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WILEY
Initial Clinical Application of Tissue pH Neutralization After Esophageal Button Battery Removal in Children

Kris R. Jatana, MD; Christine L. Barron, BA; Ian N. Jacobs, MD

Objectives/Hypothesis: Pediatric esophageal button battery (BB) injuries can progress even after removal and continue to be a significant source of morbidity and mortality. The objective in this case series is to present initial safety data for the human application of intraoperative tissue pH neutralization using 0.25% acetic acid irrigation after BB removal.

Study Design: Retrospective case series.

Methods: Pediatric patients who underwent rigid esophagoscopy for BB removal between October 2016 and December 2017 and who had the injury site irrigated with 120 to 150 mL sterile 0.25% acetic acid (pH = 3) were included in the study. Outcome measures included visual tissue appearance after irrigation, immediate or delayed esophageal perforation, and evidence of eventual esophageal stricture formation.

Results: Six pediatric patients (aged 19 months–10 years) had a 3 V lithium BB lodged in the esophagus for 2 to 18 hours and had irrigation of the esophageal injury site with sterile 0.25% acetic acid in the operating room after BB removal. None of the patients showed any evidence of thermal tissue injury. By surgeon assessment, all cases had improved visual esophageal tissue appearance. Neither immediate post-operative or delayed onset esophageal perforation nor eventual stricture development were seen.

Conclusions: Esophageal irrigation in the operating room with sterile 0.25% acetic acid after BB removal, to neutralize the highly alkaline tissue microenvironment (pH 10–13) was safe and resulted in improved visual mucosal appearance. This immediate tissue pH neutralization may help halt the progression of liquefactive necrosis by immediately bringing tissue pH to physiological range. This post-removal irrigation technique is recommended by current National Capital Poison Center BB guidelines.

Key Words: Button battery, acetic acid, neutralization, pediatric injury, battery injury, esophageal.

Level of Evidence: 4

INTRODUCTION

Pediatric button battery (BB) ingestion injuries have been a known hazard for several decades, but in recent years there has been a sharp rise in the incidence of severe injuries and death.1 Multipronged efforts have been underway by the National Button Battery Task Force (BBTF). Since it was formalized in 2012, the BBTF has been working to coordinate stakeholders from industry, public health, medicine, and government to implement strategies for reducing BB injuries in children.2,3 Despite these efforts, ingestions continue to increase in conjunction with the overall rise of BBs in circulation. In 2016, incidence of BB ingestions was 10.4 per million people, with a major complication or fatality rate of 0.94%.4 This represents a ninefold increase over a 20-year time period in the percentage suffering severe morbidity.

BBs damage esophageal tissue through an isothermic hydrolysis reaction, resulting in alkaline caustic injury that leads to liquefactive tissue necrosis. Pediatric esophageal BB injuries have the potential to progress even after endoscopic removal due to the continued presence of an alkaline environment.5 Recent research by our group has shown that neutralization of tissue pH in cadaveric porcine esophageal models was not associated with any significant change in tissue temperature.6 Therefore, immediate neutralization of tissue pH after BB removal may serve to halt the progression of liquefactive necrosis by immediately bringing tissue pH within a physiologic range.

The most recently updated National Capital Poison Center Guidelines include the consideration of 50 to 150 mL of 0.25% sterile acetic acid after BB removal in the absence of obvious perforation.5 However, there is limited literature to date describing the actual implementation in conjunction with the American Academy of Pediatrics and the American Broncho-Esophagological Association to coordinate stakeholders from industry, public health, medicine, and government to implement strategies for reducing BB injuries in children.2,3 Despite these efforts, ingestions continue to increase in conjunction with the overall rise of BBs in circulation. In 2016, incidence of BB ingestions was 10.4 per million people, with a major complication or fatality rate of 0.94%. This represents a ninefold increase over a 20-year time period in the percentage suffering severe morbidity.

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The most recently updated National Capital Poison Center Guidelines include the consideration of 50 to 150 mL of 0.25% sterile acetic acid after BB removal in the absence of obvious perforation.5 However, there is limited literature to date describing the actual implementation.
of this strategy in human subjects. Furthermore, it is important that pediatric specialists who remove BBs are aware of any strategy to prevent the progression of esophageal injury that could result in the complications listed in Table I. We present a series of initial safety and clinical outcomes for the human application of intraoperative tissue pH neutralization with 0.25% acetic acid after BB removal.

MATERIALS AND METHODS

Institutional review board approval was obtained, and consecutive cases of BB removal between October 2016 and December 2017 were reviewed. Inclusion was based upon the use of the post–battery removal 50 to 150 mL sterile 0.25% acetic acid irrigation protocol. An exclusion criterion for not using the irrigation protocol was presence of an obvious esophageal perforation during a second-look endoscopy at time of removal. All children had pre-operative imaging showing presence of an esophageal BB (Fig. 1). In all cases, the BB was removed by rigid esophagoscopy. After removal of the BB, the esophageal injury site was examined by the surgeon and the site slowly irrigated with 120 to 150 mL sterile 0.25% acetic acid using a lure-lock syringe on a 5 Fr flexible suction catheter, placed distally through the lumen of the rigid esophagoscope. Simultaneously, rigid suction was used adjacent to the catheter to continuously remove the excess irrigant (see Supporting Information, Video 1, in the online version of this article). Each surgeon’s documentation of visual esophageal tissue appearance postirrigation and clinical outcomes of immediate or delayed perforation or stricture formation in these patients were reviewed.

