American Journal of Otolaryngology–Head and Neck Medicine and Surgery 45 (2024) 104203

Contents lists available at ScienceDirect

American Journal of Otolaryngology–Head and Neck Medicine and Surgery

journal homepage: www.elsevier.com/locate/amjoto

Cochlear implantation after head and neck radiotherapy: A multicentric study and systematic review

Marzia Ariano [a,b,1,*], Mosè Sozzi [a,b,1], Francesco Lazzerini [c], Cosimo De Filippis [d], Gino Marioni [d], Sebastiano Franchella [a,b], Davide Brotto [a,b]

[a] Otolaryngology Section, Department of Neuroscience DNS, University of Padova, Padua, Italy
[b] Unit of Otolaryngology, University-Hospital of Padova, Padua, Italy
[c] Otolaryngology, Audiology and Phoniatrics Unit, University of Pisa, 56126 Pisa, Italy
[d] Phoniatrics and Audiology Unit, Department of Neuroscience DNS, University of Padova, Treviso, Italy

ARTICLE INFO

Keywords:
Cochlear implant
Hearing loss
Radiotherapy
Head and neck tumor

ABSTRACT

Objective: The objective of this study is to assess whether cochlear implantation is feasible in patients treated with radiotherapy of the temporal bone (for diseased other than vestibular schwannoma), in terms of surgical management and auditory outcome.

Methods: A systematic review of the literature was performed, screening PubMed, Embase, and Scopus databases, according to PRISMA criteria, retrieving 12 articles. Moreover, 9 cases coming from a multicentric study involving Padova and Pisa University Hospitals, were added, for a total of 62 cases of irradiated patients receiving cochlear implantation.

Results: In our multicentric study we included a total of 9 patients, 6 males, and 3 females (mean age at first cochlear implantation was 53.89 years ± 21.07), while from the literature we considered 53 cases (mean age at first cochlear implantation 48.78 years ± 12.41). We considered for both groups a set of preoperative imaging abnormalities, intraoperative complications and possible postoperative complications.

In our cohort, the preoperative pure tone average (PTA) in the implanted ear was 105.6 dB, and the postoperative one was 34.6 dB. In the literature the preoperative PTA was 111.5 dB (when reported), and the postoperative one 52.8 dB.

Conclusion: Both our experience and the literature suggest that cochlear implantation in an irradiated ear is feasible with a good auditory outcome. Surgical difficulties and fitting challenges can be easily managed by professionals aware of these findings, making these patients good candidates to this rehabilitative option.

1. Introduction

Radiotherapy (RT) uses high-dose X-rays to treat multiple conditions. In head and neck districts, these diseases are typically squamous cell carcinomas of the upper aerodigestive tract, but also brain tumors. RT is a powerful tool at the clinician's disposal, which can be used to treat several neoplastic diseases, either alone, or in combination with other techniques. Despite its unquestionable role in head and neck oncology though, multiple side effects have been reported with non-negligible effects on the quality of life [1].

The radiotherapy used in the management of head and neck tumors (for example nasopharyngeal cancers or medulloblastomas) may include the temporal bone and the brainstem in the treatment volume, and this is particularly true for patients treated in the past. This may have subsequent effects on the hearing function [2] with the possible need for cochlear implantation (CI) in the most severe cases.

The biological mechanisms causing hearing impairment in these patients are yet to be determined. Hearing loss following temporal bone irradiation can result from pathological changes within all the different levels of the auditory pathway: the external auditory canal, the tympanic membrane, the ossicles, the cochlea, the cochlear nerve and the brain [3,4]. This kind of involvement causes difficulties in cases of surigical approaches and doubts about the possible successful outcome of CI.

* Corresponding author.
E-mail address: marzia.ariano@studenti.unipd.it (M. Ariano).
[1] The first two authors equally contributed to the study.

https://doi.org/10.1016/j.amjoto.2023.104203
Received 8 December 2023;
Available online 18 December 2023

Concerning the indication, CI should be considered in case of profound hearing loss, but the overall management of the patient with such a medical history requires to consider the concrete possibility that a long follow up period of the irradiated area is needed, and a CI positioned next to the affected region could impair the proper follow up. This might influence the timing of the CI.

Patients who underwent radiotherapy may face different kinds of hearing loss, and the clinician should be aware of this while considering a CI. It may be of conductive and/or of sensorineural type, and it may result in complete deafness regardless of the underlying mechanism [2,5]. The causes can be external ear and skin damages that are often the result of a radiation-induced obliterative endarteritis, which reduces tissue vascularity, impeding tissue healing [3]. Consequently, a careful follow up program is recommended planned for post-irradiated patients (which includes frequent otoscopic examinations and aural toilet), to precociously identify possible radiation-induced external ear damages. Persistent symptoms such as ear pain and otorrhea may be due to osteoradionecrosis of the temporal bone and have to be addressed as soon as possible [3].

