

OTOLOGY

Mechanism of ear canal button battery injury and strategies for mitigation of damage

Meccanismo di lesione della batteria a bottone del condotto uditivo e sperimentazione di strategie di riduzione del danno

Gökhan Akgül¹, Mehmet Eser Sancaktar², Doğan Özdemir³, Mehmet Dursun Mehel¹, Nesrettin Fatih Turgut¹, Ayşe Çeçen³

¹ University of Health Sciences Turkey, Samsun Health Practices and Research Center, Department of Otorhinolaryngology, Samsun, Turkey; ² Ankara Training and Research Hospital, Department of Otorhinolaryngology, Ankara, Turkey; ³ Samsun University, Faculty of Medicine, Department of Otorhinolaryngology, Samsun, Turkey

SUMMARY

Objectives. In this study, the damage caused by button batteries (BB) trapped in the ear canal (EC) and strategies to reduce this damage before their removal were investigated *in vitro*.

Methods. After four EC models prepared from freshly frozen cadaveric bovine ears were thawed, 3 V lithium BBs were placed in the channels. After a three-hour period of preliminary damage, nothing was applied to the first EC model, the second EC model underwent saline administration, the third EC model underwent boric acid administration, and the fourth EC model underwent the administration of 3% acetic acid. The voltage, tissue temperature, and pH of the BBs were measured. The BBs were removed at the end of the 24th hour, and the EC models were examined by a pathologist.

Results. The greatest decrease in pH was detected in the fourth EC model in which acetic acid was administered. The depth of necrosis was 854 µm in the first EC model, 1858 µm in the second EC model, and 639 µm in the third EC model at the end of the 24th hour. No necrosis was detected in the fourth EC model.

Conclusions. Lithium BBs can cause alkaline tissue damage in a short time in cadaveric EC models. pH neutralisation strategies appear to be experimentally successful under *in vitro* conditions.

KEY WORDS: Button battery, alkali necrosis, aural foreign bodies, mitigation strategy

RIASSUNTO

Obiettivi. In questo studio, sono stati studiati *in vitro* i danni causati dalle batterie a bottone (BB) intrappolate nel condotto uditivo (EC) e le strategie per ridurre questo danno nel periodo di tempo intercorrente fino alla loro rimozione.

Metodi. Dopo che 4 modelli EC preparati da orecchi di cadavere bovino appena congelati sono stati scongelati, sono stati collocati BB al litio da 3 V nel canale. Dopo 3 ore di danno preliminare, non è stato applicato nulla al 1° modello EC, il 2° modello EC è stato sottoposto a somministrazione di soluzione salina, il 3° modello EC è stato sottoposto a somministrazione di acido bórico, il 4° modello EC è stato sottoposto ad acido acetico al 3%. Sono stati misurati il voltaggio, le temperature dei tessuti e il pH dei BB. I modelli EC sono stati esaminati da un patologo.

Risultati. La maggiore diminuzione del pH è stata rilevata nel 4° modello EC in cui è stato somministrato acido acetico. Mentre la maggiore profondità di necrosi è stata osservata nel 2° modello EC, non è stata osservata necrosi nel 4° modello EC.

Conclusioni. Le BB al litio possono causare danni ai tessuti alcalini in breve tempo nei modelli EC da cadavere. Le strategie di neutralizzazione del pH sembrano avere successo sperimentalmente in condizioni *in vitro*.

PAROLE CHIAVE: batteria a bottone, necrosi alcalina, corpi estranei uditivi, strategia di mitigazione

Received: March 1, 2022

Accepted: August 2, 2022

Correspondence

Gökhan Akgül

University of Health Sciences Turkey, Samsun Health Practices and Research Center, Department of Otorhinolaryngology, Kadıköy Mah. Park Sok. No: 199, PB: 55090, İlkadım, Samsun, Turkey
Tel. +90 362 3111500. Fax +90 362 2778865
E-mail: g.akgul-57@hotmail.com

How to cite this article: Akgül G, Sancaktar ME, Özdemir D, et al. Mechanism of ear canal button battery injury and strategies for mitigation of damage. Acta Otorhinolaryngol Ital 2023;43:149-154. <https://doi.org/10.14639/0392-100X-N2083>

