Journal of the Neurological Sciences 450 (2023) 120672

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

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

Histopathological reaction in the vestibule after cochlear implantation in *Macaca fascicularis*.

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ARTICLE INFO

Keywords:
Cochlear implantation
Vestibular organs
Histology
Utricle
Saccule

ABSTRACT

Cochlear implantation surgery (CI) is considered a safe procedure and is the standard treatment for the auditory rehabilitation in patients with severe-to-profound sensorineural hearing loss. Although the development of minimally traumatic surgical concepts (MTSC) have enabled the preservation of residual hearing after the implantation, there is scarce literature regarding the vestibular affection following MTCS.

The aim of the study is to analyze histopathologic changes in the vestibule after CI in an animal model (*Macaca fascicularis*). Cochlear implantation was performed successfully in 14 ears following MTCS. They were classified in two groups upon type of electrode array used. Group A ($n = 6$) with a FLEX 28 electrode array and Group B ($n = 8$) with HL14 array. A 6-month follow-up was carried out with periodic objective auditory testing. After their sacrifice, histological processing and subsequent analysis was carried out. Intracochlear findings, vestibular presence of fibrosis, obliteration or collapse is analyzed. Saccule and utricle dimensions and neuroepithelium width is measured.

Cochlear implantation was performed successfully in all 14 ears through a round window approach. Mean angle of insertion was >270° for group A and 180–270° for group B. In group A auditory deterioration was observed in Mf 1A, Mf2A and Mf5A with histopathological signs of scala tympani ossification, saccule collapse (Mf1A and Mf2A) and cochlear aqueduct obliteration (Mf5A). Besides, signs of endolymphatic sinus dilatation was seen for Mf2B and Mf5A. Regarding group B, no auditory deterioration was observed. Histopathological signs of endolymphatic sinus dilatation were seen in Mf 2B and Mf 8B.

In conclusion, the risk of histological damage of the vestibular organs following minimally traumatic surgical concepts and the soft surgery principles is very low. CI surgery is a safe procedure and it can be done preserving the vestibular structures.

1. Introduction

In the last 4 decades, cochlear implantation surgery (CI) has been a major breakthrough in the treatment of patients suffering severe to profound hearing loss [1]. Nowadays, CI is considered a safe and reliable procedure. Minimally traumatic surgical concepts (MTSC) and the use of atraumatic electrodes have enabled the preservation of residual hearing after the implantation [2]. Although, functional and histological studies show high rates of hearing preservation after implantation and even after reimplantation [3,4], the influence of cochlear implantation following MTSC on the vestibular function remains unclear [5].

The vestibular system lies within the membranous labyrinth of the inner ear, bordered laterally by the middle ear ~~medially by the temporal bone~~ and anteriorly by the cochlea. The vestibular endorgan has five receptors to receive input on angular stimuli: anterior, posterior and horizontal semicircular canal and to receive input on acceleration stimuli: utricle macula and saccule macula. Its structures can be impaired during the surgical act at the very initial step when the inner ear is opened both at the round window membrane or more anteriorly performing a cochleostomy. Both procedures resemble the effect of an acute perilymphatic fistula [6], provoking a floating labyrinth or the collapse of membranous structures with the corresponding modification of vestibular function [7]. However, it is not always accompanied by a simultaneous elevation in acoustic thresholds neither in acoustic

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https://doi.org/10.1016/j.jns.2023.120672
Received 4 January 2022; Received in revised form 2 May 2023; Accepted 5 May 2023
Available online 12 May 2023

distortion products given no additional damage [8], manipulation or pressure are performed after the opening of the round window or cochleostomy [9]. This could occur during the specific action of introducing the electrode array [10], or more infrequently because of electrode array misplacement into the vestibule [11]. Even with the MTSC, the traumatic action of the electrode insertion into the scala tympani carries a potential risk of affecting the vestibular function just by opening the inner ear [12] or the inflammatory cascade that the insertion of an electrode may provoke. Most of these issues have been addressed during surgery which now follows some steps or indications intending to residual hearing preservation. Modifications on the electrode design and surgical tips tend to diminish deterioration of inner ear function.

In the long term however once vestibular and balance disorders are detected after CI, such disorders might improve or remain the same depending on the study, and regardless of the functional tests results [13–15].

An histopathological study could help to elucidate the effects of inserting an electrode array into the cochlea at the vestibule level, and therefore provide some of the answers to the questions that this surgery raises, such as what type of lesion might be seen in the vestibule after CI following MTSC? The objective of this study was to evaluate the histopathologic changes in the vestibular maculae after CI in *Macaca fascicularis*. To ascertain such goal, histological analysis main objective is to assess saccule and utricle size is performed. Besides, quantification of neuroepithelium width and assessment on fine inner ear structures and appearance of biological reaction. We selected the macaque animal model due to its anatomical and physiological similarities to humans.

2. Materials and methods

2.1. Overview

In this experimental study 14 non-human primates (*Macaque fascicularis*) were included. All of them underwent surgery to place a cochlear implant electrode array. They were classified in two groups upon type of electrode array used. Group A ($n = 6$) and Group B ($n = 8$) and each macaque was labelled as Mf1A, Mf2A, Mf7B and so on. A 6-month follow-up was carried out with periodic objective auditory testing and X-ray to assess depth of insertion. After their sacrifice, histological processing and subsequent analysis was carried out.

2.2. Experimental animals

Animals weighed between 2.6 and 4.5 kg. Specimens were housed at the University of Navarra Animal Facilities and treated in compliance with European Union Regulation 86/609, and in accordance with protocols approved by the Animal Care and Use Committee of the University of Navarra (file number 005/15 and 057/13).

2.3. Electrode array

2.3.1. Group A

The electrodes used were based on clinical FLEX 28 electrode arrays with 12 contacts [16]. The electrode diameter was equal to a standard FLEX electrode array (Fig. 1). Five to six contacts were inserted into the scala tympani to avoid total occupation of the scala tympani that would certainly be traumatic; thus the average depth of insertion was approximately 14 mm (full basal turn and partially first turn; angle of insertion: 270°) (Fig. 1).

