Home Therapies to Neutralize Button Battery Injury in a Porcine Esophageal Model

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Study objective: Button battery ingestion can cause alkaline esophageal injury. There is interest in first-aid household products to neutralize the injury. The objective was to investigate which household products are effective at reducing button battery injury.

Methods: Two cadaveric porcine experiments were performed. Experiment 1 utilized esophageal mucosal segments. A button battery (3VCR2032) was placed onto the mucosa, and substances (saline control, honey, jam, orange juice, yogurt, milk, and cola) were applied every 10 minutes for 6 applications. Tissue pH was measured every 10 minutes, and macroscopic ulceration size was assessed at 120 minutes. Experiment 2 used an intact esophageal model with a battery inserted into the lumen and jam, honey, and saline irrigation as per experiment 1. Tissue pH, macroscopic and histopathology changes were evaluated at 60, 90 and 120 minutes.

Results: In experiment 1, only honey and jam had a lower mean tissue pH at 120 minutes (8.0 [standard deviation [SD] 0.9, n=12] and 7.1 [SD 1.7, n=12], respectively) compared to saline solution 11.9 (SD 0.6, n=6, $P<.0001$). Both honey (0.24 cm^2, SD 0.17) and jam (0.37 cm^2, SD 0.40) had smaller mean areas of ulceration compared to saline solution (3.90 cm^2, SD 1.03, $P<.0001$). In experiment 2, honey and jam had significantly lower mean tissue pH at all timepoints compared to saline solution. Histologic changes were evident at 60 minutes in the saline group, whereas honey and jam exhibited no or minimal changes until 120 minutes.

Conclusions: Honey and jam were able to neutralize injury caused by a button battery resulting in a smaller area of ulceration. Jam should be further explored as a possible first-aid option as an alternative to honey in suspected button battery ingestion prior to definitive management. [Ann Emerg Med. 2023;■:1-9.]

Please see page XX for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Ingesting button batteries can pose a threat to children as evidenced by the rising number of severe or fatal incidents.[1-4] This increase is due to the growing use of button batteries in a variety of consumer electronics.[5] Young children are at particular risk of injury due to their narrower esophagus, and they often place objects in their mouth. A button battery lodged in the esophagus can cause severe injury within 2 hours.[2] Animal studies demonstrate that necrosis occurs as quickly as 15 minutes after ingestion.[1]

When a button battery becomes lodged in the esophagus, an electric current is created that causes water in the mucosa to hydrolyze, producing hydroxide ions.[6] This process creates an alkaline environment, resulting in pH levels up to 13 and caustic injury.[1,7,8] The 20-mm diameter 3V lithium button batteries pose the greatest danger due to its size and voltage and is responsible for 92% of severe and fatal button battery incidents.[2,5] The CR2032 button battery accounts for 70% of these cases.[2,9] Recent animal studies have shown potential benefits of administering small doses of honey or sucralfate every 10 to 15 minutes to reduce injury.[9,10]

The use of honey as a first-aid strategy in button battery ingestion has been adopted by the North American and European Societies for Paediatric Gastroenterology, Hepatology and Nutrition.[6] The guidelines recommend either honey if less than 12 hours after ingestion or sucralfate for patients awaiting endoscopic removal. Honey as a first-aid strategy is also recommended if button battery ingestion is strongly suspected.[6] The advised dose is 10 mL every 10 minutes for a maximum of 6 doses of honey and 3 doses of sucralfate.[11] This should not delay localization and

Editor's Capsule Summary

What is already known on this topic
Button battery ingestion by toddlers can result in severe esophageal caustic injury and death.

What question this study addressed
What common household products can reduce the pH around a button battery in the esophagus to hopefully mitigate injury?

What this study adds to our knowledge
Intermittent application of honey or jam reduced pH and tissue injury. Saline solution, orange juice, yogurt, milk, or cola did not aid in reducing pH and tissue injury.

How this is relevant to clinical practice
The early ingestion of honey or jam may reduce esophageal injury early after button battery ingestion while awaiting further care.

removal of the button battery. Honey is not recommended for patients who have suspected perforation, mediastinitis, sepsis, dysphagia, or a honey allergy or are less than 1 year old (risk of infant botulism).[6,9]

The study investigated which readily available household food products best protect the esophagus early after a button battery ingestion.

