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Case-Based Review

Use of Monopolar Coagulation and Transcranial Stimulation During Surgery for Advanced Scoliosis in Patients with Cochlear Implants—Case-Based Review

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Surgery of the thoracic and lumbar spine must employ monopolar electrical coagulation due to the necessity of bleeding control because alternative methods have too many limitations. The use of such electrocoagulation in cochlear implant (CI) users carries a high risk of damaging the assistive listening device. The objective of this paper is to present the management of 2 CI system users with advanced spinal curvature who required surgical treatment for scoliosis. A review of the literature was conducted on the use of medical procedures based on the conduction of electrical potentials within CI users. This paper presents 2 cases of surgery for spinal deformity in children who use CI. The precautions employed with regard to the utilization of monopolar coagulation are delineated. In neither case was damage to the CIs identified, despite the utilization of monopolar coagulation. A review of the literature revealed 415 documented instances of CIs being exposed to electrical current flow, of which 2 resulted in damage to the device. One case involved a patient who was defibrillated during cardiac arrest, while the other was related to dental pulp measurements on cadaveric teeth. Although monopolar electrocoagulation is considered a high-risk procedure for patients with CIs, this paper demonstrates that such procedures can be performed safely with appropriate precautions. It seems reasonable to conduct further experimental studies aimed at developing safe protocols to minimize the risk of damage to CI, ensuring that patients can undergo necessary medical procedures.

KEYWORDS: Coagulation, cochlear implants, monopolar coagulation, spine surgery, surgery

INTRODUCTION

Cochlear implants (CI) are sophisticated medical devices that act as auditory nerve stimulators. They work by converting sound waves into electrical signals that stimulate the auditory nerve. The system consists of several main components, including a microphone, a sound processor, a delivery system, and electrodes placed in the cochlea. An external microphone is used to collect sound waves from the environment, which are then sent to the sound processor. The sound processor analyzes and encodes the sounds by converting them into electrical signals that stimulate the auditory nerve endings, mimicking the natural process of hearing. Signals from the sound processor are transmitted transcutaneously to the receiver coil. In the case of monopolar coagulation, the electric current can induce voltages within the receiver coil that may damage the electrodes in the cochlea. Therefore, caution must be exercised during surgical procedures using an electrical current. The use of monopolar coagulation is contraindicated by CI manufacturers (Physician's Guide for CI532 implant Cochlear/Medical Procedures for MED.-EL Implant Systems).[1-3]

Electrocautery is a surgical technique used for tissue cutting, coagulation (sealing blood vessels), and tissue destruction by applying a high-frequency electrical current. There are 2 primary types of electrocautery: monopolar and bipolar. Monopolar electrocautery

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consists of a handheld device that delivers an electrical current to the target tissue via an active electrode. The current flows from the active electrode through the tissue and returns to the generator via a grounding pad attached to the patient's skin at a distant site. Bipolar electrocautery utilizes 2 closely spaced electrodes within the handheld device. The electrical current flows directly between these electrodes, effectively confining the energy to the target tissue without requiring a distant grounding pad.

Monopolar electrical coagulation is used for extensive procedures in the thoracic and lumbar spine. This method is essential for its effectiveness in stopping bleeding, allowing precise cutting, and minimizing blood loss due to the extent of the surgical access. Alternative methods, such as bipolar coagulation, ultrasonic knives, and lasers, are potentially safer for CI users requiring surgery[4,5] but have their limitations. Bipolar coagulation is safer for CI users but less effective for major surgery. Ultrasonic knives and lasers are effective in controlling bleeding, but they are much less effective and prolong the operation time in major surgery. Using these devices in scoliosis surgery could lead to a prolonged procedure, increasing the risk of infection.[6] Hence, spinal surgery in CI patients presents unique challenges to surgeons due to the need for monopolar electrocoagulation and transcranial monitoring of peripheral nerves.[7-11] CI patients undergoing this type of procedure require protection and monitoring to minimize the risk of implant damage. This includes isolation of the patient's head, insulation on a substrate that does not conduct electricity, and protection against flooding of the head area with body fluids and water from the drill.[11]

Qualification for scoliosis reduction is mainly based on telemetry radiographs of the spine. According to the Scoliosis Research Society (SRS) guidelines,[12] patients with a Cobb angle of the main curve greater than 40-45 degrees should qualify for surgery.[13] Leaving a deformity of this magnitude or greater untreated carries a high risk of significant disease progression. The gold standard of scoliosis surgical treatment is a reduction in the curve and posterior spinal fusion using titanium pedicle screw systems. This method usually requires an extensive posterior approach to the spine.