RESULTS

There were six patients identified between October 2016 and December 2017 who were included based upon use of the irrigation protocol. These were comprised of two females and four males, aged 19 months to 10 years. The BB type, duration in esophagus, and outcomes are listed in Table II. There were no acute complications associated with the use of 0.25% acetic acid in any of these patients. The surgeon-documented visual appearance of the esophageal tissue in all cases was improved after irrigation (Fig. 2); there was no evidence of thermal tissue injury. Clinical outcome measures with follow-up of a minimum of 4 months (range, 4–11 months) for all patients showed no immediate or delayed perforation. Between 6 and 12 weeks after removal, there was no evidence of stricture formation on repeat endoscopy (one patient) or esophagram (five patients).

DISCUSSION

Progression of esophageal tissue damage after removal is a hallmark of BB injury.1,2 A BB damages esophageal tissue through an isothermic hydrolysis reaction, resulting in an alkaline caustic injury that leads to liquefactive tissue necrosis. Significant esophageal burns can occur in as little as 2 hours, and the severity of damage is proportional to the time that the BB remains lodged in the esophagus.3 In children <6 years of age who ingested a 20-mm-diameter lithium BB, 12.6% experienced a major complication such as a perforation, tracheoesophageal fistula, fistulization into major vessels, esophageal strictures, vocal cord paralysis, or spondylodiscitis.4 A list of reported BB complications are summarized in Table I.

Notably, esophageal tissue injuries from BB ingestion have the potential to progress even after the BB is removed due to the continued presence of an alkaline environment. Symptom onset may be delayed up to 9 days,

<table>
<thead>
<tr>
<th>Site</th>
<th>Complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esophagus</td>
<td>Mucosal burns to complete perforation, mediastinitis, stenosis/stricture formation; may require gastrostomy tube insertion</td>
</tr>
<tr>
<td>Larynx</td>
<td>Vocal cord paralysis (unilateral or bilateral) from recurrent laryngeal nerve dysfunction; may require tracheostomy tube insertion when bilateral</td>
</tr>
<tr>
<td>Thyroid</td>
<td>Parenchymal hemorrhage</td>
</tr>
<tr>
<td>Tracheobronchial</td>
<td>Tracheoesophageal fistula, battery aspiration, bronchial stenosis</td>
</tr>
<tr>
<td>Spine</td>
<td>Spondylodiscitis</td>
</tr>
<tr>
<td>Aorta or other major vessels</td>
<td>Aortoesophageal or other major arterial fistula (death)</td>
</tr>
</tbody>
</table>

TABLE I. Known Complications of Esophageal Button Batteries.
after BB removal for tracheoesophageal fistulas and up to 28 days following removal for aortoesophageal fistulas.\textsuperscript{1} Likewise, delays of weeks to months have been noted for esophageal strictures\textsuperscript{1} or spondylodiscitis.\textsuperscript{7} Therefore, mere removal of the BB is not sufficient to prevent future complications. This highlights not only the importance of rapid endoscopic removal, but of additional strategies to neutralize the site of alkaline injury after the BB is removed. The clinical application of the 0.25% acetic acid irrigation protocol is intended for esophageal use at this time.

<table>
<thead>
<tr>
<th>Case</th>
<th>Age, Sex</th>
<th>Battery Type</th>
<th>Battery Diameter, mm</th>
<th>Esophageal BB Duration, hr</th>
<th>0.25% Acetic Acid Irrigation Volume, mL</th>
<th>Follow-up Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19 months, M</td>
<td>CR 2032/3 V</td>
<td>20 mm</td>
<td>2</td>
<td>150</td>
<td>6 months, no complications</td>
</tr>
<tr>
<td>2</td>
<td>2 years, F</td>
<td>CR 2032/3 V</td>
<td>20 mm</td>
<td>18</td>
<td>150</td>
<td>11 months, no complications</td>
</tr>
<tr>
<td>3</td>
<td>8 years, M</td>
<td>CR 2032/3 V</td>
<td>20 mm</td>
<td>5.5</td>
<td>150</td>
<td>4 months, no complications</td>
</tr>
<tr>
<td>4</td>
<td>10 years, M</td>
<td>CR 2025/3 V</td>
<td>20 mm</td>
<td>5</td>
<td>120</td>
<td>6 months, no complications</td>
</tr>
<tr>
<td>5</td>
<td>3 years, M</td>
<td>CR 2032/3 V</td>
<td>20 mm</td>
<td>4</td>
<td>150</td>
<td>10 months, no complications</td>
</tr>
<tr>
<td>6</td>
<td>2.5 years, F</td>
<td>CR 1216/3 V*</td>
<td>12.5 mm</td>
<td>6</td>
<td>150</td>
<td>4 months, no complications</td>
</tr>
</tbody>
</table>

*Three ingested: one esophageal, two intestinal/distal.
BB = button battery; F = female; M = male.