Regarding conductive hearing loss, it is well established that it is often due to secondary chronic or effusive otitis media, related to Eustachian tube dysfunction following RT. Some studies hypothesize an induced mucosal oedema impairing Eustachian tube patency and leading to middle ear fluid collection [5]. Complications related to these mechanisms may cause a worsening of hearing loss. Sensorineural hearing loss may be due to many factors [5]. It could be the result of direct radiation injury to the hair cells with progressive intracochlear fibrosis and hair cell loss [3]. Other authors hypothesize that also radiation induced small vessel damage could play a role, leading to inner-ear vascular insufficiency [6,7]. Sensorineural hearing loss can occur as early as 3 months to 1 year after treatment. It tends to be progressive, and, in most cases, it leads to a complete hearing loss [8]. Another possible complication of RT to the auditory pathway is brainstem necrosis [9]. This serious complication, described in the past [9], has now been minimized by the current use of effective shielding techniques. Consequently, even if very rarely, temporal lobe necrosis occurs more frequently than brainstem necrosis [9]. This dreadful complication might have a latency period ranging from 1.5 to 13 years, presenting with cognitive dysfunction, epilepsy, and central hearing dysfunction. Necessarily, deafness caused by temporal lobe necrosis cannot be eligible to CI [9].

To sum up, regarding all the possible anatomical structures involved in hearing loss after radiation therapy, it is clear that, although an involvement of the brain and central neural structures is still possible, this usually results in reversible conditions [3,6–11]. Moreover, the cases in which radiation therapy affects the distal part of the hearing organ are far more numerous [3,6–11]. So CI is not contraindicated, but should be performed with caution and specific precautions.

In the literature, many papers focus on the effects of RT on the VIII cranial nerve tumors, but this is not the topic of the present study.

The aim of this paper is to provide a systematic review of the available literature about CI after radiotherapy for head and neck tumors; furthermore, 9 new cases from a multicentric data collection have been reported and critically discussed.

2. Methods

We defined our study using the PICO protocol as follows (Patient: patients that underwent head and/or neck irradiation with hearing loss, Intervention: cochlear implantation, Comparison: none, Outcome: hearing restoration).

PubMed, Embase, and Scopus were systematically screened up until August 2023.

Pubmed database was screened using both mesh term search (“Radiotherapy”[Mesh]) AND (“Cochlear Implants”[Mesh] OR “Cochlear Implantation”[Mesh]) and the free term search (Radiotherapy OR radiation therapy OR radiotherapies), AND (cochlear implantation OR cochlear implant) in “All fields” category.

Embase was screened with the “Advanced Search” feature (Radiotherapy OR radiation therapy OR radiotherapies) AND (cochlear implantation OR cochlear implant). Scopus was screened within “article title, abstract, keywords” with the same free term search.

The literature search and the collection of data was performed independently by two investigators (MA and MS). Every misalignment with regards to article eligibility was solved through discussion with the senior author (DB).

All the retrieved publications were evaluated to identify the most relevant ones. Exclusion criteria included duplications or aggregations of pre-existing data and articles which were not written in English. We did not set any temporal filters on publication dates. We did not consider articles regarding other kinds of ear prosthesis (e.g. bone conduction prosthesis or middle ear implant).

The literature review was performed according to the PRISMA criteria (Fig. 1).

Risk of Bias assessment was performed independently by two authors (DB and MS).

In addition to the literature, new data about 9 new cases from a multicentric recruitment among tertiary referral Italian Centers experienced in cochlear implantation were considered for the discussion: University of Padova and University of Pisa. We considered all the patients with a history of head and neck radiation therapy (excluding vestibular schwannoma patients), which underwent following cochlear implantation on either ear, regardless of the side of RT (if present). The full list is available in Table 1 in Supplemental materials.

3. Results

The database search resulted in 148 articles in Pubmed (MESH term plus free term search), 112 articles in Embase and 91 in Scopus. The final list of the selected articles included 12 articles (Fig. 1). The full list is available in Table 2 in Supplemental materials.