© Società Italiana di Otorinolaringoiatria e Chirurgia Cervico-Facciale



OPEN ACCESS

This is an open access article distributed in accordance with the CC-BY-NC-ND (Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International) license. The article can be used by giving appropriate credit and mentioning the license, but only for non-commercial purposes and only in the original version. For further information: <https://creativecommons.org/licenses/by-nc-nd/4.0/deed.en>

Introduction

Ear canal (EC) foreign bodies occur quite frequently, especially in the paediatric age group¹. Although EC foreign bodies, including button batteries (BBs), do not pose a serious problem, it is known that they can present in the form of ear discharge, otalgia, bleeding, tinnitus, dizziness, or facial paralysis². The size of BBs has decreased as the size of small devices such as household appliances, toys, watches and hearing aids has decreased. These high-energy BBs might easily attract children's attention with their bright colours and can become stuck in the EC³.

In current *in vitro* studies, it is suggested that battery damage occurs due to the production of harmful free radicals, which cause a rapid increase in pH as a result of denatured organic material undergoing electro-caustic reaction and hydrolysis of water in the medium⁴. These effects are more pronounced in liquid media. For this reason, it is important to keep BBs dry in the EC and remove them quickly⁵. The moisture of ECs, presence of cerumen and administration of therapeutic dams while the BB is still inside or bleeding during the intervention are among the reasons for increased tissue damage caused by oxidation of BBs^{5,6}. Many methods have been tested in animal experiments to reduce BB damage in the upper aero-digestive system, reporting successful results⁷.

Mucosal damage by BBs begins within 1-2 hours⁷, and 25.7% of EC foreign bodies present to the emergency department after more than 24 hours⁸. As the removal of BBs from ECs is often delayed, the degree of damage and the potential risk of ossicular erosion, facial nerve damage, hearing loss and formation of vestibular labyrinthitis increase^{5,6,9}.

A limited number of case reports on damage and complications caused by BBs in the EC exist in the literature. The main complications reported in these studies were tympanic membrane perforation, ossicular damage, skin necrosis, malignant external otitis, prolonged otalgia and otorrhagia⁹⁻¹².

The damage mechanisms of lithium BBs in the EC and treatment strategies to reduce this damage are explored in our *in vitro* animal model.

Materials and methods

The study was conducted in the stages at the Samsun Training and Research Hospital Pathology Laboratory within the Health Sciences University.

Preparation of the EC models

EC models obtained from freshly frozen cadaveric cattle heads of similar sizes were prepared in approximately

2-cm-long segments that were approximately 1 cm in internal diameter in the form of a ring after being thawed at room temperature (22°C) to preserve the integrity of the annular canal and skin. A 3 V lithium BB (CR927, positive electrode manganese dioxide, negative electrode lithium, diameter 9.5 mm, thickness 2.7 mm) was placed inside each EC model with the negative pole in contact with the skin (Fig. 1). All EC models were humidified externally with 1 puff of saline spray (pH 6.8) every 3 h for 24 h.

Ensuring the reaction of BBs in five EC models: preliminary damage induction

One drop of saline solution every 30 minutes was administered into the channels of the EC models for 3 h, and the area where the BB and EC came into contact was kept moist. The pH of the tissue, the voltage of the battery and the temperature of the environment were measured at the end of the process, and visual changes were photographed (Fig. 1). One of the models was examined single-blind by a pathologist at the end of the third hour, and the other four models were left for the next procedure.

Strategies used to reduce the damage caused by the BBs

The following processes were administered to the four EC models in which the BBs reacted at the end of 3 hours:

1. the outer part of the EC model was moistened with 1 puff/h of saline spray, and nothing was applied inside the canal;
2. a saline solution (pH: 6.8) was administered in the EC model in the form of 1 drop/h over the area with which the BB was in contact (control group);
3. one drop/h of alcohol boric (pH 4; 3% boric acid, 70% alcohol) was administered to the EC model over the area with which the BB was in contact;
4. a solution with 3% acetic acid (pH 2) was administered in the EC model at a rate of 1 drop/h over the area with which the BB was in contact.