Table II. Summary of Six Esophageal Button Battery Cases, 0.25% Acetic Acid (pH 3) Irrigation Performed.

Fig. 2. Endoscopic esophageal images. (A) Prior to button battery removal. (B) Immediately after button battery removal. (C, D) Immediately after 150 mL of sterile 0.25% acetic acid irrigation.
time. Irrigation for tissue pH neutralization of the ear canal and nasal cavity is currently not recommended.

Given the in vitro exothermic nature of acid-based neutralization reactions, it was previously theorized that the neutralization of caustic burns in vivo may result in additional thermal tissue injury. However, more recent studies in cadaveric models have shown that neutralization of tissue pH is not associated with significant temperature changes or additional visible tissue damage. This may be explained in part by the fact that water, a major component of all human tissue, has a high heat capacitance and may absorb any thermal energy released during neutralization. Jatana et al. demonstrated that using at least 50 mL of 0.25% acetic acid (pH 3) in porcine esophagi achieved neutralization to a pH of 6, whereas irrigation with normal saline alone was not enough to achieve tissue pH neutralization. In light of these recent findings, the updated National Capital Poison Center Guidelines include the consideration of 50 to 150 mL of 0.25% sterile acetic acid after BB removal in the absence of obvious visible perforation. Recent work demonstrated both in vitro and in vivo, using animal models that honey and sucralfate (Carafate) can be protective and help neutralize pH prior to BB removal. However, the 0.25% acetic acid irrigation intervention is intended for use in the operating room immediately after BB removal. This case series is the first to document multiple outcomes for the in vivo human application of intraoperative tissue pH neutralization after BB removal. There were no complications associated with the use of acetic acid irrigation in any of the patients, indicating that this may be a safe method to prevent progression of esophageal tissue injury. Furthermore, 0.25% sterile acetic acid (pH 3) is commercially available and stocked at most hospital pharmacies. Although more acidic solutions with a pH ≤2 have the potential to result in coagulative necrosis, a type of tissue injury typically associated with eschar formation that limits substance penetration and injury depth. This risk is vastly outweighed by the potential for alkali burns, which result in liquefactive necrosis that penetrates deeper into tissues, resulting in saponification and thrombosis in blood vessels that impede blood flow to already damaged tissue.

This is an initial series of cases that have utilized this technique, so far demonstrating safety and potential efficacy to reduce injury progression after removal. Only one case report has been published in the literature from New Zealand that utilized our technique. These authors attributed their positive outcome of no perforation or eventual stricture formation in their 15 month-old patient with severe circumferential esophageal injury from two BBs to the use of this acetic acid irrigation technique. A limitation of our case series is that we were not able to standardize the injury assessment given that it is based on a retrospective analysis of different surgeon’s operative assessments. However, what was consistent was that none of these cases had a visible perforation after removal, which is currently an inclusion criterion for use of this technique. Another limitation of our case series is the small sample size of six patients to date.

Of note, the three batteries ingested by one patient in this case series were only 12.5 mm in diameter (Fig. 2). Although the majority of literature on BBs focuses on complications from batteries of 20 mm in diameter or larger, it is important to note that smaller BB also carry risk for injury. This is true in particular for children less than 12 months old, given the smaller diameter of their esophagus. In one meta-analysis of 6,262 battery ingestions, the diameter was smaller than 20 mm in more than 90% of ingestion cases. Despite the lower voltage and nonlithium chemistry of many smaller BBs (1.5 V compared to 3 V for traditional 20.0-mm BBs), local pH and tissue injury from smaller BBs progressed to the same level in porcine esophageal models, albeit more slowly. Although smaller BBs may be less likely to get lodged in the esophagus, the potential for severe injury clearly exists. According to data from the National Capital Poison Center, BBs <20 mm in diameter were responsible for seven cases of severe esophageal injury in children under 12 months of age, resulting in complications of tracheoesophageal fistula, esophageal perforation, esophageal stricture, and mediastinitis. This is an important consideration for stakeholders seeking to create industry guidelines and regulations to mitigate BB injuries in children.

Esophageal BBs present a severe hazard leading to morbidity and mortality in children. Any intervention to slow the progression of injury either before or after removal may provide benefit. Future directions do include continuing to track clinical outcomes in children when this 0.25% acetic acid neutralization protocol is utilized.

CONCLUSION

The primary mechanism of BB esophageal injury is the rapid rise in pH due to hydrolysis of water and generation of hydroxide ions near the negative pole. Neutralization of highly alkaline esophageal tissue pH has not been found to cause significant thermal tissue injury using in vitro animal models. This hypothesis is now supported by these initial in vivo human cases. In this series, we presented six consecutive pediatric cases where irrigation using 0.25% sterile acetic acid was successfully performed with no acute or delayed perforation or stricture development. Rapid neutralization of esophageal tissue pH as soon as possible after BB removal may prevent the continued tissue injury associated with a prolonged alkaline environment and reduce long-term complications.

Acknowledgments

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BIBLIOGRAPHY