2.3.2. Group B

The CI Electrode Array HL14 used is a preclinical research array *[Shepherd, T.* et al. *(2011)]*, manufactured by Cochlear Ltd. It has 14 contacts and it is 10.5 mm long from the most basal electrode to the distal tip of the array. The tip diameter of the HL 14 array is 0.35 mm, increasing to 0.5 mm at the basal electrode that is located 6 mm from the tip of array. Fig. 1 shows the HL14 electrode array, including its characteristics and depth reached in case of full insertion of 11.5 mm.

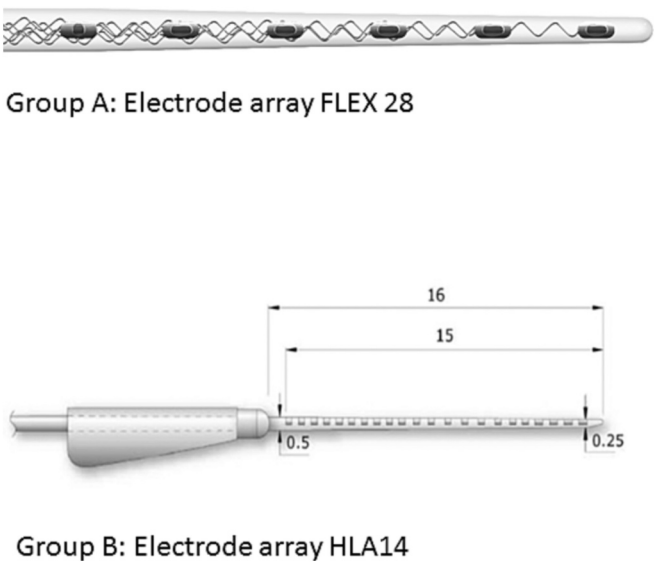


Fig. 1. Electrode arrays for each group.

2.4. Surgical procedure

The surgical procedure was performed following MTS principles as described by Friedland et al. [2] which in summary are the following:

1. To avoid suction of blood neither bone dust in the round window area.
2. To place hyaluronic acid in the round window once its membrane is opened.

The surgical technique employed is, therefore, analogous to the one used in humans [4,17]. This fact is of utmost importance to achieve the objectives proposed and to extrapolate results to clinical practice.

The surgical technique included (1) incision in the region behind the ear and elevation of the musculocutaneous flap; exposure of the cortical mastoid bone located behind the external ear canal. (2) Identification of anatomical landmarks: superiorly, linea temporalis, inferiorly, and mastoid process; anteriorly, external auditory canal; posteriorly, lateral sinus. (3) Cortical mastoidectomy preserving the walls of the external auditory canal intact; first drilling maneuver seeking to expose the antrum and identify the incus and the lateral semicircular canal. A suction-irrigation system was used similar to the system used in humans. (4) Posterior tympanotomy to obtain visual control of the round window niche and the promontory. (5) In those cases, where good visual control of the round window membrane was not achieved, a Skeeter 0.7 to 1 mm diamond burr (Skeeter ultralite-oto-tool Xomed, Medtronic, Inc. Minneapolis, MN) was employed to drill the overhangs of the round window niche. (6) The round window membrane was opened with the beveled edge of a hypodermic needle. (7) Insertion of the electrode array was made freehand, slowly through the round window. The implant's cable was placed in the attic-mastoid region. The middle ear spaces were not obliterated with connective or muscle tissue.

2.5. Auditory testing

Auditory evoked potentials of the brain stem (PEATC clicks) were used for the assessment of hearing. These tests were carried out under sedation and before the surgical implantation procedure and after 6 months. The PEATC was performed using the Smartep system (Intelligent System, Miami, FL, USA) under the following conditions: click-type stimulus of 0.1 ms duration, 1024 scans, rarefaction mode in an intensity

between 20 and 80 dB SPL. Subcutaneous electrodes were inserted in the vertex (F-E2, M013909) and in both mastoid regions, in addition to a reference electrode in the forehead. The sound stimuli (clicks) were generated with an Optiamp8002 stimulator and transmitted by means of standard inserts offered by the system (ER2 Etymotic Research Inc. IL 60007, USA). PEATC at 100, 80, 60, 50, 40, 30 and 20 dB SPL was recorded at 2–4 kHz frequencies. The scans to be performed are 1024 for each frequency, the criterion of presence of M4 wave was used as threshold (equivalent to the V wave in humans) (Alegre et al., 2001).

Threshold shift is calculated for each specimen based on threshold obtained before surgery and before sacrifice.

2.6. Extracting and histologic processing of temporal bones

The petrosal ridges were extracted for histologic processing using the classic methodology [18]. The extracted specimens were then decalcified in a solution containing 100 g Ethyl-enediaminetetraacetic acid (131,669.121; Panreac Química SLU, Barcelona, Spain), 12.11 g Trizma base (Sigma, St Louis, MO; 1,001,782,459), 6 g NaOH (141,687.1211; Panreac), 75 g polyvinylpyrrolidone (QC00171047) in 1 L dH2O. Each specimen was dehydrated with alcohol (ethanol absolute 121,086.1212; Panreac) in increasing gradients and xylol (Xileno 251,769.2714; Panreac) and embedded in paraffin (Tissue-TekIII embedding wax; Sakura, Torrance, CA). The mold was solidified at room temperature. Slices (width: 5 mm) were obtained by HM340E microtome (Microm International GmbH, Walldorf, Germany) with Accu-Edge low profile blades (Sakura), performing at 40 mm intervals. Each slice was soaked in water (Electrothermal Ahmedabad, India) and placed on a Menzel-Glaser microscope slide (ThermoScientific, Waltham, MA). Staining is performed using Masson's trichrome.

After cutting the leaves, visualization is performed through a Leica® S8AP0 stereoscopic microscope (Greenough with Leica S8 APO apochromatic optics) to verify correct cutting and then digitization of various preparations for analysis with Aperio CS2 (Leica Biosystem, San Diego, California, USA). With the Aperio Image Scope software, Microsistemas S.L.U., allows us to carry out the corresponding measurements in microns (μm) of structural dimensions.

2.7. Histological analysis

To assess the effect of cochlear implant surgery a detailed histological analysis was focused in the vestibule by a blinded observer with experience in inner ear histology.