MATERIAL AND METHODS

This paper aimed to present the management of 2 CI users with severe spinal deformities who required surgical treatment. Extensive measures were taken to protect the CI coil from electrical damage.

MAIN POINTS

- There is an increasing number of users of cochlear implants (CIs) worldwide, which provide essential support for people with profound hearing loss. Performing surgical procedures with monopolar coagulation in such patients is associated with a potential risk of CI damage.
- There is increasing evidence in the literature that current-flow devices can be used in such a way that, while maintaining safety measures, the risk of CI damage is minimized.
- It is advisable to promote knowledge regarding the safety of performing various surgical procedures in profoundly hearing-impaired patients with CI, both among surgeons and practitioners of other surgical specialties.

Free-field tonal audiometry measurements and free-field speech comprehension tests—a speech discrimination test and 1-syllable tests in the Polish language at a sound level of 65 dB SPL—were performed before and after the surgical treatment. Electrode impedance measurements were also performed before and after surgery, alongside measurements of the auditory nerve response in the CI.

A literature review was conducted on the use of current flow-based medical procedures in CI users. The PubMed and Google Scholar databases were searched. The following keywords were used: CI, monopolar electrocoagulation, electrocoagulation, cardioversion, defibrillation, and electroconvulsive therapy. The following keywords were not included: electromagnetic, magnetic resonance, bipolar, implantable cardiac devices, and implantable medical devices. Animal studies, cadaveric devices, case reports, and case series were used for a retrospective analysis. Figure 1 shows the selection of publications for this review. Full articles in English and German were included, and papers for which abstracts and full versions were unavailable were rejected. The number of procedures performed with electrocoagulation is included in the results table. Papers describing physicians' awareness of the potential risks of electrocoagulation in CI users and review papers were cited but not included in the analysis of CI injuries.

In the cases presented, after the literature was analyzed and consultations were held with the patients and their parents, the decision was made to perform spinal curvature surgery using monopolar coagulation.

This study was conducted in accordance with the ethical standards of the World Medical Association's Declaration of Helsinki Ethical Principles for Medical Research involving Human Subjects and its subsequent amendments. Written consent was obtained from the patients and patients' parents for publication of the results of the tests obtained during hospitalization.

RESULTS

CASE 1

A 16-year-old patient was admitted to the Department of Pediatric Orthopedics and Oncology of Musculoskeletal System for corrective spinal surgery due to progressive adolescent idiopathic scoliosis type 3C, according to the Lenke classification.[12,13] The treatment aimed to reduce the curve and restore the coronal and sagittal balance. The Cobb angles of the curves were 41° and 59° in the thoracic and thoracolumbar spine, respectively. The patient had congenital bilateral sensorineural hearing loss and received a Cochlear CI24r CI system in their second year of life, currently equipped with a Nucleus7 processor. The boy used the CI system, demonstrated well-developed speech with normal articulation, and attended a mainstream school, in line with his age. In a free-field test, the average hearing threshold was 25 dB at frequencies of 500 Hz, 1 kHz, 2 kHz, and 3 kHz. The patient's speech understanding was 80% in single-syllable tests at 65 dB SPL. Impedance and NRT measurements of the CI were performed.

The patient underwent surgical scoliosis reduction and posterior fusion from Th4 to L4 using a screw system. The patient's head was secured and isolated on a non-conductive surface. Electrocoagulation was performed at or below the Th3 segment (Th3-L4) during surgery.