The BBs were removed from the EC models with forceps, and their voltages were measured with a digital voltmeter after 3, 6, 12 and 24 hours (UNI-T UT 33D Digital Auto Range Multimeter, Dongguan City, China). The tissue pH values were determined with litmus paper (Merck KGaA, Darmstadt, Germany), and the tissue temperature was measured and recorded with a digital infrared thermometer (Bosch PTD 1, Malaysia). The BBs were then returned to their places in the EC models. At the end of each time period, visual damage was photographed (Fig. 2). All EC models were examined after the BBs were removed single-blindly by a pathologist who observed the depth of necrosis, and all models were photographed at the end of 24 hours.

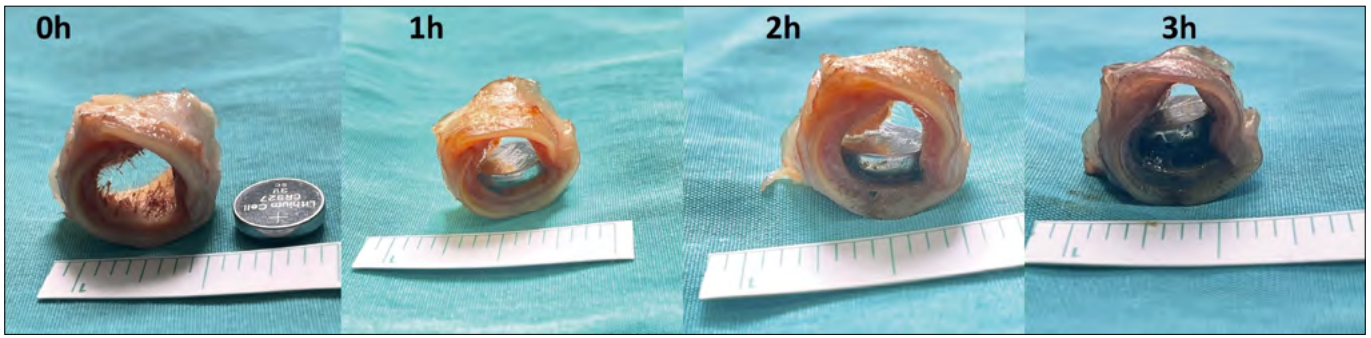


Figure 1. Placement of a 3 V lithium BB in the EC and reaction steps of BB by applying saline (h, hour).