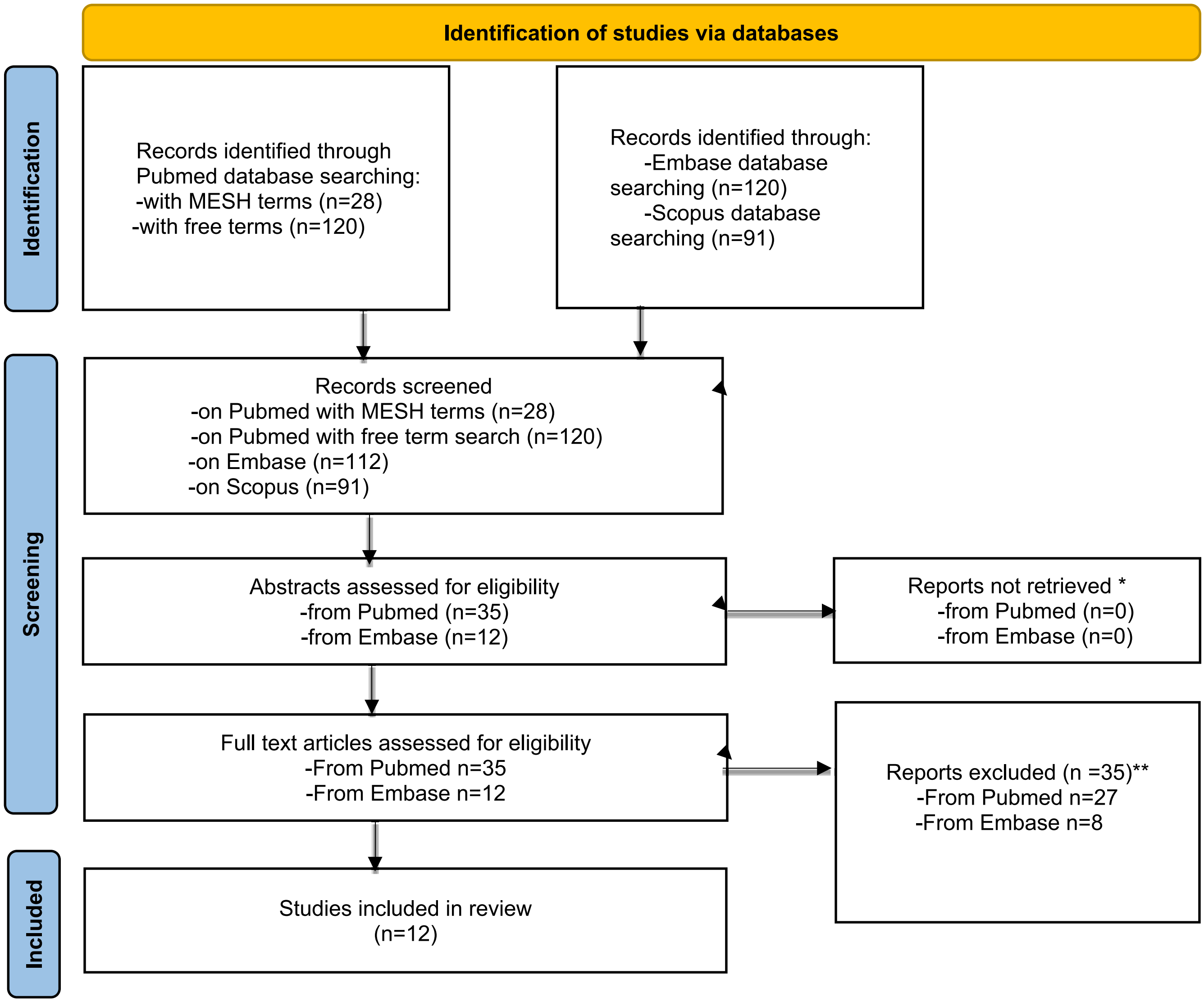
3.1. Multicentric case series

In our multicentric investigation, a total of 9 patients (6 males, and 3 females, 56.3 + 21.7 years) were involved. All patients received head and neck irradiation and subsequent cochlear implantation. The RT was performed for various reasons: 3/9 patients were treated for nasopharyngeal carcinoma, 1/9 for pharyngeal carcinoma, 1/9 for oral carcinoma, 2/9 for brain tumors 1/9 for vocal cord carcinoma and 1/9 for pituitary gland tumor. Radiation therapy preceded cochlear implantation ranging from 34 to 5 years. Mean age at first cochlear implantation (1 patient received 2 CIs) was 53.89 $\pm$ 21.07 years.

In preoperative imaging, by means of computed tomography (CT) and/or magnetic resonance imaging (MRI), 4/9 patients (44.4 %) showed ear anomalies: in 4 cases there were anomalies at the CT scan, two of them had also altered preoperative MRI (see Table 1 in Supplemental materials). The anomalies ranged from fibrotic tissue in the middle ear, to sclerotic ossicular chain, chronic otomastoiditis with epitympanic and external auditory canal osteolysis, and hypoplastic VIII cranial nerve (the last two found also by MRI scan) (Table 3 section a).

The surgical technique for cochlear implantation in all of the patients included in our cohort was a standard mastoidectomy and posterior tympanotomy.