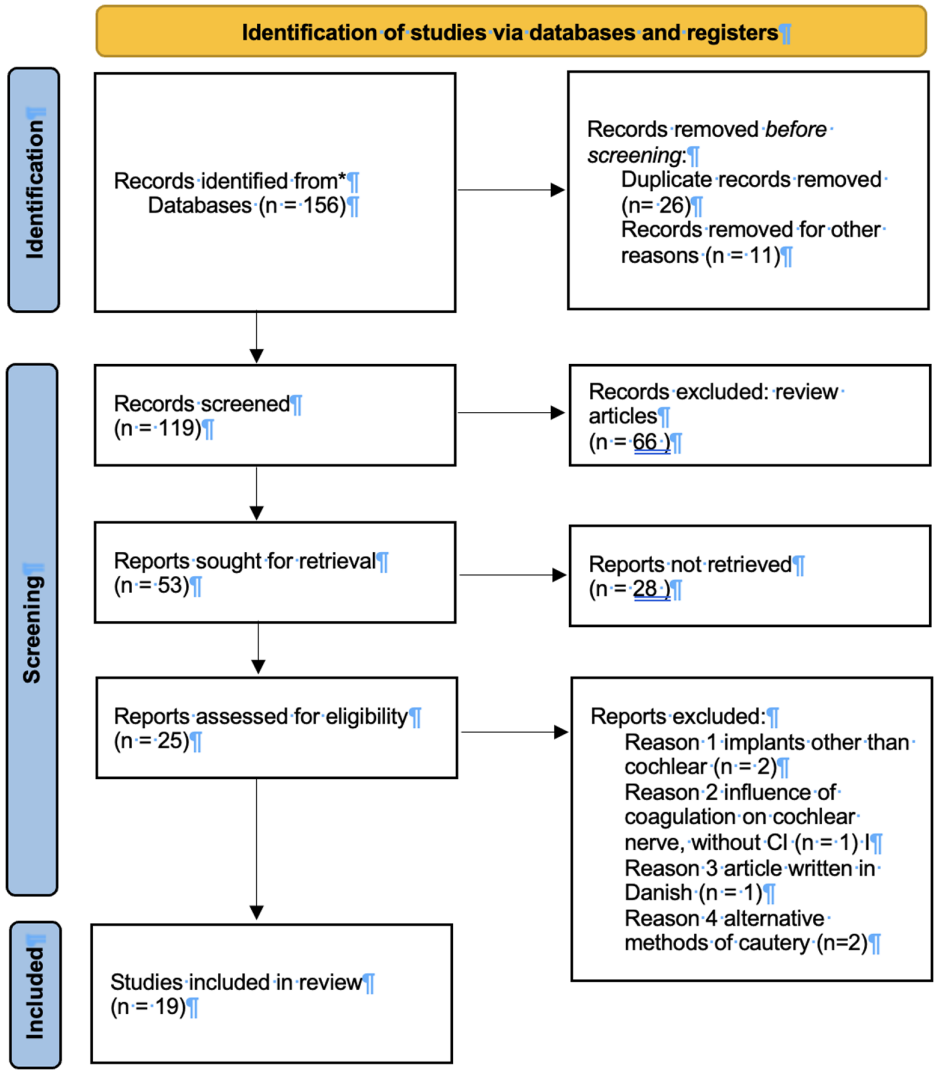

Figure 1. Prisma flow diagram for new systematic reviews, which included searches of databases and registers.

Coagulation was set at a low level, i.e., 30W. The impedance test of the CI electrodes and NRT was performed in the operating room immediately after surgery. There were no changes before and after surgery. The readings indicated that the implant was functioning properly, and there were no changes in the electrodes (Figure 2). Audiological tests were performed on the second postoperative day. Both the free-field tonal audiometry and verbal audiometry results showed no differences from the preoperative results.

Figure 2 shows the outcome of the surgery and the results of the CI electrophysiology studies.

CASE 2

A 17-year-old patient was admitted to the Department of Pediatric Orthopedics and Oncology of Musculoskeletal System for the surgical treatment of scoliosis. The patient was treated with ototoxic drugs for pneumonia at the age of 1 year. Due to complications of bilateral hearing loss, at the age of 3 years, he was fitted with a CI system for the right ear (type: Digisonic SP, Saphyr processor). The boy demonstrated well-developed speech, with slightly distorted articulation, and attended a mainstream school. In a free-field test, the average hearing threshold was 30 dB at frequencies of 500 Hz, 1 kHz, 2 kHz, and 3 kHz. The patient's speech understanding was 90% in single-syllable tests at 65 dB SPL. Cochlear implant electrode impedance measurements were performed.Written consent was obtained from the patients' parents for publication of the results of the tests obtained during hospitalization.