First, we analyzed the structure of the saccule and utricle. For this and given the characteristics of the histological method here used, both were measured considering their length and width. After proper preparation, when the specimen was considered ready for study it was then carefully positioned in the microtome to obtain serial sections that when going through the cochlea provided a mid-modiolar view (Fig. 2). In the vestibule the utricle and saccule were identified as shown in figure (Fig. 3). In each of them two measures were performed that correspond to two almost perpendicular lines. One corresponds to the longest distance between the entry point of the nerve and the membrane of utricle or saccule and the other is a perpendicular line to that connecting the membranous wall. Measurements were performed in each histological slide in which the structure was depicted. A mean length value and width value is calculated for each specimen.

Second, we performed an assessment of the intravestibular structures: utricular and saccular maculae and the tissue reaction. Besides, quantification of neuroepithelium type I and II cells width of the utricle macula and saccule have been performed. Once the saccule and utricle have been identified, the corresponding macula is searched within its structure. Both hair cells and support cells were visualized in the macula and included in the measurement (Fig. 4). The measurement of the thickness of said macula was used through the Aperio Image Scope software.

Results are presented as mean (standard deviation, SD). Students *t*-test (two-tailed) was used to compare means between two groups with $p < 0.05$ considered statistically significant (SPSS 13.0, IBM). In addition, the state of the fine cochlear structures (spiral ligaments, vascular striae, spiral laminae, cochlear aqueduct, vestibular and tympanic scales) and the appearance of biological reactions such as fibrosis or secondary ossification, trauma generated during the insertion of the electrode, could be observed or due to the long-term presence of a foreign body.

Both intracochlear and vestibular histological analysis is correlated within each specimen as well as the auditory threshold.

3. Results

3.1. Overview

Cochlear implantation was performed successfully in all 14 ears following MTS principles. Round window membrane insertion was performed in all cases. Mean angle of insertion was >270° for group A and 180–270° for group B. Follow-up was uneventful for all specimens for 6 months except for Mf 6B, whose follow-up was shortened to 1 month due to medical complications.

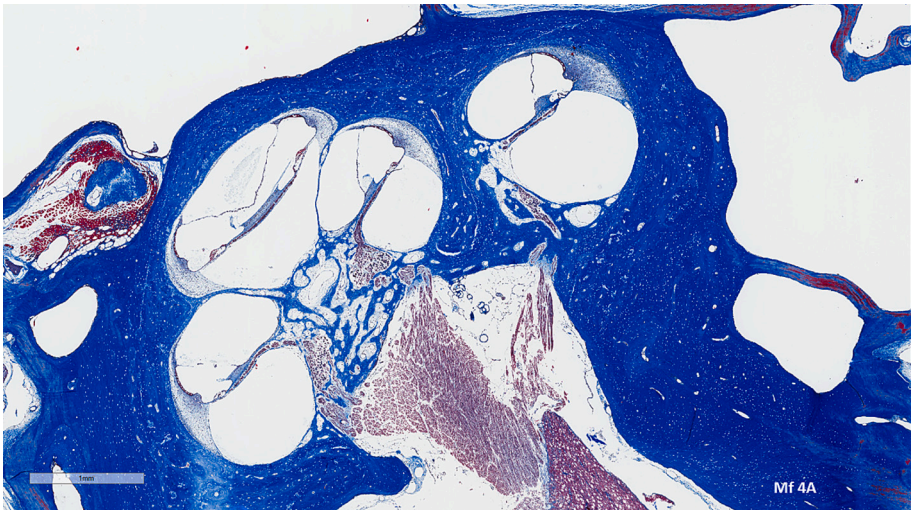


Fig. 2. Midmodiolar cochlear section.

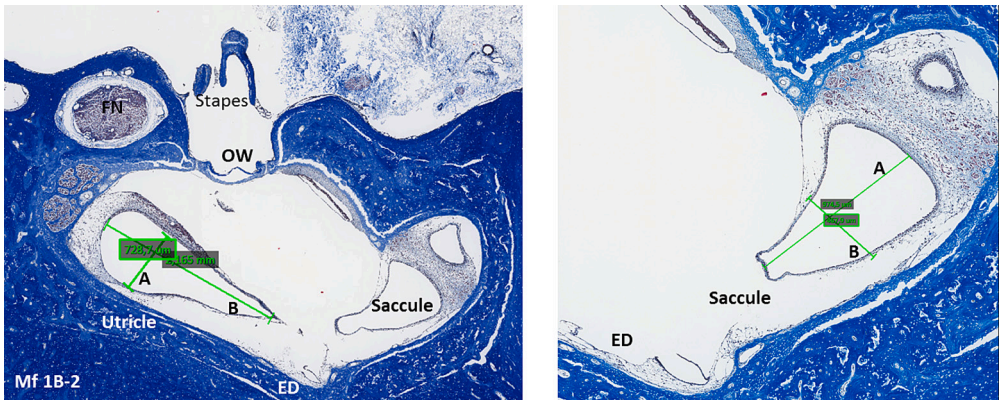


Fig. 3. Measurements saccule and utricle.

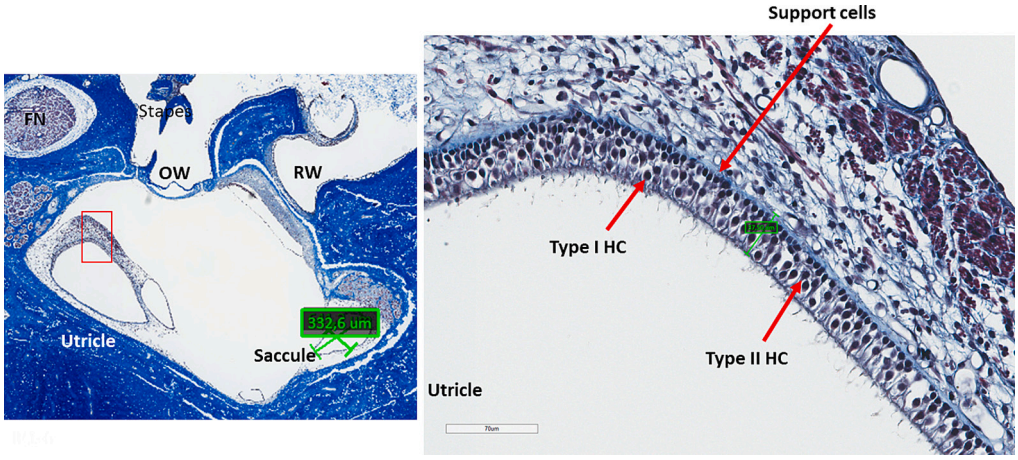


Fig. 4. Neuroepithelium measurements.