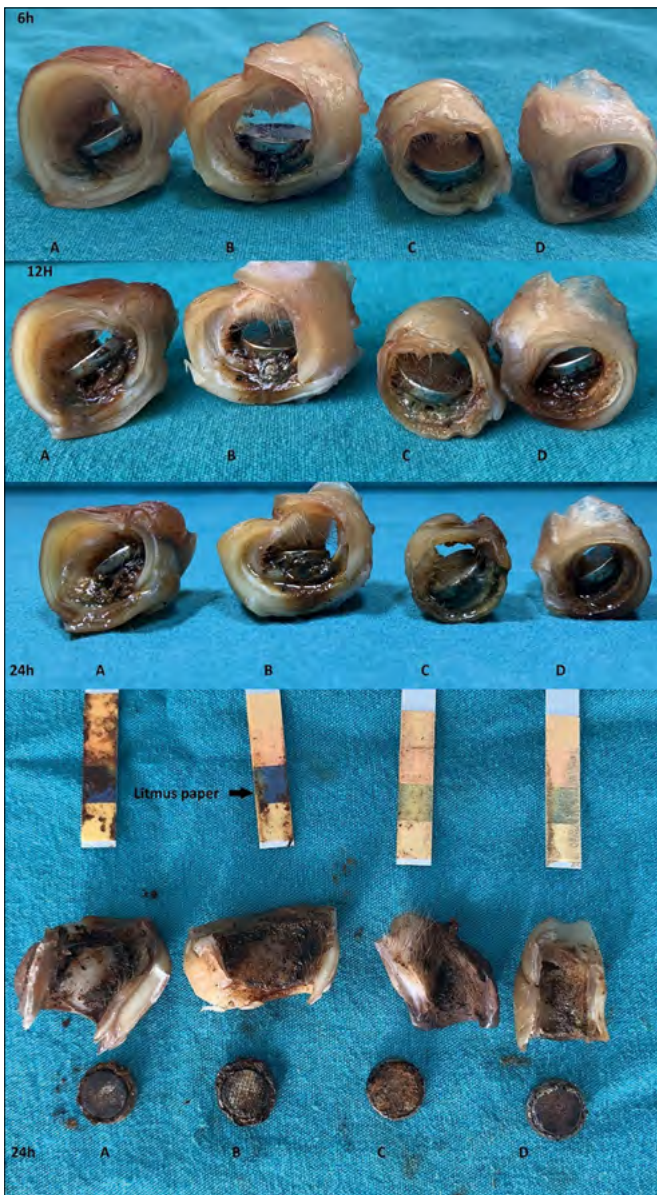


Figure 2. Images of changes at 6, 12, and 24 h. (A) Lithium BB, (B) Lithium BB + saline, (C): Lithium BB + boric acid, (D) Lithium BB+ acetic acid.

Results

Preliminary damage, BB voltage, tissue pH, and temperature changes

Gas bubbles and brown discoloration around the BB started to appear in the first 1.5 hour. The visual changes at 0, 1, 2 and 3 hours were photographed (Fig. 1). After 3 hours, the pH value of all four models was 13, and their temperature was 22°C. The voltage values were measured as 2.65 V in the first model, 2.60 V in the second, 2.58 V in the third, and 2.63 V in the fourth. No necrosis was detected in the model sent to pathology at the end of the third hour.

Evaluation of the strategies used to reduce the damage

After 24 hours, the following results were obtained:

1. in EC model (only BB): pH 11, voltage 1.3 V, temperature 22.5°C, depth of necrosis 1.612 μm ;
2. in EC model (BB + saline): pH 10, voltage 1.2 V, temperature 23°C, depth of necrosis 1.858 μm ;
3. in EC model (BB + boric acid): pH 7, voltage 1.4 V, temperature 23°C, depth of necrosis 723 μm ;
4. in EC model (BB + acetic acid): pH 4, voltage 1.6 V, temperature 23.5°C, no necrosis was detected.

No significant visual differences were observed between the EC models after 3, 6, 12 and 24 hours (Fig. 2). The pH, temperature, and voltage values at these time points are shown in Figure 3. In the model in which acetic acid was applied, the pH completely lost its alkalinity in the initial hours, and the environment was acidic. No necrosis was observed in this model. The ambient pH was neutralised after 12 hours in the model to which boric acid was administered, and the tissue necrosis depth was less than it was in the first and second models, in which the ambient pH was observed to be highly alkaline for 24 hours, and the depth of necrosis was greater. Pathological images are shown in Figure 4. No significant differences were detected between the models in terms of ambient temperature after 24 hours. Although the BBs lost their voltage to a large extent after 24 hours in all models,

