).The backward pathway usually includes a back telemetry voltage sampler that reads the voltage over a period of time on the recording electrode. The voltage is then amplified by the programmable gain amplifier (PGA), converted into digital form by an analog to digital converter (ADC), and stored in memory to be sent out to the external unit via back telemetry. The ASIC chip also includes many control units from the clock generated from the RF signal to the command decoder. There are several circuits and devices that cannot be easily integrated in the ASIC chip, including the voltage regulator, the power generator, the coil and RF tuning tank, and the back telemetry data modulator.

3.4 Electrode Arrays

The electrode array is the direct interfaces between the electrical output of the speech processor and the auditory neural tissue. In the last three decades, these electrode arrays have evolved from single channel to multiple channels with 12 to 22 active contacts, from an in situ position near the

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lateral wall of the scala tympani to a position closer to the modiolus, and from larger molded silicone elastomeric "carriers" to smaller profiles. These changes are summarized here and reflect improved understanding of cochlear anatomy and electrophysiology and their relationship to cochlear implant performance.

3.4.1 Current Intracochlear Electrodes

Figure 6 illustrates three commonly applied cochlear implants, the Med-El Combi 40+™, Advanced Bionics Helix™ and Cochlear Contour™. Each of these devices is similar in construction with stimulating contacts fabricated from platinum-iridium (PtIr) alloy foil held on a silicone elastomer carrier. The connecting cable and lead wires in all cochlear implants are subject to breakage, particularly in active children. In addition, these wires dominate the mechanical properties of the electrode array and the increased stiffness they impart may be a cause of increased trauma.

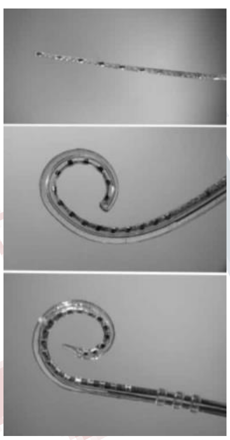

Fig. 6. Top: Med-El Combi 40+™' Middle Advanced Bionics Helix™; Bottom: Cochlear Contour™electrode arrays.

3.5 Fitting Program

Because each patient is unique, the cochlear implant has to be customized to meet his or her conditions and needs. A fitting program is used to interface between a PC and the external speech processor. The interface provides two-way communication during fitting sessions, which is generally conducted one month after surgery and adjusted annually or as necessary. The fitting program collects critical patient-specific information from patient preference of speech processing strategies to the setting of threshold and comfortable loudness values on all electrodes. Once these critical electric stimulation parameters are set, the fitting program stores the information as a "map" on the PC, which is then downloaded to the memory (usuallyEPROM) of the speech processor.

3.6 System Integration

To provide safe, reliable and useful electric hearing, the cochlear implant imposes extreme physical, power, environmental and handling constraints on both system design and system integration. First, the implant must be safe, causing no harm, chronic pain or discomfort to the people who use it. Second, the implant must be reliable, because children who receive cochlear implants will depend on them to develop their speech and communication skills and will use their devices for a significant portion of their life before it is replaced if at all. This imposes a serious need to design the product to withstand the implant environment for up to, if not beyond, 30 years. Third, for the implant to reside safely and unobtrusively on the patient's head, severe restrictions are imposed in the physical size and shape of the package available to house electronics. Fourth, the implant is powered by batteries so that a low power consumption design is vital. Furthermore, the implant should be able to handle not only a very harsh operating environment inside the human body for a long time but also extreme physical abuse such as mechanical impact in case of a fall or crash. The implant users want to participate in the normal activities of daily living unshackled by the need to use and protect an overly delicate prosthesis. Finally, the implant must be designed in close collaboration with surgeons and patients to accommodate a broad range of anatomical variations and to ensure reliable, effective and satisfactory outcomes. To illustrate the importance of system integration, the following two sections illustrate some of the problems that occurred in earlier generations of the cochlear implants and had led to reduced overall system performance, cumbersome administrative overhead, and increased risk to the patients.

IV. SOCIETY AND CULTURE

4.1. Usage

As of October 2010, approximately 188,000 individuals had been fitted with cochlear implants. As of December 2012, the same publication cited approximately 324,000 cochlear implant devices having been surgically implanted. In the U.S., roughly 58,000 devices were implanted in adults and 38,000 in children. As of 2016 the Ear Foundation in the United Kingdom, estimates the number of cochlear implant recipients to be around 600,000.