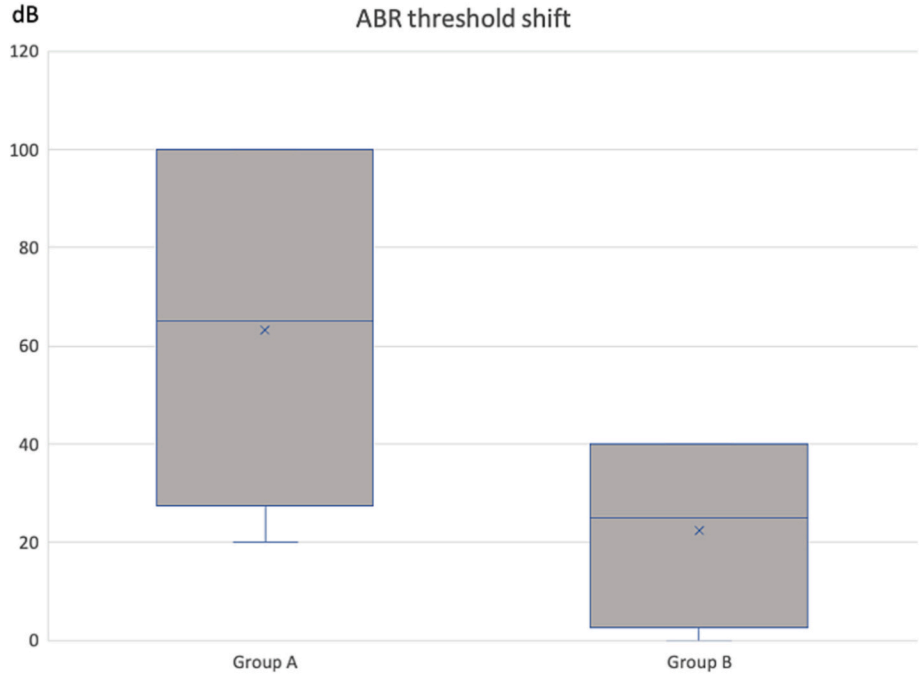


Fig. 5. Mean ABR threshold shift for each group.

3.2. Auditory and cochlear findings

ABR click tones auditory thresholds shift after 6 months follow-up was severe in three of the macaca: 100 dB in Mf1A and Mf2A, and 90 dB in Mf5A. A lower shift was depicted for the rest of them: 40 dB for Mf3A, Mf3B, Mf5B, Mf7B; 30 dB for Mf4A and Mf4B; 20 dB for Mf6A and Mf1B and 10 dB for Mf8B. No threshold shift was depicted for Mf2B.

Mean threshold shift are represented in Fig. 5.

Previous mentioned findings correlate to intracochlear histological findings. In cases Mf 1A, Mf2A and Mf5A intracochlear damage is seen despite surgical atraumatic principles. Marked ossification of scala tympani was depicted in Mf1A and Mf2A and an obliteration of cochlear aqueduct is depicted in Mf5A (Fig. 6).

In cases Mf2B, Mf3B and Mf4B a limited fibrous reaction around the electrode array area within the scala tympani is seen (Fig. 7). In any case within group B such findings provoked a complete hearing loss. In the rest of them, no intracochlear histological findings were depicted.

3.3. Histological findings

Utricle and saccule measurements have been performed in every histological slide where the structures have been completely identified and adequately preserved. Once selected images have been measured, mean values have been calculated for each macaque (see Table 1 and Fig. 8). Among group A, mean length and width for utricle is 2.19 μm (SD 0.56) and 534.51 μm (SD 133.01) respectively. Whereas mean length and width for saccule is 79.7 μm (SD 192.42) and 513.46 (SD378.08). A collapse of the saccule is observed in Mf1A and Mf2A (Fig. 9). Among group B, mean length and width for utricle is 1.65 μm (SD 0.53) and 580.97 (SD 120,05) respectively. Mean length and width for saccule is 1.33 μm (SD 0.197) and 566.41 μm (SD 190.81). Comparison between group A and B shows no statistical differences for utricle length ($p = 0.103$), utricle width ($p = 0.521$), saccule length ($p = 0.364$) and width ($p = 0.754$).

The neuroepithelium of the macula of the utricle and the saccule were identified in each histological section for their measurement (see Table 2). Mean group A, is 29.67 μm (SD 10.23) and 32.24 μm (SD11.35) for utricle and saccule. Mean group B is 34.77 μm (SD9.19) and 33.00 μm (SD3.51) for utricle and saccule respectively. Comparison between group A and B shows no statistical differences for utricle ($p = 0.364$) and saccule ($p = 0.868$).

No tissue reaction was seen within the macula in any case. Regarding its width, for group A, mean values were 27.30 μm for utricle and 30.94 μm for saccule whereas for group B, mean values are 34.77 μm for utricle and 33.009 μm for saccule. Among group A, special attention was paid to Mf 1A and Mf2A given the severe auditory deficit detected. At the utricle, the neuroepithelium seems more damaged than the rest such that it looks thinner (Fig. 10) being the width 14.08 μm and 25.39 μm respectively (Fig. 11). These two Mf show intracochlear damage with marked fibrotic and ossification reaction within the scala tympani and thus an obliteration of cochlear aqueduct.

Among all cases, cochlear aqueduct was identified in 13 out of 14 macaca. Signs of obliteration were seen in Mf5A, Mf 1A and Mf2A (Fig. 6). Whereas signs of fibrous reaction and ossification is seen in Mf1A and Mf2A within the scala tympani, no signs of tissue obliteration are depicted within the scala vestibuli. In all three cases, both maculae are adequately preserved and no other signs of tissue reaction are seen within the vestibule.

Endolymphatic sinus is enlarged in MF 2A, 5A, 2B and 8B. No other signs of hydrops within the vestibule or the cochlea are seen among these cases (Fig. 12).