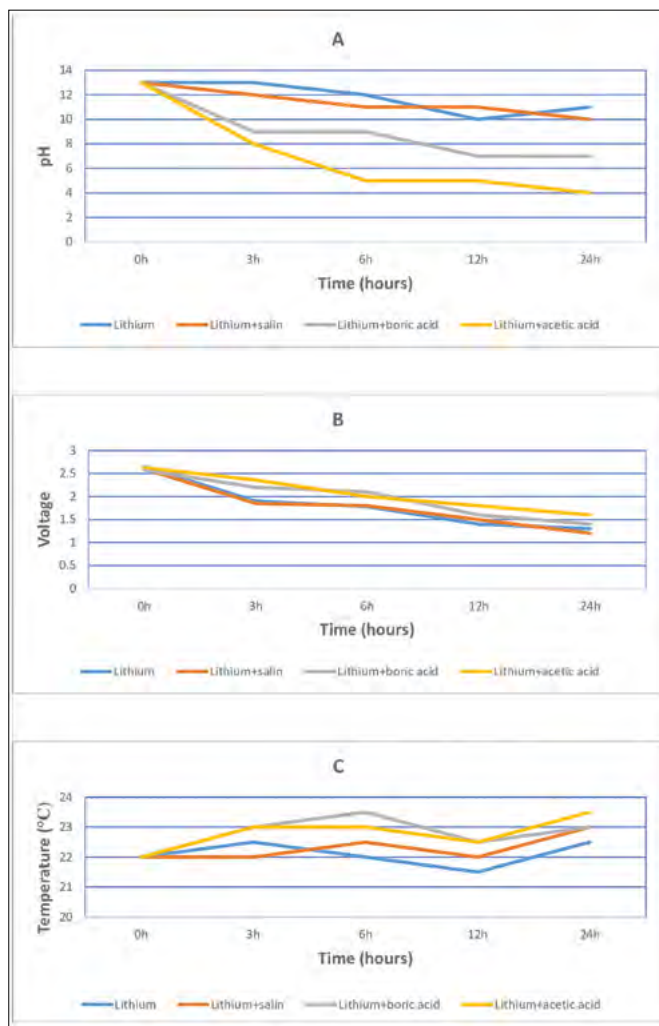


Figure 3. (A) pH, (B) voltage, (C) temperature, change of ambient data of BB over time.

it was observed that the voltage loss was similar in all the models.

Discussion

An estimated 65,788 paediatric patients presented to emergency departments in the US with battery exposure in the 20-year period between 1990 and 2009¹³. An estimated 3,748 of these patients were admitted with BBs in the external auditory canal¹³. Additionally, 0.20 of every 100,000 children admitted to the emergency department annually are admitted because of BBs in the EC¹³. As BBs are smooth and have a shiny appearance, they can be quite attractive and interesting to younger children when they are accessible¹⁰. BB foreign bodies can have fatal results, especially if they are swallowed¹⁰.

Successful removal of EC foreign bodies depends on many factors, including initial evaluation, patient cooperation, obtaining full vision of the foreign body, type of foreign body, co-existing otitis externa, previous failed removal attempts and availability of adequate equipment¹⁰. Most patients are initially evaluated in the emergency department. If there is difficulty in removal, it should not be pursued, and an ENT specialist should be consulted. Although common sequelae of foreign bodies in the EC are bleeding, infection, tympanic membrane perforation and canal wall laceration, BBs can also cause permanent damage to surrounding tissues because of the release of harmful chemicals, leading to necrosis, permanent hearing loss and stenosis in the EC^{3,6}.

The most commonly used BB types are alkaline, silver oxide, zinc-air and lithium. Among these, lithium BBs are faced most frequently as foreign bodies^{11,12,14}. Tissue damage by BBs occurs according to three mechanisms⁹.