4.2. Criticism and controversy

Much of the strongest objection to cochlear implants has become from within the Deaf community, some of whom are prelingually Deaf people whose first language is sing

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language. For some in the Deaf community, cochlear implants are an affront to their culture, which as they view it, is a minority threatened by the hearing majority. This is an old problem for the Deaf community, going back as far as the 18th century with the argument of manualism vs. oralism. This is consistent with medicalisation and standardization of “normal" body in the 19th century, when difference between normal and abnormal began to debate. It is important to consider the sociocultural context, particularly in regards to the Deaf community. This considers itself to possess its own unique language and culture. This account for the cochlear implant being seen as an affront to their culture as many do not believe that deafness is something that needs to be cured. However, it has also been argue that this does not necessarily have to be the case: the cochlear implant can act as a tool deaf people can use to access the "hearing world" without losing their Deaf identity.

Cochlear implants for congenitally deaf children are considered to most effective when implanted at a young age, during the critical period in which the brain is still learning to interpret sound. Hence they are implanted before the recipient can be deciding for themselves, on the assumption that deafness is a disability. Deaf culture critics argue that the cochlear implant and the subsequent therapy often become the focus of the child's identity at the expense of a possible future deaf identity and ease of communication in sign language, and claim that measuring the child's success only by their mastery of hearing and speech will lead to poor self-image as "disabled" rather than having the healthy self-concept of proudly deaf person.
Children's with cochlear implants are more likely to be educated orally, in the standard fashion, and without access to sign language and are often isolated from other deaf children and form sign language. Cochlear implants have been one of the technological and social factors implicated in the decline of sign language in the developed world. Some of more extreme responses from deaf activists have labeled the widespread implantation of children as "cultural genocide".

As the trend for cochlear implant in children grow, Deaf-community advocates have tried to counter the "either or" formulation of oralism vs manualism with a "both and" approach; some schools are now successfully integrating cochlear implants with sign language in their educational programs.

4.3 Success rate of CI

Small implant, great results. The best results were found among children who received the cochlear implant at 0-3 years of age. They achieved 90-95 percent hearing and language improvement. 80-90 percent of these children develop a hearing and speech equal to those of children with normal hearing.

V. CONCLUSION

The results that we have presented from adults and children’s with cochlear implants indicated that most are successful users. Many individuals with implants are now able to communicate and understand speech without lip reading and some are able to talk over the phone. Children's with implant can develop spoken language skills and attend normal schools. Thank to persistent and outstanding collaborative work by engineers, audiologist, scientists, physicians, and entrepreneur, safe and charge balanced stimulation has now provided or restored hearing to more than 1, 20,000 people are worldwide. The present review has systematically and comprehensively presented the cochlear implant system design and specifications, identified key subsystem components and functions, provided valuable system integration and evaluation information, and discussed broad perspective and impact beyond the cochlear implant. It is fair to conclude that the cochlear implant not only has a long and distinguished history but also a bright future as it continues to broaden its utility for treatment of a wide range of hearing impairment and to serve as a model to guide development of other neural prostheses.

VI. FUTURE SCOPE

We have identified several areas of importance that should be considered for the future development of cochlear implant in children and adults.
1. Expand our knowledge of the acoustic of Speech background noise and everyday sounds.
2. Determine how the hearing impairment auditory system codes sounds and which transformation improves coding.
3. Design cochlear implant that can be readily modified.
4. Develop optimal fitting strategies for individual patients.
5. Increase the number of nerve fibers receiving different information.
6. Develop a device that is completely implantable.
7. Provide a noninvasive removable device.
8. Implant some patients with more residual hearing.
9. Design synergistic cochlear implant, hearing aids, and tactile aid.

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10. Device measures of auditory skills for children from birth to 2 years of age.
11. Utilize computer assisted aural Rehabilitation.
12. Develop aural Rehabilitation programs tailored to the fitting characteristics of the speech processor.
13. Provide an enriched auditory educational program.
14. Provide cochlear to disadvantaged populations.

Figure 7 shows presently available options in treating hearing impairment. The traditional hearing aid will likely occupy the largest market, helping millions with moderate to severe hearing impairment. The middle ear implant uses similar cochlear implant technology but uses mechanical output to directly drive the cochlea, which will likely help those with conductive or mixed hearing loss, with unilateral loss, and with chronic dysfunction of the middle ear. The auditory nerve implant is also revived to provide low stimulation current and sharp spatial selectivity, potentially solving the poor pitch perception problem in electric hearing. Hardware from the microphone to the implant packaging will become better and smaller, making totally implantable devices feasible and effective.

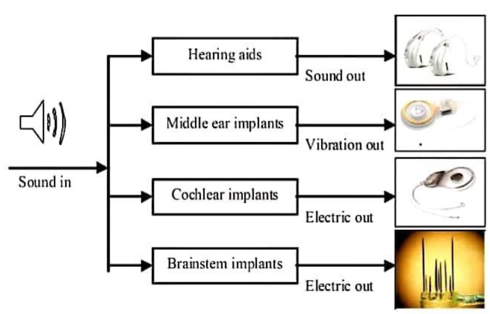

Fig. 7. Treatment of hearing impairment using hearing aids, middle ear implants, and cochlear implants.

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