The Cobb angles of the curves were 50° and 10° in the thoracolumbar and lumbar spine, respectively. The patient underwent surgery to correct the curvature of the thoracic and lumbar spine (Th4-L2). Electrocoagulation was performed at or below the Th3 segment (Th3-L2) during surgery. As in the previous case, coagulation was set at a low level, i.e., 30W. Motor-evoked potential measurements were used to monitor the distance of the screws from the spinal cord during the procedure. The electrode impedances were measured again after the procedure. There were no changes in impedance at any of the electrodes. The readings indicated that the implant was working properly, and there were no changes in the electrodes.

The audiological tests were carried out on the second day after the operation, and no differences were found compared with the tests carried out before the orthopedic operation. In the audiological follow-up and implant impedance measurements after reoperation,

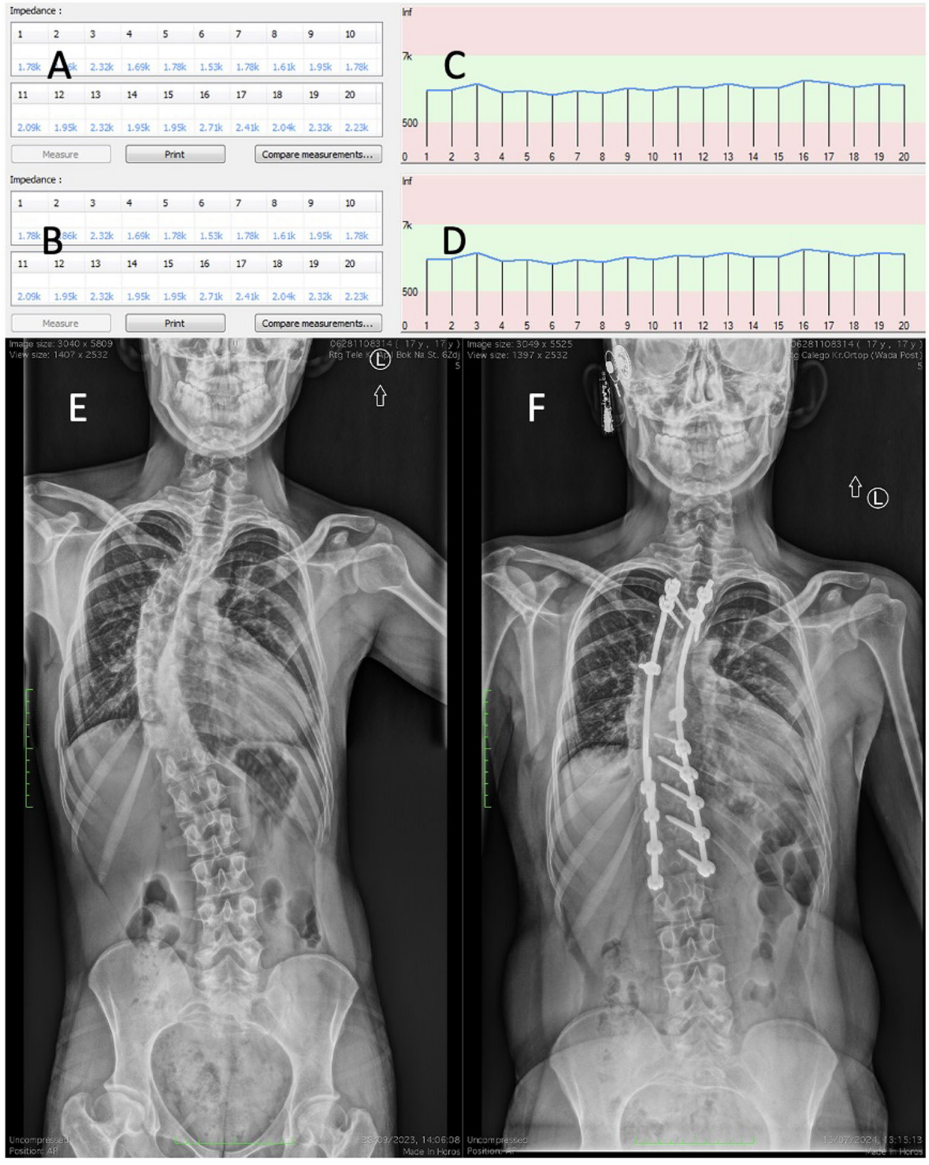

Figure 2. A. eCAP values before surgery. B. eCAP values after surgery; C. electrode impedance values before surgery; D. electrode impedance values after surgery; E. spinal x-ray before surgery; F. spinal x-ray after surgery.

the results of the free-field tonal audiometry, verbal audiometry, and impedance measurements showed no differences from those before surgery. The measurement results and spinal images before and after surgery are shown in Figure 3.