Regarding intraoperative findings in our cohort, one (1/9, 11.1 %) presented intraoperatively with a sclerotic mastoid, five (5/9, 55.5 %) had thin skin observed during surgical incision, one (1/9, 11.1 %) had a pre-surgery dehiscence in the region of the surgical wound, none of the patients (0/9) had incomplete insertion of the array, one (1/9, 11.1 %) had Gusher during surgery and one (1/9, 11.1 %) was found to have a tympanic membrane perforation (Table 3 section b).



*Articles excluded if not pertinent, if not available full text, if duplicates
**Articles excluded if not pertinent

Fig. 1. PRISMA flowchart for literature research.

Table 3
Ear alterations at preoperative imaging (a), intraoperative findings (b), postoperative complications (c), in our cohort.

a. Preoperative imaging: ear alterations			b. Intraoperative findings			c. Postoperative complications		
CT	4/9	44.4 %	Incomplete array insertion	0/9	0 %	FN stimulation*	2/9	22.2 %
MRI	2/9	22.2 %	Sclerotic mastoid	1/9	11.1 %	CI esplantation/reimplantation°	1/9	11.1 %
			Gusher	1/9	11.1 %	Distrofic skin with magnetulceration/displacement°	2/9	22.2 %
			Thin skin	5/9	55.5 %	Tinnitus and dizziness°	1/9	11.1 %
			Dehiscence	1/9	11.1 %	Haematoma under CI site*	1/9	11.1 %
			TM perforation	1/9	11.1 %			

CT: computed tomography, MRI: magnetic resonance imaging, TM: tympanic membrane, CI: cochlear implant, FN: facial nerve, *:short term complications, °:long term complications.

We found out in our cohort both short-term and long-term complications, setting an arbitrary temporal cutoff at 3 months.

Regarding short-term postoperative complications, two (2/9, 22.2 %) had facial nerve stimulation, one (1/9, 11.1 %) had an haematoma in the cochlear implant site which was drained. For long-term ones instead, one patient (1/9, 11.1 %) underwent CI explantation and subsequent reimplantation due to skin ulceration, two (2/9, 22.2 %) patients had skin ulceration with magnet displacement/instability and one (1/9, 11.1 %) patient reported tinnitus and dizziness, all of them experienced the complication some years after the implantation (Table 3 section c).

Hearing outcomes in our cohort were satisfactory. The mean PTA score was considered before and after the CI (assessing the hearing thresholds at 500-1000-2000-4000 Hz). Hearing outcomes were available up to 1 year after CI in all 9 of our patients, while for 4 of them we

Table 4
Preoperative and postoperative mean PTA (pure tone average) in the implanted ears (when available). When hearing loss referred to as "anacusia", we assumed a PTA of 110.

	Our cohort	Literature review
Preoperative PTA (mean)[a]	105.6	111.5 (when present)
Postoperative PTA (mean)[b]	34.6	52.8

[a] In the implanted ear.
[b] At the last visit.

considered the PTA at the last visit, dating 3 years after the procedure. After cochlear implantation the mean PTA of the implanted ear improved from 105.6 dB to 34.6 dB (Table 4).

3.2. Literature review

Considering selected literature, 53 patients that underwent CI after radiotherapy treatment could be retrieved from the 12 articles included in this review.

The results have been summarized in Table 2 (Supplemental materials). The description of the cases was quite heterogeneous, making the comparisons and an overall analysis quite difficult. Apart from one article [12] which did not mention the patient's age, the mean age at CI was 48.78 ± 12.41 years.

In preoperative imaging, 14/53 (26 %) patients had ear abnormalities at the CT; 11/53 (21 %) had also an anomaly reported at the MRI, including soft tissue density in the middle ear and mastoid cavities [13], dehiscence of the mastoid segment of the facial nerve bony canal [3], skull base osteoradionecrosis [8], severe and extensive radioactive osteomyelitis with or without bone and skin defect [8]. All these aspects were probably due to the previous radiotherapy. Biggs et al. [4] reported the incidental finding of an inner ear abnormality, with a complete loss of the bony partition between the lateral end of the internal auditory meatus and the cochlea, without the modiolus (most probably a congenital abnormality) (Table 5 section a).

About the surgical technique, CI implantation was performed with mastoidectomy and posterior tympanotomy in 7 patients [2,6,8,13]. Eleven patients underwent extended radical mastoidectomy, of which 7 underwent external ear canal blind sac closure [8,9,11]. In 4 cases there was no data on the surgical approach [5,7,9,12], and in four cases the surgical approach was influenced by previous ear surgery with radical mastoidectomy and blind sac closure [3,4,7,10].