MATERIALS AND METHODS

Design

Two experiments were completed based on previous published methodology.[9,12] A cadaveric porcine esophageal tissue model was used for both experiments.

Materials

Cadaveric esophagi were obtained from 33 male pigs (Landrace, 5 to 6 months, 80 to 112 kg), commercially sourced from Wollondilly Abattoir (Picton, Australia). The following materials and instruments were used: 3VCR2032 button battery (Maxell Ltd, Japan), pH probe (Hanna Instruments, HI11311, Australia) and voltmeter (ANSMANN, 4000392, China). Household products tested included 4 jam brands, including Cottee's® Strawberry (New Zealand), Coles® Raspberry (Poland), Rose's® Strawberry Conserve (New Zealand), and St Dalfour® Apricot (France); 4 honey brands, including Gardener Mixed Blossom® (Australia), Capilano® (Australia), Cloverdale® (Australia), and B honey® (Australia); Coca-Cola® (United States); orange juice (Golden Circle®, Australia); full cream milk; strawberry yogurt (Chobani®, United States) and 0.9% sodium chloride (saliva control).

Methodology

Experiment 1: Esophageal mucosal segments. Experiment 1 utilized methodology similar to that reported by Anfang et al.[9] Eighteen pig esophagi were sectioned into 54 separate 8-cm long segments. Segments were opened along their length to expose the mucosa, positioned on a 30° incline and irrigated with 10 mL of saline solution. A 3VCR2032 button battery was placed on the esophageal mucosa with the anode facing the mucosa (t=0 minutes). Excess tissue was folded over the cathode to mimic an intact esophagus. Tissue pH was measured prior to each irrigation every 10 minutes until 120 minutes by opening the esophageal segment, lifting the button battery, measuring the pH of the mucosa (where the anode was placed), replacing the battery, irrigating the mucosa, and then refolding the segment. The irrigating substance was applied to the area just superior to the battery through syringe for a total of 6 irrigations. Voltage discharge of the battery was measured by comparing the difference in battery voltage from 0 to 120 minutes using a voltameter. At 120 minutes, the button battery was removed, and samples washed and photographed (no flash, room lighting, at ∼15 cm distance) immediately against a transparent ruler using an Apple iPhone® 12 Pro Max for later analysis of macroscopic (gross) surface area damage. The experiment was repeated 3 times for each brand of honey and jam and was retested 6 times for all other products.

Experiment 2: Intact esophagus model. Experiment 2 utilized an intact esophageal model with the aim to minimize battery removal time. Experiment 2 tested only the best performing substances from experiment 1 against a saline control. Fifteen esophagi were sectioned into 45 separate 8-cm long segments. Unlike experiment 1, these segments were left undissected. The button battery was inserted into the middle of the intact segment lumen at t=0, and the esophagi placed on a 45° angle. Every 10 minutes beginning at t=10 minutes, 10 mL of saline solution, honey or jam was applied to the segment opening through syringe for a total of 6 irrigations. For honey and jam, the brand that performed closest to the mean in experiment 1 was selected. Three segments were utilized for each substance and timepoints of 60, 90 and 120 minutes. Segments were then dissected open, and the tissue pH and residual voltage of the battery were measured. The segments were photographed and prepared for histologic evaluation. This process was repeated for each substance 5 times for assessment of pH, voltage discharge and macroscopic (gross) surface area damage and in triplicate for the histopathology microscopic evaluation.

Outcomes

The primary outcome measure was pH of the specimen mucosa after 120 minutes of button battery contact. Secondary outcomes were pH at other timepoints, amount of button battery discharge in volts (V) after 120 minutes, gross surface area damage (cm^2) as measured using SketchAndCalc™ (2022) from photographs (Appendix E1, available at http://www.annemergmed.com), and histopathology (experiment 2). Histopathology samples were pinned onto corkboards and submerged in 10% neutral buffered formalin for more than 48 hours. Specimens were trimmed to the area of interest and sectioned into 4-mm thick cassettes before staining with hematoxylin and eosin. An unblinded histopathologist (AS) utilized a similar grading system to Jia et al[12] to measure extent of esophageal injury: 0, no obvious lesions; 1, lesions in the mucosal layer (subdivided into 1a, mucosal lesions limited to the epithelial layer, and 1b, mucosal lesions reaching the subepithelial stroma +/− the muscularis mucosae); 2, lesions reaching submucosa with the presence of patchy erosion; and 3, lesions involving muscularis propria. The index implemented for this study was modified to exclude inflammatory cell infiltration, capillary dilation and granulocyte infiltration as a cadaveric model was used.