3.4. Audiological and histological correlation

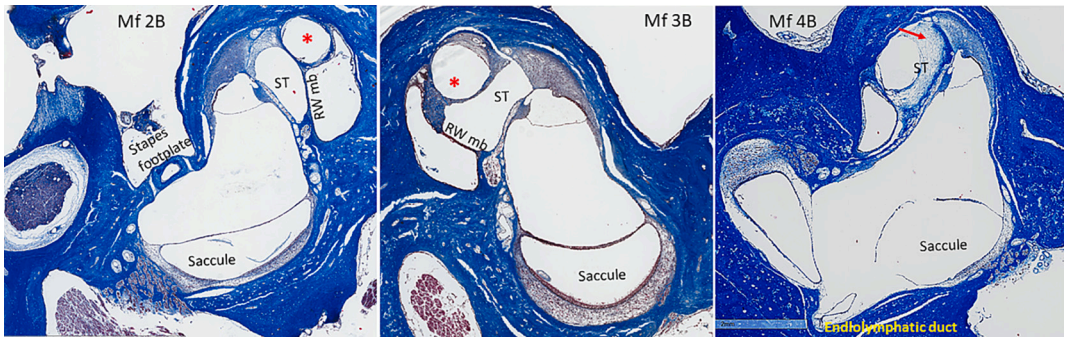
In group A Mf 1A, 2A and 5A show signs of auditory functional damage. Histological analysis shows ossification and fibrous reaction in the scala tympani for Mf1A and Mf2A and cochlear aqueduct obliteration for Mf 5A. Interestingly enough in Mf 2A and Mf5A an enlargement of the endolymphatic sinus is seen. These results suggest that some grade of hydrops is provoked by electrode array insertion in these cases (Table 2).

Among group B, no signs of auditory functional damage are depicted. However, a fibrotic reaction within the scala tympani is seen in Mf 2B, 3B and 4B. Such tissue reaction does not provoke damage to any intracochlear structures. Regarding the endolymphatic sinus, it seems enlarged in Mf 2B and Mf8 B. Thus, some grade of hydrops may be seen with no auditory functional damage (Table 2).

4. Discussion

During cochlear implant surgery, not only a potential risk of damaging the cochlea and the hearing structures is present, but also, due to its proximity within the inner ear, the vestibular end organs can also be affected [19]. In this study, we did not find any major histopathologic findings of damage of the vestibule organs in the Macaca's fascicularis implanted ears. Basic histological components of the cochlea are consistent among mammalian species, including the *Macaca fascicularis*, one of the best-studied nonhuman primate models for biomedical research [20,21]. This particular Macaque species (*Macaque fascicularis*, Mf) was chosen for its close phylogenetic proximity to humans that often provides a critical link between basic research and human clinical applications.

There is scarce literature regarding the histopathologic changes in the vestibule after cochlear implantation [22]. Some authors have described a saccular affection, histopathologically described as a distortion of the saccular membrane, a saccule partially or completely collapsed, or a hidropic saccule [23,24]. The susceptibility of the saccule might be expected to be higher than the utricle or semicircular canals because of its proximity to the direction and pathway of the inserted electrodes. The cochlear duct (CD) and the ductus reuniens (DR) are also in the same pathway. A direct injury or collapse of both structures is also possible. Moreover, they can be blocked externally by fibrous tissue or



Figs. 6. Intracochlear findings group A. CA: cochlear aqueduct; ES: endolymphatic sinus; OW: oval window; ST: scala timpani; SV: scala vestibuli.

Fig. 7. Intracochlear findings group B. Red arrow shows fibrous reaction around the array; * marks the fibrous ring around the array. RW mb: round window membrane; ST: scala timpani. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Table summarizes mean measurements (μm) for each Mf. Each Mf is labelled with A if Flex28 electrode or B if HL-14 electrode is implanted.

	Utricle		Saccule	
	Length	Width	Length	Width
Mf 1A	2.55	685	472.48	248.7
Mf 2 A	2.43	321.68	1.08	1.2
Mf 3 A	1.26	614.22	0.96	659.5
Mf 4 A	2.83	625.5	1.23	731.8
Mf 5 A	2.24	477.53	1.25	926.1
Mf 6 A	1.86	483.13	1.22	nd
Total mean group A	2.19 (SD 0,56)	534.6 (133.01)	79.70 (192.42)	513.46 (133.01)
Mf 1 B	1.23	571.73	1.42	443.7
Mf 2 B	1.24	561.94	1.34	425.01
Mf 3 B	2.02	818.62	1.19	537.18
Mf 4 B	2.54	530.2	1.74	870.4
Mf 5 B	2.00	634.7	1.25	787.06
Mf 7 B	1.10	502.6	1.16	364.98
Mf 8 B	1.43	447	1.27	536.57
total mean group B	1.65 (SD 0.53)	580.98 (120.05)	1.34 (0.19)	566.41 (120.05)
T student	P = 0.103	P = 0.521	P = 0.364	P = 0.521

bone debris. An obstruction of the DR or de CD at the hook region can result in collapse of the dependent saccule [24,25]. Among our specimens, a collapse of saccule macula is observed in both Mf1A and Mf2A. And an enlarged endolymphatic sinus in Mf5A with normal macula.

Tien et al. studied 11 pairs of human's temporal bones from patients with unilateral implants [23]. Only 4 patients had a normal vestibule histology in the non-implanted ear, and among those, only one patient had an affection in the implanted ear, which might be attributed to the implantation (saccule membrane distortion). The rest of the 7 patients had a pathological finding in both ears including the presence of fibrosis, reactive neuromas, macular deformity, ossifying fibrous tissue, and hydrops. All of them had different diagnosis, were implanted with two different types of electrodes (3 M single-channel and Nucleus 22-channel), and even though the cochlear access is not described, by the year of the article and the type of electrode, a cochleostomy was probably used. Considering that both the etiology and the surgical technique have a direct impact in the vestibular function, it is difficult to determine in the patients in whom a histological change already existed, to what extent surgery may have been decisive [13]. Sun et al. in a study performed in rhesus monkeys that underwent a multichannel vestibular prosthesis (MVP) revealed a minimal histopathologic impact on inner ear structures [26].