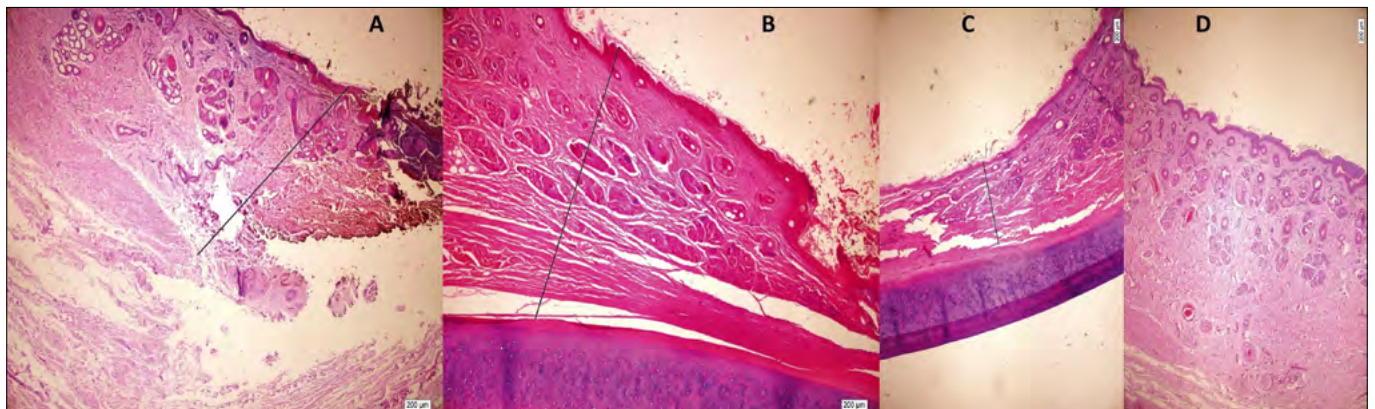


Figure 4. Pathological images after 24 hours. (A) Lithium BB, (B) Lithium BB + saline, (C) Lithium BB + boric acid, (D) Lithium BB + acetic acid. Depth of necrosis A: 1612 µm, B: 1858 µm, C: 723 µm, D: no necrosis. (×40 magnification; H&E paint; Olympus light microscope shot using DP2 program, Olympus Corp. Shinjuku, Tokyo, Japan).

The first is a thermal electro-caustic reaction that coagulates and denatures the organic material; the second is a hydrolysis reaction releasing harmful free radicals as the end product⁴; and finally, the third mechanism is pressure necrosis associated with BB, an effect increased by a prolonged presence of the battery^{9,14}.

The time taken to visit a physician for BB foreign bodies admitted with complications ranges from 24 hours to four months in case reports^{3,5,10,11}. Diagnosis may be delayed until symptoms appear, especially in young children and when there are no witnesses. Even in witnessed cases, the urgent removal of BBs may be delayed during transport to specialist centres because some healthcare centres do not have personnel trained in foreign body removal⁷. This delay may be more common in rural areas⁷.

Many substances that lower the ambient pH have been used in the past to reduce the damage of alkali liquefactive tissue necrosis. It has been observed that less mucosal damage occurs in the lower gastrointestinal system, such as the stomach, which was attributed to the acidic pH of that environment¹. Jatana et al.¹⁵ defined two important periods: before and after removal of BBs. They measured tissue damage in cadaveric oesophageal models using acidic solutions, such as lemon juice, orange juice, cola and 0.25% acetic acid, before the BB was removed. This study found that tissue damage was less severe in visual and pathological terms than in the saline control group. The authors also reported that alkaline necrosis began within a short time and that acidic beverages easily available at home could be given in the early stages. Tissue necrosis may continue after the removal of BBs, so it may be necessary to take precautions against this¹⁶. It was found that the depth of necrosis was less severe in the pathological evaluation of the oesophageal area, which was washed with 0.25% acetic acid after the batteries were removed in another animal study. After this study, the authors successfully applied this method in six paediatric patients and recommended the application of this treatment protocol after the removal of BBs¹⁶. Sancaktar et al.^{17,18} tried similar treatment strategies in cadaveric septum models before and after battery removal, neutralising the BB with lemon juice, apple vinegar, tea, cola, tap water and saline while the BB was inside the model. They reported that the best pH neutralisation was achieved with lemon juice (pH 2.5) and apple vinegar (pH 3). They also found that the tissue necrosis depth was lower with lemon juice and apple vinegar. They administered 0.25% acetic acid after the battery was removed in a cadaveric septum model and found that the damage was reduced compared to the control group^{17,18}. Rachel et al.⁷ found that honey and Carafate® showed significant protective effects in *in vitro* and *in vivo* animal experiments. They also found that these two substances neutralised the increased pH and resulted in less tissue damage. As a result of their study,

they reported that administering these substances earlier in the critical process until the removal of the button battery had the potential to reduce damage and accelerate healing. In our study, we found that administering 0.25% acetic acid and alcohol boric solution to the cadaveric *in vitro* external EC resulted in less damage.

In a multi-institutional study in which patients admitted with BB foreign bodies in the aero-digestive system were examined as a retrospective case series, batteries were detected in the external auditory canal in 4 of 81 paediatric patients¹¹. The foreign body was found to be bilateral in one patient. Two of the patients were asymptomatic, and the other two were admitted with otalgia, headache, ear discharge and hearing loss. In one of the patients, the erosive lesion of the external auditory canal continued for six weeks after the removal of the battery. Huang et al.¹² reported six foreign body cases in the ear canal in their series that included 116 paediatric BB foreign bodies. Although five patients were asymptomatic, they detected tympanic membrane perforation and ossicular chain damage as complications in one patient.