CASE 1

DISCUSSION

The number of CI users is expected to increase, particularly among children, who may require various surgical procedures in the future. Implanted patients will use the implant system for decades, increasing the likelihood that they will undergo various medical procedures based on the flow of electricity. Electrocoagulation is one of the most commonly used methods that use the flow of electricity. However, defibrillation, cardioversion, electroconvulsive therapy, and canal measurement should not be overlooked. Electrocoagulation can be divided into monopolar and bipolar electrocoagulation. In the former, the flow of electrical impulses passes between the instrument and a ground electrode, usually placed on the patient's leg. The use of monopolar electrocoagulation is potentially dangerous for CI users for several reasons.

The first is the risk of damage to the implant, as the electric current used during coagulation can induce voltages in the coil of the CI receiver, which, in turn, can damage the delicate electronic circuits and electrodes in the cochlea.[14] Surgeries performed on the head and neck are particularly risky due to the proximity of the coil to the receiver. Surgery in more distant areas, such as the spine, has a lower risk but cannot be eliminated, according to the manufacturers' information brochures. An analysis of the available publications did not confirm these risks, which should be considered potential. The first studies on this subject were carried out in animals (pigs),[15] in which adenotomy with monopolar coagulation was performed after the implantation of a CI. No device damage occurred in any of the cases studied. Another group consisted of studies in cadavers using coagulation[14,16] and electroshock.[17] Jeykumar et al's[14] study found neither