Clinical vestibular impairment can be also caused by a direct damage of the cochlea. CI can damage the lateral cochlear wall or basilar membrane, generating cochlear hydrops [27,28]. The severity of the vestibular abnormalities is correlated with the severity of the intracochlear damage caused by the implanted electrode. Tien concluded that the chance of vestibular damage is minimal as long as the electrode remained in the scala tympani without breaking through the BM or the osseous spiral lamina [23].

Taking in consideration that a normal hearing animal model is implanted in our study, none of the non-implanted ears showed a histological affection, therefore the etiology bias is limited. All the procedures were done following MTSC and the soft surgery principles described by Friedland [2], and there were no cases of cochlear hydrops or BM rupture. This reflects that a procedure following MTSC and the soft surgery principles has not only a small risk of cochlear damage, but also a small risk of vestibular damage. This findings agrees with our study, in both specimens (Mf1A and Mf2A) with fibrous reaction and ossification is seen in the scala tympani, a collapse of macula of the saccule is seen.

The endolymphatic sinus was enlarged in four specimens. Although it could be argued that the proximity of this structure to the vestibule could make it susceptible of damage during cochlear implantation, no other remarkable signs of hydrops within the vestibule or the cochlea were found in those specimens. Moreover, the regulation of endolymph movements in and out of the endolymphatic sinus, and therefore its enlargement, is not necessarily related to a cochlear dysfunction [29]. Some other possible changes in the peripheral vestibular system described, which were not found in this study, include the presence of

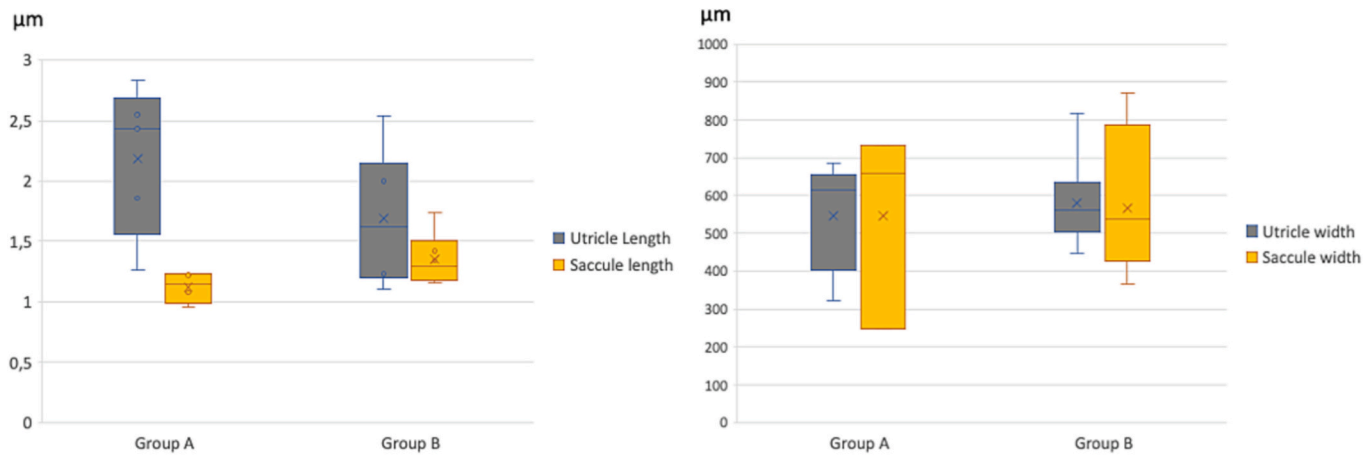


Fig. 8. Mean measurements for utricle and saccule length and width for each group.

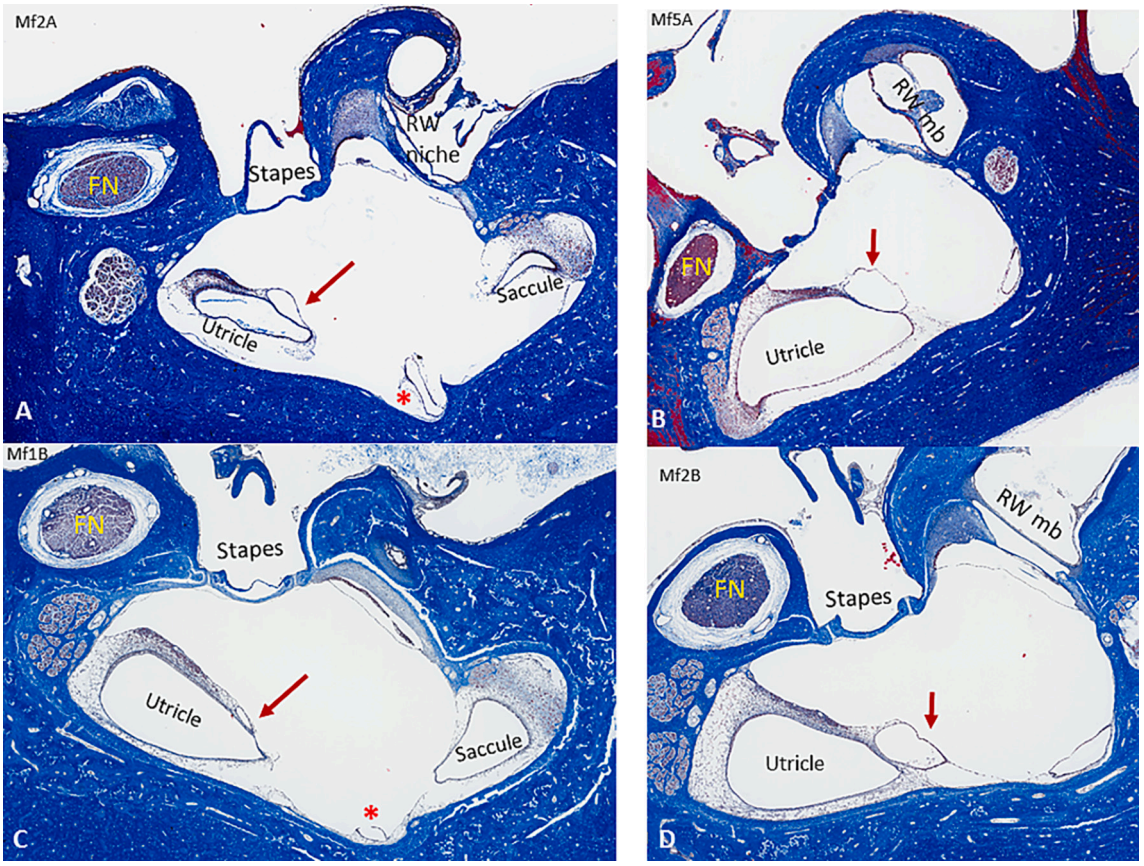


Fig. 9. The image shows inner ear structures. Note the collapse of the saccule.