Many ear drops are available for the treatment of infectious diseases of the EC, such as otitis externa and otomycosis, which reduce the pH of the environment. Acetic acid and alcohol boric solution are used successfully in such diseases^{19,20}. We applied these acidic solutions, which can be used safely in humans, for pH neutralisation in our animal study. In previous animal experiments, it was determined that the most damaging type of battery was lithium and the least damaging was zinc-air, and it was reported that the most common type of BB foreign body in the EC was lithium^{13,15,17}. Based on these reports, we decided to carry out this study with lithium BBs. As the mucosa of the upper aero-digestive system is naturally moist, BBs discharge more easily and quickly in this area, causing damage. The EC is drier than the upper aero-digestive system mucosa because of its different anatomical-histological structure, which seems to slow the BB's discharge and delay the related damage. BBs in the EC are generally detected earlier and removed without causing serious complications. In a country such as ours, in which the population of children is high and there are many refugee children in the countryside, it is even more important, as it is difficult and takes more time to reach healthcare centres and specialists. We could not find any studies in the reviewed literature investigating the effects of delayed BBs in the EC or testing solutions to reduce damage. In our *in vitro* model, BBs were reacted, and treatment strategies were tried afterward. Although the solutions used in our study had also been used safely in infectious or inflammatory diseases of the EC, which represents a positive overlapping outcome, these results cannot be considered a recommendation. These

experimental results must be confirmed with prospective randomised *in vivo*, clinical human studies.

The limitations of this study were the use of a single sample for each modelling and the use of only one type of battery. The batteries were removed from the EC for a short time during the measurements. The possible effects of this on the measured values are not known. In addition, the method used to measure the ambient pH provides only changes in the superficial part. Furthermore, ischaemia due to compression necrosis, which is one of the damaging mechanisms of cells, and actual wound healing were not seen because this was a cadaveric study.

Conclusions

Visual damage was seen after 1.5 hour of exposure to lithium BBs in our *in vitro* bovine model. In experimental terms, the alkali damage caused by BBs can be decreased by providing pH neutralisation with acidic solutions, such as acid boric or acetic acid. More prospective randomised studies are required to validate this strategy before it is tested on humans.

Conflict of interest statement

The authors declare no conflict of interest.

Funding

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

Author contributions

All authors participated on the planning and conception of the study and the analytical strategy; GA, MES and DY performed the data analyses and wrote the manuscript. In addition, MDM, NFT, AC contributed to the photographing of visual data. All authors have assisted in data management, analyses and critical review of the manuscript.

Ethical consideration

The ethical aspect of this study was approved by the OMU Animal Experiments Local Ethics Committee (HADTEK). (68489742-604.01.03-E.18528, date: 23.10.2020).

The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki. Written informed consent was obtained from each participant/patient for study participation and data publication.