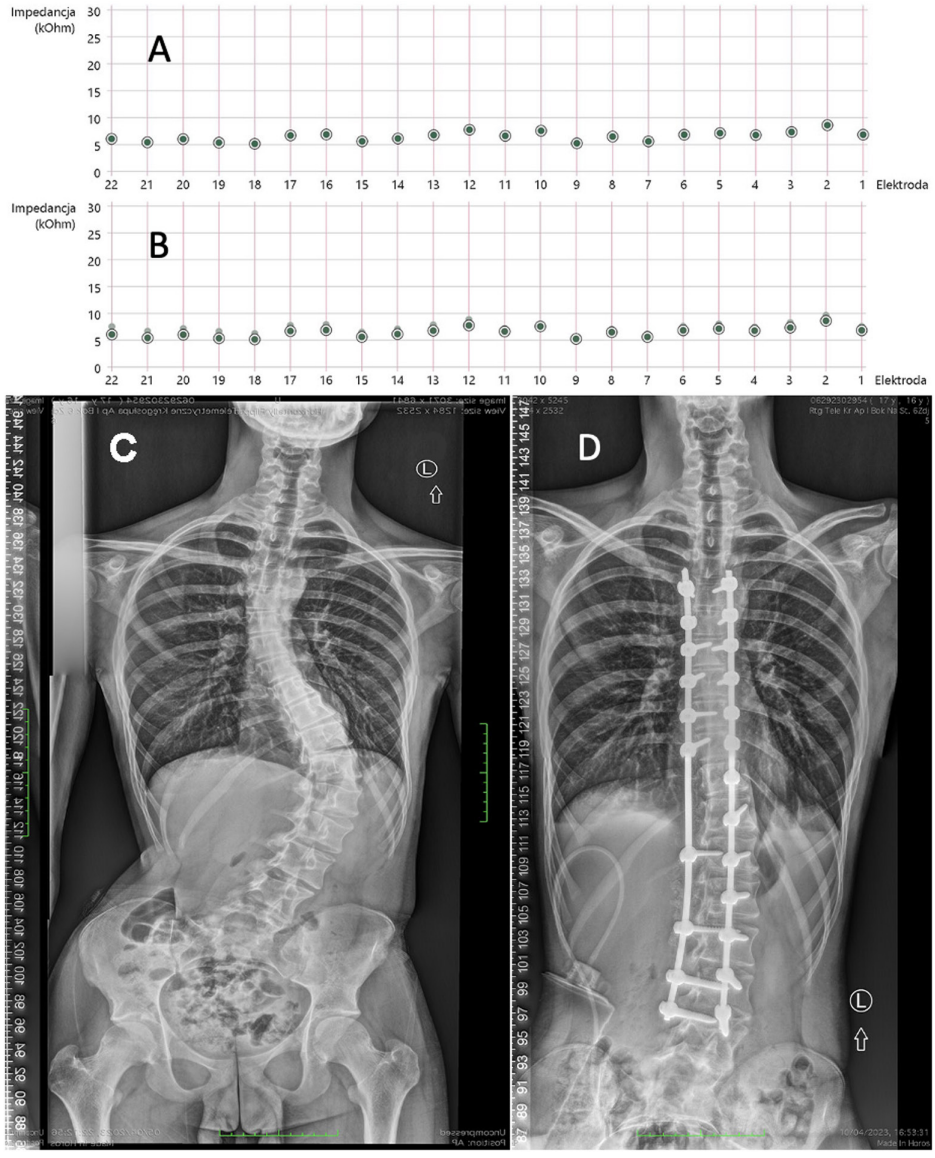

Figure 3. A. Measurement of electrode impedance before surgery; B. measurement of electrode impedance after surgery; C. X-ray of the spine before surgery; D. X-ray of the spine after surgery.

an increase in the cochlear fluid temperature after MoEc [Monopolar electrocoagulation] (which is the second potential risk) nor damage to the implants when using monopolar coagulation on both the thoracic and temporal muscles. The only study in which damage to the CI occurred was Roberts et al's work,[18] which investigated the effects of using an electric pulp tester, apex locator, electrocautery unit, electrosurgery unit, and panoramic radiographer on CI function. It was shown that multiple attempts to use dental measuring devices and bipolar electrocoagulation did not damage the CI. Monopolar electrocoagulation at power levels 1, 3, and 5 (the manufacturer's power) also did not affect the implants, but the first application at power level 7 resulted in CI damage. The trials were not repeated because of the high cost of the implantable part. This is the only confirmed case of CI failure due to monopolar electrocoagulation to date.

Another group of publications concerned descriptions of the use of MoEc in CI users in vivo. In 2016, Tien et al[19] published an article on the use of monopolar electrocoagulation in 2 CI users for adenotonsillotomy procedures, in which no CI injury occurred. The use of electrocoagulation was incidental. MoEc was also used in a CI patient described by Poetker et al,[20] where an 80-year-old patient required a cardiac bypass on day 2 after CI implantation due to ischemic heart disease. The CI functioned perfectly after the operation. Dozens of cases of monopolar coagulation have been described in the literature, and none resulted in device failure.[8,19-21] The largest group of CI patients underwent MoEc procedures due to the lack of attention of the surgeons concerning the presence of the CI. This is evident from a survey published by Cass et al,[8] in which 63 exposures to MoEc were reported in 35 CI patients, both in the chest and abdomen and in the head and neck. No damage to hearing implants was reported in the whole group, and the use of electrocoagulation was due to a lack of awareness of the potential risk of damage to the hearing aid. Another paper by Dornhofer et al[21] presented a review of the literature and surveyed centers with extensive experience in CI surgery. Questionnaires were sent to patients asking about exposure to MoEc. There were 84 cases of such exposure in 78 patients. No

implant was damaged, and 14% of the procedures involved the head and neck. The authors estimated the risk of CI damage to be 0.005%, based on their data and the potential number of implanted patients and exposure to MoEc.

There are reports in the literature of procedures where the use of monopolar electrocoagulation in CI patients was deliberate, preceded by a careful analysis of the literature. These procedures were mainly scoliosis surgeries, where it is necessary to perform an extensive surgical approach in the shortest possible time[6] while ensuring hemostasis. Simultaneously, electrophysiological measurements of sensory and motor potentials are often performed during these procedures, which may have additional potential effects on the electronic cochlear prosthesis, such as an implant; however, their detrimental effects on the device have not been confirmed.[7,10,11,24] Such an analysis was carried out in the cases described. Alternative methods of surgical incision have been tested, which appear to be better regarding implant safety,[4,5] but they do not meet the high demands for hemostasis and operating time that scoliosis correction surgery places on the surgeon. The high demands of this procedure are illustrated by McMahon's paper, in which a survey of orthopedic surgeons was conducted, asking whether the presence of implantable devices changed the surgical plan. Of the respondents, 60% answered in the affirmative.[9]

Table 1 summarizes the existing literature related to the potential impact of MoEc on CIs.