Statistical Methods

Statistical analyses were performed using GraphPad Prism 9 software (GraphPad Software, USA). Data were tested for a normal distribution using the Shapiro-Wilk test. Normally distributed data were reported as mean and standard deviation (SD). For each outcome, multiple comparison analysis was performed by ANOVA with post-hoc Tukey correction. Data were statistically significant at $P<.05$.

Ethics Approval

The University of New South Wales animal ethics committee granted an ethics exemption for this project as the cadaveric samples were commercially sourced.

RESULTS

Experiment 1: Esophageal Mucosal Segments

Table 1 and Figures 1, 2, and 3 summarize the results of experiment 1. Only honey and jam showed a reduction in

Table 1. Results of household substances tested using an in vitro porcine esophageal model in experiment 1.

Product	pH of Product	Final pH of Tissue at 120 Minutes (Mean, SD)	Change in Tissue pH from 0 to 120 Minutes (Mean, SD)	Change in Voltage of the Battery (Mean, SD)	Gross Surface Area of Lesion (cm^2) (Mean, SD)
Saline solution (0.9%) (n=6)	6.5	11.9 (0.6)	4.9 (0.6)	0.5 (0.05)	3.90 (1.02)
Jam: Cottee's Strawberry (n=3)	3.2	9.4 (0.6)	2.9 (0.5)	0.2 (0.1)	0.60 (0.39)
Jam: Coles Raspberry (n=3)	3.2	6.6 (1.0)	0.2 (0.9)	0.3 (0.02)	0.34 (0.26)
Jam: Rose's Strawberry Jam Conserve (n=3)	3.3	6.0 (0.6)	−0.9 (0.6)	0.3 (0.03)	0.49 (0.45)
Jam: St Dalfour Apricot (n=3)	3.5	6.3 (1.1)	−0.4 (1.1)	0.3 (0.02)	0.06 (0.02)
Jam: All brands combined (n=12)		7.1 (1.7)	0.5 (1.8)	0.3 (0.1)	0.37 (0.40)
Honey: Gardener Mixed Blossom (n=3)	4.3	7.1 (0.5)	0.0 (0.5)	0.2 (0.01)	0.16 (0.08)
Honey: Capilano (n=3)	4.9	8.0 (1.1)	0.8 (1.1)	0.3 (0.03)	0.25 (0.10)
Honey: Cloverdale (n=3)	4.9	8.5 (0.1)	1.8 (0.1)	0.6 (0.1)	0.15 (0.05)
Honey: B Honey (n=3)	5.7	8.2 (1.2)	2.3 (0.4)	0.2 (0.1)	0.41 (0.22)
Honey: All brands combined (n=12)		8.0 (0.9)	1.2 (1.1)	0.3 (0.2)	0.17 (0.24)
Coca-Cola® (n=6)	2.9	11.3 (1.4)	−3.6 (1.0)	0.5 (0.1)	2.01 (1.26)
Orange Juice: Golden Circle (n=6)	4.0	12.2 (0.3)	5.5 (0.1)	0.5 (0.1)	2.71 (1.14)
Milk: Dairy Farmers Full Cream (n=6)	6.9	12.0 (0.7)	5.0 (0.3)	0.4 (0.1)	2.83 (0.52)
Yogurt: Chobani (n=6)	4.3	12.0 (1.0)	5.5 (0.5)	0.5 (0.2)	1.59 (0.67)