fibrosis and ossification of the vestibule and traumatic neuromas. No change in cell counts, the density of hair cells, and endolymphatic duct affection have been described [23,24,30]. One of the drawbacks of our study is the absence of quantification of cochlear hydrops. Future studies may address such analysis.

Regardless of the possible changes at a histological level, vestibular and balance disorders after CI might be impaired, improved or remain the same depending on the study [15]. There are several hypothesis of why the vestibular function can improve after the surgery, the most cited are: CI could alter a previously uncompensated vestibular lesion, thereby inducing a vestibular compensation; electrical stimulation could somehow provide inputs to the vestibular system, thus improving balance in some way; the dizziness handicap inventory (DHI) assesses different emotions such as frustration, avoidance behavior, fear or depression, and perhaps CI allows patients to regain confidence, improving their perception of vestibular and balance disability [30–32].

There are several hypotheses of why the vestibular function can be impaired after the surgery and is still a matter for further research. Excluding a direct histological damage of the inner ear, including the vestibular organs and the cochlea as previously described, other mechanisms might explain the vestibular affection. Among the main ones are: the evolution of the pre-existing condition; a serous labyrinthitis (A labyrinthine irritation and inflammation from foreign bodies like blood, bone dust ore the electrode); intraoperative perilymph loss; and

Table 2
Table vestibular-histological findings.

	ABR click tones shift pre/post	Intracochlear findings	Vestibular findings	Utricle neuroepithelium (μm)	Saccule neuroepithelium (μm)
Mf 1 A	100 dB	Ossification ST	Saccule collapse	14.08	14.41
Mf 2 A	100 dB	Ossification ST	Endolymphatic sinus dilatation and saccule collapse	25.39	33.76
Mf 3 A	40 dB	Fibrous ring	no	38.26	38.95
Mf 4 A	30 dB	Fibrous ring	no	26.33	37.22
Mf 5 A	90 dB	Cochlear aqueduct obliteration	Endolymphatic sinus dilatation	42.92	49.1
Mf 6 A	20 dB	Fibrous ring	no	31.07	30.01
Mf 1 B	20 dB	no	no	42.36	36.15
Mf 2 B	0 dB	ST fibrosis	Endolymphatic sinus dilatation	33.006	27.12
Mf 3 B	40 dB	ST fibrosis	no	28.36	30.83
Mf 4 B	30 dB	ST fibrosis	no	34.7	31.19
Mf 5 B	40 dB	Fibrous ring	no	28.84	33.62
Mf 6 B	–	no	Utricle disruption*	ND	ND
Mf 7 B	40 dB	no	no	51.27	37.15
Mf 8 B	10 dB	no	Endolymphatic sinus dilatation	24.88	34.97

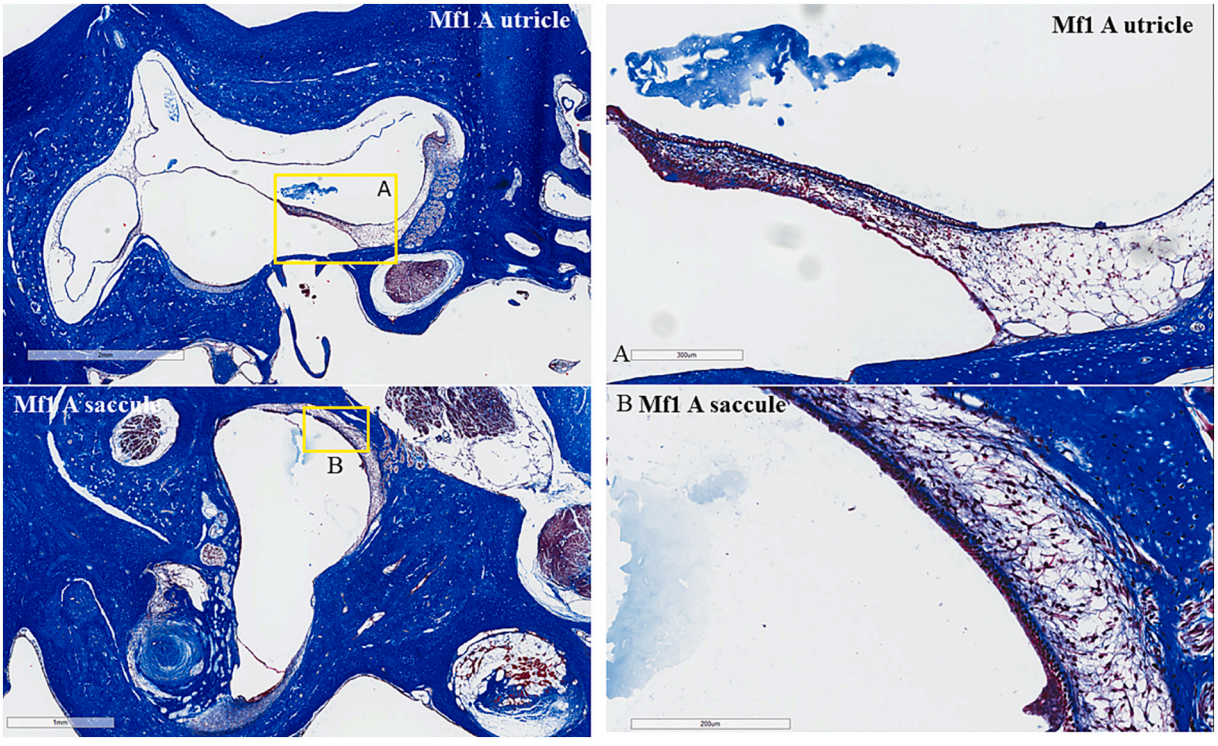


Fig. 10. Neuroepithelium histological findings group A.

otoconia dislodged as a result of intraoperative drilling [15,19,28,33,34].