Regarding intraoperative findings, the literature reported some cases of incomplete array insertion (2/53, 3.77 %) [2,8], and cases of thin skin (1/53, 1.88 %) [13] and wound dehiscence (1/53, 1.88 %) [10]. One case of Gusher (1/53, 1.88 %), an intracochlear and vestibular fluid loss at the moment of cochlear implant insertion, has been reported [13]. In one case (1/53, 1.88 %) there was the description of a preoperative mastoid-cutaneous fistula requiring surgical closure [10]. There was one report (1/53, 1.88 %) of pneumo-labyrinth with a very high electric impedance over most of the electrodes' contact area which delayed cochlear implant activation [13], and overall, three (3/53, 5.6 %) cases of inflammation tissue in the middle ear, with easily bleeding mucosa [2,3,5]. In five patients (5/53, 9.4 %) it was observed a mastoid consistency softer than normal [6], and in 2 patients (2/53, 3.77 %) the facial nerve was found uncovered by bone in its vertical portion during mastoidectomy [6]. In one case, preoperative otoscopy showed a localized area of osteitis in the canal and a moist central tympanic perforation [9]. In one article (1/53, 1.88 %) the authors state that an underlying radiation encephalopathy, secondary to the previous radiation therapy, impaired the CI function [8] (Table 5 section b.).

As previously described for our cohort, we considered short-term and long-term complications, setting as an arbitrary temporal cutoff 3 months.

Among the short-term postoperative (fitting-related) complications, facial nerve stimulation was very rare, only 1/53 (1.88 %), reported by Adunka et al. [3], while in 2/53 (3.77 %) of patients, elevated impedance was measured at the level of the electrodes, delaying cochlear implant activation [3,13]. In one case (1/53, 1.88 %) it was reported the long-term complication of array extrusion in the left external auditory canal, 6 years after surgery (Table 5 section c.).

Not all the studies provided objective data on hearing function after cochlear implantation, but all agreed in saying that the CI was successful. Whenever possible, we considered the mean PTA score before and after the CI (assessing the hearing thresholds at 500-1000-2000-4000 Hz). After cochlear implantation, in the implanted ear, the PTA improved from 111.5 dB to 52.8 dB (Table 4).

4. Discussion

According to our experience, patients presenting profound hearing loss after radiotherapy are not so uncommon in clinical practice, considering the central role of this treatment for head and neck tumors. The choice of a cochlear implantation is considered challenging by some clinicians, because of the concern of a poor auditory outcome or a difficult surgical management.

To date, in literature, 62 patients have been described with cochlear implantation after radiotherapy (53 in previous reports and 9 of our cohort) suggesting that, in most cases, cochlear implantation is a feasible procedure, with good auditory outcome. Nonetheless, although it is easy to understand that these results may not be as good as those of non-irradiated patients [14], cochlear implantation still constitutes a life-changing tool for the ones which underwent RT for head and neck cancer.

Despite these considerations, our experience and the literature review suggest that these patients require specific management to optimize the procedure. First of all, the indication of implantation should be considered carefully. To precisely know the entity of electrical excitability of surviving auditory neural elements, some authors suggest a preoperative electrostimulation via an extra-tympanic ear canal electrode to further select the patients undergoing the implantation [2]. Another important factor when deciding to implant a patient with a history of head and neck tumor, is to consider the opportunity to visualize the area, to monitor the results of the treatment and for the risk of recurrence. In fact, it is well known that MRI is extensively used during follow ups. The presence of the cochlear implant may influence the visualization of the nearby structures, thus hampering the surveillance over time [10]. Consequently, the implantation should be considered when the risk of recurrence is estimated to be minimal, or when a cochlear implant would not impair the proper visualization of the anatomical structures of interest. MRI is feasible even in cochlear implant users, but the position of the magnet and the intensity of the magnetic field used can cause different shadow effects that should be taken into consideration while dealing with these kinds of patients. Recent studies [15] suggested that, depending on the cancer site, cochlear implant magnets can be placed in different positions of the temporal bone, to allow a better visualization of the various anatomical structures. For example, at 90° orientation, radiological artifacts mainly involve anterior brain structures, while in the 160° orientation, the problems of visualization involve the posterior fossa structures. Moreover, in the event of tumor recurrence or secondary malignancy in the cochlear implant region requiring a surgical approach, it is important to remember that only bipolar electrocautery could be used for intraoperative hemostasis [10]. Unfortunately, no data are available about

Table 5
Ear alterations at preoperative imaging (a), intraoperative findings (b), postoperative complications (c), in the literature.