References

- 5 Thompson SK, Wein RO, Dutcher PO. External auditory canal foreign body removal: management practices and outcomes. *Laryngoscope* 2003;113:1912-1915. <https://doi.org/10.1097/00005537-200311000-00010>
- 6 Kim KH, Chung JH, Byun H, et al. Clinical characteristics of external auditory canal foreign bodies in children and adolescents. *Ear Nose Throat J* 2020;99:648-645. <https://doi.org/10.1177/0145561319893164>
- 7 Svider PF, Johnson AP, Folbe AJ, et al. Assault by battery: battery-related injury in the head and neck. *Laryngoscope* 2014;124:2257-2261. <https://doi.org/10.1002/lary.24686>
- 8 Voelker J, Voelker C, Engert J, et al. Severe tracheobronchial harm due to lithium button battery aspiration: An in vitro study of the pathomechanism and injury pattern. *Int J Pediatr Otorhinolaryngol* 2020;139:110431. <https://doi.org/10.1016/j.ijporl.2020.110431>
- 9 Premachandra DJ, McRae D. Severe tissue destruction in the ear caused by alkaline button batteries. *Postgrad Med J* 1990;66:52-53. <https://doi.org/10.1136/pgmj.66.771.52>
- 10 Svider PF, Vong A, Sheyn A, et al. What are we putting in our ears? A consumer product analysis of aural foreign bodies. *Laryngoscope* 2015;125:709-714. <https://doi.org/10.1002/lary.24935>
- 11 Anfang RR, Jatana KR, Linn RL, et al. pH-neutralizing esophageal irrigations as a novel mitigation strategy for button battery injury. *Laryngoscope* 2019;129:49-57. <https://doi.org/10.1002/lary.27312>
- 12 Karimnejad K, Nelson EJ, Rohde RL, et al. External auditory canal foreign body extraction outcomes. *Ann Otol Rhinol Laryngol* 2017;126:755-761. <https://doi.org/10.1177/0003489417731578>
- 13 Bhisitkul DM, Dunham M. An unsuspected alkaline battery foreign body presenting as malignant otitis externa. *Pediatr Emerg Care* 1992;8:141-142. <https://doi.org/10.1097/00006565-199206000-00007>
- 14 Thabet MH, Basha WM, Askar S. Button battery foreign bodies in children: hazards, management, and recommendations. *Biomed Res Int* 2013;2013:846091. <https://doi.org/10.1155/2013/846091>
- 15 Shaffer AD, Jacobs IN, Derkay CS, et al. Management and outcomes of button batteries in the aerodigestive tract: a multi-institutional study. *Laryngoscope* 2021;131:e298-e306. <https://doi.org/10.1002/lary.28568>
- 16 Huang T, Li WQ, Xia ZF, et al. Characteristics and outcome of impacted button batteries among young children less than 7 years of age in China: a retrospective analysis of 116 cases. *World J Pediatr* 2018;14:570-575. <https://doi.org/10.1007/s12519-018-0188-9>
- 17 Sharpe SJ, Rochette LM, Smith GA. Pediatric battery-related emergency department visits in the United States, 1990-2009. *Pediatrics* 2012;129:1111-1117. <https://doi.org/10.1542/peds.2011-0012>
- 18 Litovitz T, Whitaker N, Clark L. Preventing battery ingestions: an analysis of 8648 cases. *Pediatrics* 2010;125:1178-1183. <https://doi.org/10.1542/peds.2009-3038>
- 19 Jatana KR, Rhoades K, Milkovich S, et al. Basic mechanism of button battery ingestion injuries and novel mitigation strategies after diagnosis and removal. *Laryngoscope* 2017;127:1276-1282. <https://doi.org/10.1002/lary.26362>
- 20 Jatana KR, Barron CL, Jacobs IN. Initial clinical application of tissue pH neutralization after esophageal button battery removal in children. *Laryngoscope* 2019;129:1772-1776. <https://doi.org/10.1002/lary.27904>
- 21 Sancaktar ME, Bayraktar C, Bakırtaş M. Injury mechanism of button batteries in the nasal cavity and possible mitigation strategies during impaction. *Laryngoscope* 2020;130:2487-2493. <https://doi.org/10.1002/lary.28913>
- 22 Sancaktar ME, Bakırtaş M. A potential post-removal pH neutralization strategy to mitigate nasal button battery injuries. *Int J Pediatr Otorhinolaryngol* 2020;133:110011. <https://doi.org/10.1016/j.ijporl.2020.110011>
- 23 Romsaithong S, Tomanakan K, Tangsawad W, et al. Effectiveness of 3 per cent boric acid in 70 per cent alcohol versus 1 per cent clotrimazole solution in otomycosis patients: a randomised, controlled trial. *J Laryngol Otol* 2016;130:811-815. <https://doi.org/10.1017/S0022215116008598>
- 24 Thorp MA, Kruger J, Oliver S, et al. The antibacterial activity of acetic acid and Burow's solution as topical otological preparations. *J Laryngol Otol* 1998;112:925-8. <https://doi.org/10.1017/S0022215100142100>