Most of the studies addressing possible vestibular functional changes after CI conclude that CI surgery has a significant negative effect on the results of caloric as well as cVEMP test [13,14]. Even though both tests are more sensitive than the VHIT or posturography [13,35], the results differ significantly among clinics, probably because the mean time of follow-up is widely variable, the abnormality parameters are not always the same (might be expressed as a change in latency, amplitude, and threshold or simply classified as hyporeflexia or areflexic), the amount of SCM contraction, middle ear function and or possible occupation, age and gender. On the other hand, it has been recently reported an association between utricular hyperfunction and perioperative dizziness after CI [36]. Even though a functional affection might be detected after

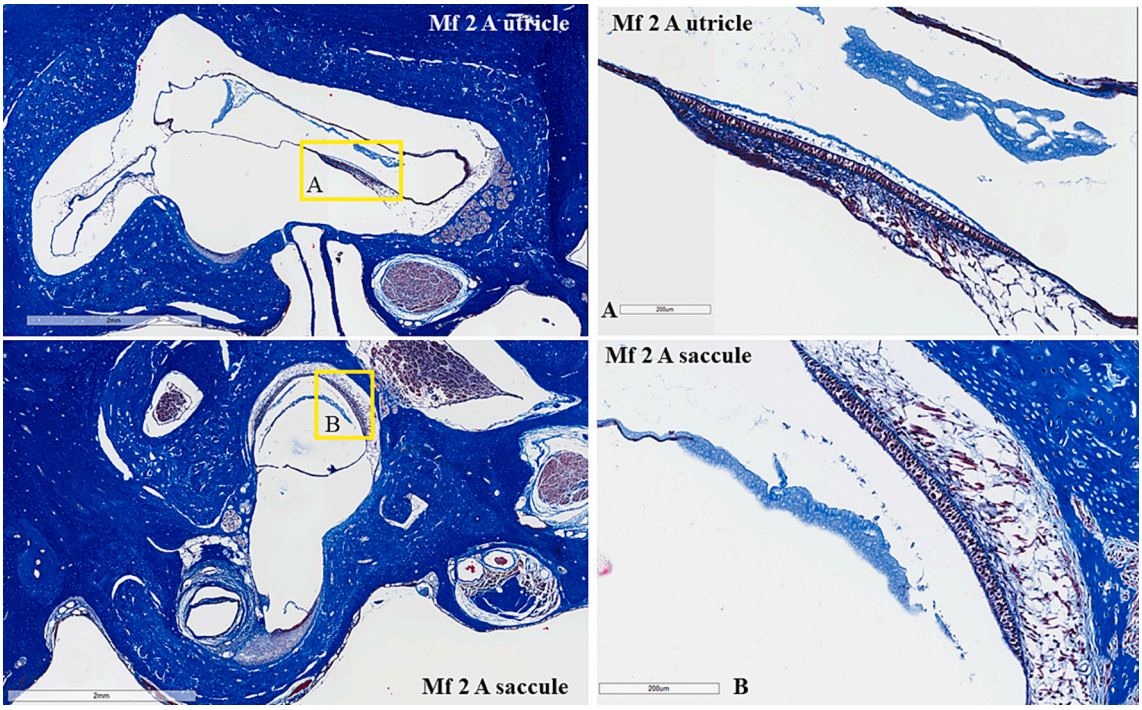


Fig. 11. Neuroepithelium histological findings group B.

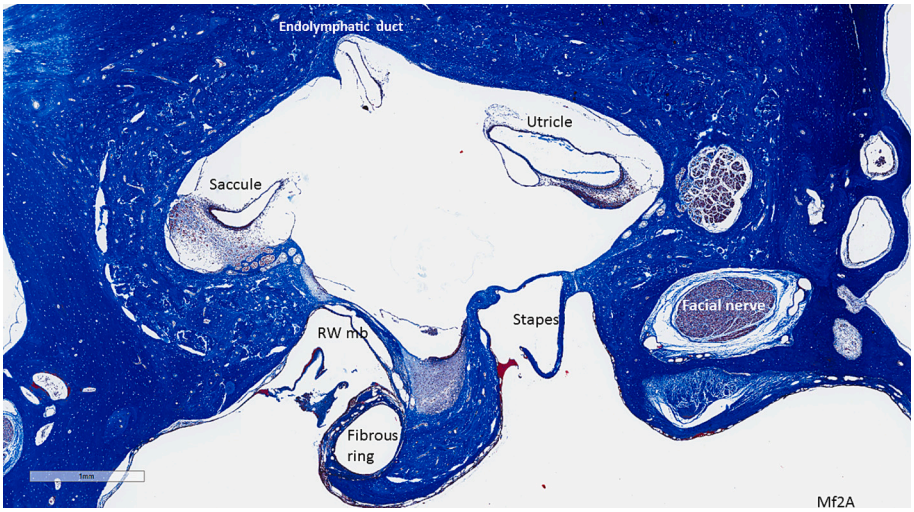


Fig. 12. Endolymphatic sinus findings: arrow shows endolymphatic sinus. Note it is enlarged for images A, B and D. image C shows normal size. * marks the endolymphatic duct. FN:facial nerve; RW: round window.

the surgery, the correlation between postoperative self-described dizziness handicap and objective tests of labyrinthine function is poor. A recent meta-analysis of vestibular function after CI reported a significant negative effect on caloric and VEMP, although the overall patient-reported symptomatic manifestations of these objective findings were found to be insignificant [13,14].

Although the vestibular function was not assessed, this study concludes that the risk of a histological damage of the vestibular organs following minimally traumatic surgical concepts and the soft surgery principles is very low. CI surgery is a safe procedure and it can be done preserving the vestibular structures. If a vestibular impairment after the surgery is present, it is important to take into account other possible factors besides a possible damage related to the procedure.

Acknowledgements

We sincerely thank María Antonia Gallego for the help provided in the Temporal Bone Laboratory.

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