a. Preoperative imaging: ear alterations			b. Intraoperative complications			c. Postoperative complications		
CT	14/53	26.4 %	Incomplete array insertion	2/53	3.77 %	FN stimulation*	1/53	1.88 %
MRI	11/53	20.75 %	Sclerotic mastoid	0/53	0 %	CI esplantation/reimplantation*	0/53	0 %
			Gusher	1/53	1.88 %	array extrusion°	1/53	1.88 %
			Thin skin	1/53	1.88 %	Elevated electrodes impedances*	2/53	3.77 %
			Dehiscence	1/53	1.88 %			
			Other:	14/53	26.4 %			
			● Soft mastoid	5/53	9.4 %			
			● ME bleeding mucosa	3/53	5.7 %			
			● Dehiscent FN	2/53	3.78 %			
			● Mastoid-cutaneous fistula	1/53	1.88 %			
			● Pneumolabyrinth	1/53	1.88 %			
			● TM perforation	1/53	1.88 %			
			● RE	1/53	1.88 %			

ME: middle ear, FN: facial nerve, TM: tympanic membrane, RE: radiation encephalopathy, *: short term complications, °: long term complications

the impact of direct radiotherapy on cochlear implants (for patients who may require it in case of recurrence) [10], but we should not consider this risk a contraindication to this rehabilitation option in these patients.

Imaging by means of CT and MRI is crucial for a tailored surgical planning, since around a third of patients of the literature (44 % in our cohort) may present anomalies at preoperative imaging. The anomalies in our cohort range from fibrotic tissue in middle ear, to sclerotic ossicular chain, to chronic otomastoiditis with epitympanic and external auditory canal osteolysis, to hypoplastic VIII cranial nerve. Also in the literature, there was the report of soft tissue density in the middle ear and mastoid cavities [13]. We did not experience some more severe complications reported by the different studies, such as dehiscence of the mastoid segment of the facial nerve bony canal [3], skull base osteoradionecrosis [8], severe and extensive radioactive osteomyelitis with or without bone and skin defects [8]. All these changes, even according to the authors, are probably the result of radiation therapy, but there was also the case of the incidental finding of a most probably congenital inner ear abnormality, with a complete loss of the bony partition between the lateral end of the internal auditory meatus and the cochlea [4], highlighting the importance of preoperative imaging in planning the surgical steps of a CI. Despite all these findings, insertion issues are reported in a very limited number of patients (3,77 % in the literature [2,8], 0 % in our cohort), suggesting that this surgery might be challenging, but well managed by experienced surgeons.

Hereby follows the possible complications and challenges which may differentiate an irradiated temporal area from a normal one. Skin frailty is a well-known complication of radiotherapy treatment, that is supposed to be determined by an obliterative endarteritis, which reduces the vascularization of the tissues [3]. After surgery, in these patients, the pathological changes in the skin could complicate or even prevent wound healing, resulting in wound dehiscence or even implant extrusion: [3] in our cohort there was a single case of an electrode dehiscence. Chua et al. [11] observed an electrode extrusion through the posterior wall of the external ear canal. Regarding thin skin covering the temporal bone, it was observed in more than a half of our patients (5/9), while only one case that was previously reported [13]. Nonetheless our experience and the literature suggest that incisions in erythematous or atrophic skin areas should be avoided, choosing at the same time limited incision approaches, gentle handling of the skin flaps and limiting the use of electrocautery. During follow ups, considering the frailty of the operated area, careful monitoring of the surgical incision and the magnet region is needed [3], in order to prevent extrusions or infections of the area (Fig. 2). For patients considered at higher risk of cutaneous complications, skin flaps should also be considered.

Concerning the surgical technique, literature reports a wide use of petrosectomy and radical mastoidectomy with blind sac closure, while in our cohort a more conservative approach (mastoidectomy and posterior tympanotomy) was chosen. The reason for these surgical choices is probably that in the literature, most patients had already undergone some sort of otologic procedure, dictating the need for demolition approaches. On the contrary, none of the patients of our cohort underwent previous otologic interventions, and this allowed us to insert cochlear implants via the classical route. Data about the outcomes and possible complications of the surgical approach in these patients are not available, but strict follow up for potential recurrence of tympanic membrane perforations should be considered.

Fig. 2. Photographs of a case of our cohort showing thin skin, with bulging of the internal part of the CI and the mark of the coil due to excessive pressure induced by the magnet.

Radiotherapy can induce changes in the temporal bone that could provide a region at risk of subsequent infection or that could put at risk of surgical injury important structures such as the neurovascular ones (i. e.: facial nerve, carotid artery and jugular vein) since anatomic landmarks can be altered and/or difficult to identify [3]. In most articles, the bone is described to be softer and more fragile than normal, imposing extra care during surgical drilling [6,9,10]. In our series this feature was not confirmed, probably due to the limited number of patients included. There was, though, the case of a sclerotic mastoid, even if we could not assess if this finding was a consequence of the radiotherapy treatment or a congenital anatomical variant. If temporal bone necrosis is observed prior to CI surgery, the surgeon must address it with a complete removal of necrotic bone, providing at the same time an adequate tissue vascularity, for example through preoperative hyperbaric oxygen therapy [3].