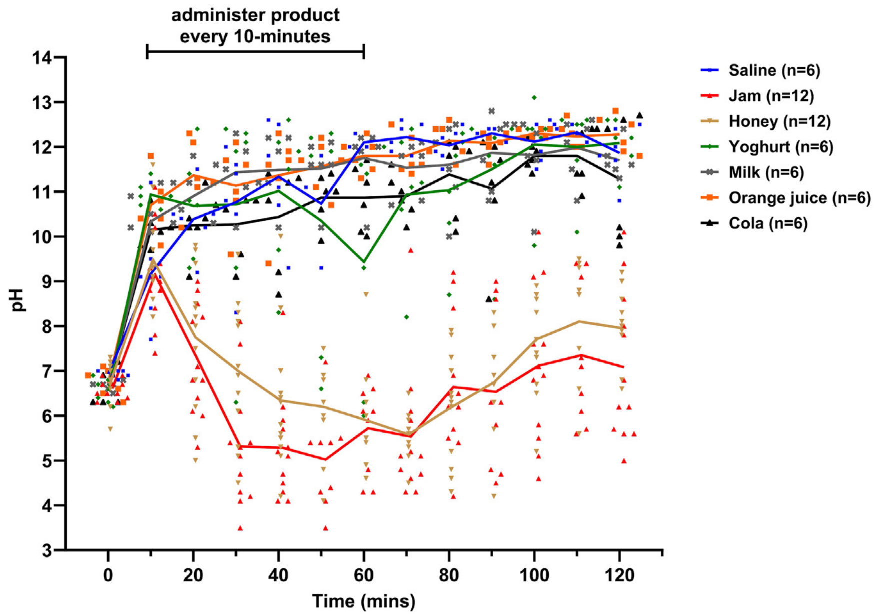

Figure 1. Mean esophageal tissue pH over time in experiment 1. Data points are plotted and mean values are visualized as line graphs. Saline solution (blue square), honey (tan-brown upside-down triangle), jam (red triangles), cola (black triangle), orange juice (orange rectangle), milk (gray cross) and yogurt (green diamond). Here, n=12 for jam and honey, and n=6 for cola, orange juice, milk, yogurt and 0.9% saline solution.

tissue pH compared with control at 120 minutes. When the results of honey and jam brands were combined, esophageal specimens treated with honey or jam had a lower mean final tissue pH values of 8.0 (SD 0.9) and 7.1 (SD 1.7), respectively, compared to 11.9 (SD 0.6) for the saline control (*P*<.0001) (Table 1, Figure 1A and 2A). At 120 minutes, the mean difference in pH of saline solution versus honey and jam was 3.9 (95% confidence interval [CI] 2.26 to 5.56) and 4.8 (95% CI 3.13 to 6.44), respectively. There were no differences between honey and jam in terms of pH reduction at all timepoints (*P* value is not significant [NS]) (Figure 1; Appendix E2, available at http://www.annemergmed.com).

At 120 minutes, the mean difference in pH of honey versus jam was 0.9 (95% CI −0.47 to 2.22). All honey brands (n=3) showed similar performance across all major time points (*P* value is NS). Most jam brands (n=3) showed similar performance (Table 1, Appendix E3, available at http://www.annemergmed.com) except Cottee's® strawberry jam with a significantly higher mean tissue pH value at 60 minutes (pH=6.5, SD 0.3), 90 minutes (pH=8.8, SD 0.2), and 120 minutes

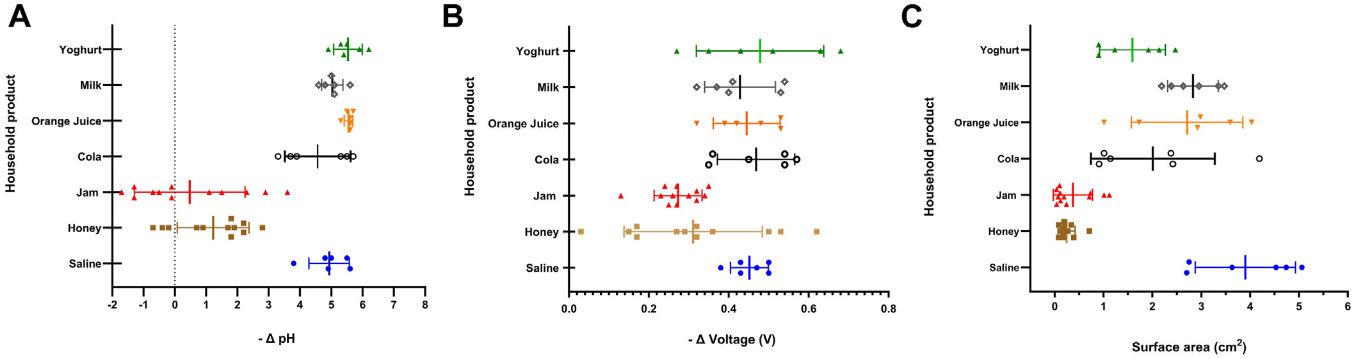

Figure 2. Experiment 1 results. *A*, Mean difference in esophageal tissue pH at 120 minutes compared to 0 minutes. *B*, Mean difference in voltage discharge of the button battery. *C*, Mean surface area of macroscopic mucosal lesion (cm^2). Bars represent standard deviation. Here, n=12 for jam and honey, and n=6 for cola, orange juice, milk, yogurt and 0.9% saline solution.