Alongside monopolar electrocoagulation, medical devices such as electroshock, cardioversion, defibrillation, and dental pulp measurements also rely on the flow of electrical current that potentially compromises implanted hearing aids. Nevertheless, other than in Roberts et al's[18] work, this has not been confirmed in equivalent studies. The results of these studies are summarized in Table 1.[7,10,11,17,20,22,23,25-29]

Although there is no conclusive evidence that monopolar electrocoagulation always results in damage to CIs, caution should be exercised, especially during procedures in the head and neck region and where precise monitoring of nerve function is required. Cochlear implant manufacturers continue to classify such procedures as high-risk and recommend minimizing the use of electrocoagulation or using alternative methods whenever possible.

Based on the available studies and literature, it can be concluded that the use of monopolar coagulation in patients with CIs can be safe with appropriate precautions. Safety precautions include the following:

1. The surgical site: Surgery in areas farther away from the head and neck, such as the spine, may be safer, as the risk of direct current exposure to the implant is reduced.
2. The method of head isolation: It is essential to use adequate isolation of the patient's head to prevent the induction of voltages in the CI receiver coil. This includes isolation on a non-conductive substrate and protection against flooding of the head area with body fluids and water from the drill.
3. Electrode impedance monitoring: Regular measurements of electrode impedance before and after surgery allow real-time monitoring of the condition of the implant and the rapid detection of any damage.
4. Reducing the coagulation power: Using low power (e.g., 30 watts) during electrocoagulation can significantly reduce the risk of implant damage while ensuring effective hemostasis.

Similar to the previous limitations of magnetic resonance imaging (MRI) for CI patients, where MRI scans of up to 3T are now possible,

Table 1. Literature Review Describing the Use of MoEc-Based Devices, with an Assessment of Their Impact on Cochlear Implants

Animal Study, Cadaver, In Vivo	Type of Procedure Used	Number of Cases/Exposures Described	Number of Implants Damaged as a Result of the Procedure
1. Cass et al[8] in vivo 2. Jeyakumar et al 2013[16] cadavers 3. Jeyakumar et al 2015[14] cadaver 4. Roberts et al[18] cadaver 5. Tien et al[19] in vivo 6. Antonelli et al[15] cadaver	Monopolar electrocoagulation	1. 35 patients, 63 expositions 2. 2 human cadavers, 15 cochlear implants, 120 expositions 3. 1 cadaver, 2 devices, 8 expositions 4. 60 expositions 5. 2 expositions 6. 12 pig cadavers, 12 expositions	1. 0 2. 0 3. 0 4. 1 5. 0 6. 0
1. Abiola et al[7] Transcranial monitoring in vivo 2. Studer et al[10] in vivo 3. Yelin et al[11] 4. Pan et al[22]	Transcranial stimulation	1. 1 2. 1 3. 2 4. 1	1. 0 2. 0 3. 0 4. 0
1. McRackan et al[17] cadavers 2. Labadie et al[23] in vivo 3. Jiam et al[24]	Electroshock	1. 10 implants, 12 electroshock sessions 2. 1 patient 3. 1 patient, 9 sessions	1. 0 2. 0 3. 0
1. Kim et al[25] in vivo 2. Shield et al[26] in vivo 3. Kaneshiro et al[27] in vivo	Defibrillation/cardioversion	1. 1 2. 1 3. 1	1. 0 2. 1 3. 0
Roberts et al[18]	Dental measurements based on electrical current flow	120 expositions	0
	Total number of damaged CIs from electrical current flow-based procedures	415 expositions	2

it is possible to develop safe protocols for monopolar coagulation. However, this requires further experimental and clinical studies to define the limits of voltage and power that can be safely applied, as well as the development and standardization of procedures to protect CIs during surgery.

CONCLUSION

Although monopolar electrocoagulation is considered a high-risk procedure for patients with CIs, both the literature review and the cases described indicate that such procedures can be performed safely with appropriate precautions. Knowledge must be disseminated about the potential risks of using medical procedures based on the flow of electrical current in CI users, as there is still a lack of awareness among medical professionals. Meanwhile, further experimental studies should be carried out aimed at developing safe protocols to minimize the risk of damage to the CI to ensure that patients can undergo necessary medical procedures.

Availability of Data and Materials: Data supporting this study are included within the article. Other data on the patients described are available, upon request, from the corresponding author.

Ethics Committee Approval: N/A.

Informed Consent: Written informed consent was obtained from the patients' parents who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

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