Pathological changes in the tympanic membrane, such as perforation following RT (found both in our series and in previous reports), may need a myringoplasty. The concomitant chronic Eustachian tube dysfunction may in any case compromise the surgical success despite the integrity of the tympanic membrane [9]. Changes of the middle ear mucosa, including a chronic inflammatory hyperplasia, easily bleeding granulation, cholesterol granulomas [2,5,8,16] and frequent adhesions [10] may be present too, even though we did not encounter them in our cohort. These conditions might lead to an additional difficulty to locate the round window for electrode insertion and this should be surgically addressed to prevent infections or extrusions of the array. Some surgeons [2,3], were forced to perform a cochleostomy in the promontory to open the scala tympani because of the abundant inflammatory tissue in the middle ear masking the round window. Pathological changes in the inner-ear, for example cochlear fibrosis or necrosis could impair the effective and complete electrode insertion. In some cases, none in our series, it was observed a scalar obstruction similar to that encountered in post-meningitis cases [3]. This event should be identified by means of preoperative imaging, detecting hypointense fluids within the inner ear at T2-weighted MRI imaging and unexpected reduction of the lumen of the scala tympani in CT images (though the CT should be considered less sensitive). The detection of these red-flags should be considered to select the most suitable electrode to ease its insertion. Indeed, the specific anatomy may force the surgeon to choose a straight electrode over a precurved one or to prefer a short electrode if a partial insertion is probable, for example. Preoperative imaging might also be useful to identify the possible coexistence of underlying (though rare) pathologies such as cochlear malformations, which might require alternative surgical strategies to face cerebrospinal fluid (CSF) leakage, as reported by Moteky et al. [13] When the access via the round window is deemed difficult, the surgeon should consider performing a cochleostomy as described by Chua et al. [11], or even positioning the array in the *scala vestibuli*. If possible, a one stage surgery should be preferred to avoid the risk of difficulty in locating the round window in second-stage surgery [8].

Postoperative management should be tailored for these specific patients considering that some of them might present facial nerve stimulation at cochlear implant fitting (22.2 % in our cohort, 1.88 % in literature, but the data may be under-reported). This finding may be due to inadequate fitting or to the altered diffusion pattern of the spread of electricity due to the altered bone structures nearby the cochlea. This issue can also be managed in experienced centers with limited impact on the auditory results. In general, both in our cohort and in the previous reports, all patients showed better audiological outcomes after surgery, with a demonstrated improvement of communication skills and better quality of life (Table 4). Nonetheless, it is possible that the number of patients with poor outcomes is underestimated, due to the probable publication bias existing in the literature. In fact, there may be the tendency to report only the good outcomes when a procedure is investigated, while the poorer and complicated ones remain untold.

Concerning our case series, some limitations should be mentioned: 1) the number of patients of our cohort was limited, 2) the protocol and field of radiation was not available for most patients and was not included in the present study (these parameters may affects both the results and the risk of surgical complications), 3) the heterogeneity of patients in terms of period of treatment was wide (with similar biases as the previous point) (Table 4).

5. Conclusions

Head and neck irradiation often lead to hearing loss. Once the risk of tumor recurrence could be considered minimal, hearing rehabilitation via CI should be proposed to these patients. If CI is chosen, the surgeon should apply extra care considering all the difficulties of post-irradiated structures, planning a tailored surgical strategy.

Despite the possible concerns about CI after head and neck district radiotherapy, our experience and the available literature suggest that the procedure is feasible, with good auditory outcomes. The surgical difficulties (for example fragile bone and skin) and the fitting challenges (for example postoperative facial nerve stimulation) can be managed by professionals aware of these findings, making these patients good candidates to this rehabilitative option.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjoto.2023.104203.

Consent

Written informed consent from the patients involved.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Marzia Ariano: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Writing – original draft. **Mosè Sozzi:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Writing – original draft. **Francesco Lazzerini:** Resources, Visualization. **Cosimo De Filippis:** Supervision, Visualization, Writing – review & editing. **Gino Marioni:** Supervision, Visualization, Writing – review & editing. **Sebastiano Franchella:** Visualization, Writing – review & editing. **Davide Brotto:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

None.

Acknowledgements

None.

References

[1] Samsøe G, Bruvo M, Gerberg L. The quality of life of men one year after radiotherapy for head and neck cancer: the fine details of experience matter [published online ahead of print, 2022 May 17]. Radiography (Lond) 2022;28(3): 654–9. https://doi.org/10.1016/j.radi.2022.04.010.

[2] Formanek M, Czerny C, Gstoettner W, Kornfehl J. Cochlear implantation as a successful rehabilitation for radiation-induced deafness. Eur Arch Otorhinolaryngol 1998;255(4):175–8. https://doi.org/10.1007/s004050050038 [PMID: 9592673].

[3] Adunka OF, Buchman CA. Cochlear implantation in the irradiated temporal bone. J Laryngol Otol Jan 2007;121(1):83–6. https://doi.org/10.1017/S0022215106002180 [Epub 2006 Oct 16. PMID: 17040614].

[4] Biggs ND, Ramsden RT. Cochlear implantation in a previously irradiated temporal bone—a case report. Cochlear Implants Int Sep 2001;2(2):129–34. https://doi.org/10.1179/cim.2001.2.2.129 [PMID: 18792094].

[5] Chua DY, Thong MK, Tan HK, Govil S. Successful rehabilitation with cochlear implant in post-irradiation-induced hearing loss in nasopharyngeal carcinoma patient. Cochlear Implants Int Sep 2004;5(Suppl. 1):158–61. https://doi.org/10.1179/cim.2004.5.Supplement-1.158 [PMID: 18792281].

[6] Yue V, Leung EK, Wong TK, Tong MC, Van Hasselt CA. Cochlear implantation for post-irradiation deafness. Cochlear Implants Int Sep 2004;5(Suppl. 1):165–8. https://doi.org/10.1179/cim.2004.5.Supplement-1.165 [PMID: 18792283].

[7] Chang WW, Yeung KN, Luk BP, Leung KK, Sung JK, Tong MC. Cochlear implantation in postirradiated ears: a case-control comparative study. Laryngoscope Investig Otolaryngol Oct 28, 2020;5(6):1163–7. https://doi.org/10.1002/lio2.486 [PMID: 33364408; PMCID: PMC7752086].

[8] Huang Y, Wang X, Huang H, Ge R, Liu X, Huang D, et al. Long-term outcomes of Cochlear implantation in irradiated ears of nasopharyngeal carcinoma patients. Laryngoscope Mar 2021;131(3):649–55. https://doi.org/10.1002/lary.28909 [Epub 2020 Aug 20. PMID: 32815553].
[9] Low WK, Gopal K, Goh LK, Fong KW. Cochlear implantation in postirradiated ears: outcomes and challenges. Laryngoscope Jul 2006;116(7):1258–62. https://doi.org/10.1097/01.mlg.0000225935.80559.11 [PMID: 16826071].
[10] Roland Jr JT, Cosetti M, Liebman T, Waltzman S, Allen JC. Cochlear implantation following treatment for medulloblastoma. Laryngoscope Jan 2010;120(1):139–43. https://doi.org/10.1002/lary.20669 [PMID: 19693928].
[11] Chua CA, Low D, Tan TY, Yuen HW. Cochlear implantation in an NPC patient post-irradiation presenting with electrode array extrusion through the posterior canal wall. Am J Otolaryngol May–Jun 2017;38(3):356–7. https://doi.org/10.1016/j.amjoto.2017.01.021 [Epub 2017 Jan 19. PMID: 28132728].
[12] Chang KP, Huang TS, Hsu HC, Su SY. Cochlear implantation in a post-irradiated patient for nasopharyngeal carcinoma. Cochlear Implants Int Sep 2004;5(Suppl. 1): 227. https://doi.org/10.1179/cim.2004.5.Supplement-1.227 [PMID: 18792311].
[13] Moteki H, Fujinaga Y, Goto T, Usami SI. Pneumolabyrinth, intracochlear and vestibular fluid loss after cochlear implantation. Auris Nasus Larynx Oct 2018;45 (5):1116–20. https://doi.org/10.1016/j.anl.2018.03.004 [Epub 2018 Apr 19. PMID: 29680680].
[14] Soh JM, D'Souza VD, Sarepaka GK, Ng WN, Ong CS, Low WK. Cochlear implant outcomes: a comparison between irradiated and non-irradiated ears. Clin Exp Otorhinolaryngol Apr 2012;5(Suppl. 1):S93–8. https://doi.org/10.3342/ceo.2012.5.S1.S93 [Epub 2012 Apr 30. PMID: 22701157; PMCID: PMC3369992].
[15] Canzi P, Magnetto M, Simoncelli A, Manfrin M, Aprile F, Lafe E, et al. The role of cochlear implant positioning on MR imaging quality: a preclinical in vivo study with a novel implant magnet system. Eur Arch Otorhinolaryngol Jun 2022;279(6): 2889–98. https://doi.org/10.1007/s00405-021-07005-y [Epub 2021 Aug 9. PMID: 34370074; PMCID: PMC9072450].
[16] Chua DY, Thong MK, Tan HK, Govil S. Successful rehabilitation with cochlear implant in post-irradiation-induced hearing loss in nasopharyngeal carcinoma patient. Cochlear Implants Int Sep 2004;5(Suppl. 1):158–61. https://doi.org/10.1179/cim.2004.5.Supplement-1.158 [PMID: 18792281].