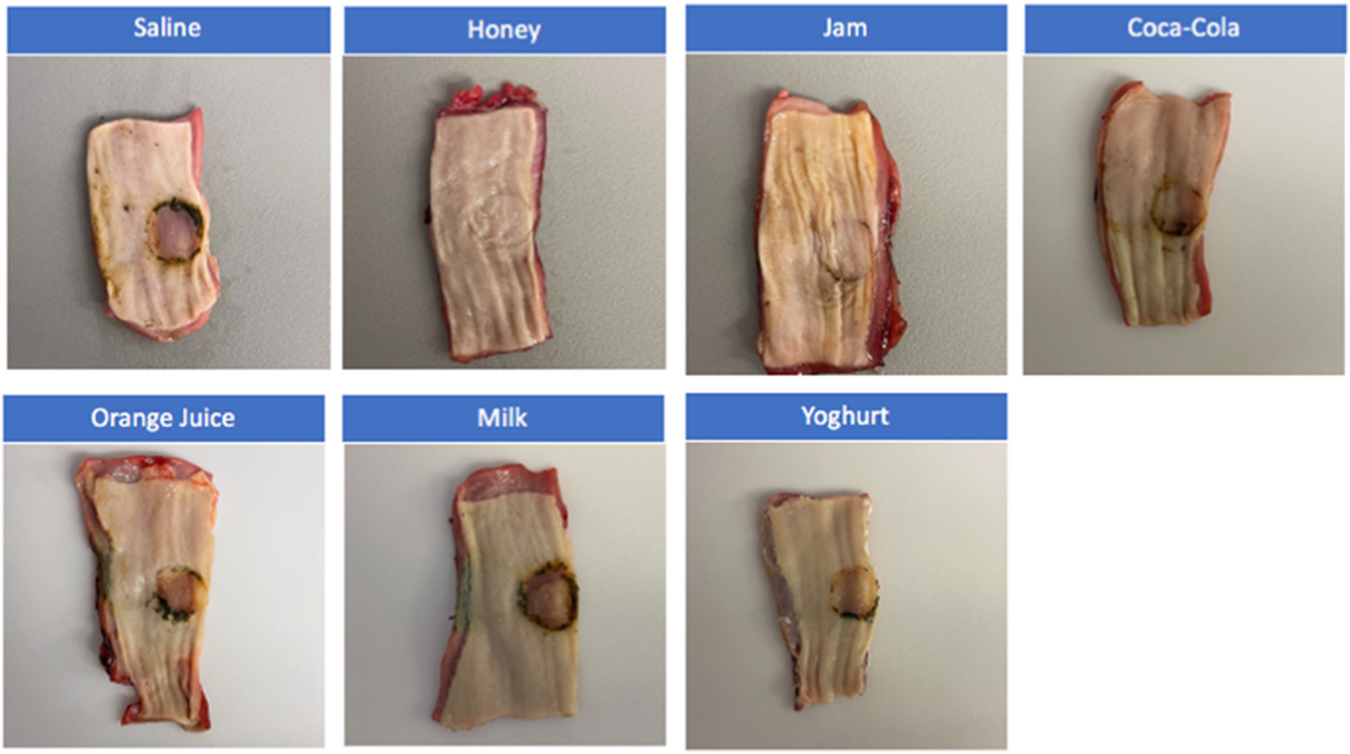

Figure 3. Macroscopic (gross) images of esophageal samples from experiment 1 after 120 minutes of button battery application and irrigation of tested household substances.

(pH=9.4, SD 0.6) compared to the other jams (Table 1, Appendix E3). These values were still less than saline solution (*P*<.05).

The mean voltage discharge of the button batteries over 120 minutes when irrigated with saline solution was 0.5 V (SD 0.05, n=6). Honey and jam had a mean voltage discharge of 0.3 V (SD 0.2, n=12) and 0.3 V (SD 0.1, n=12), respectively (Table 1, Figure 2B). Only jam was significantly lower compared to saline solution with a mean voltage difference of 0.18 V (95% CI 0.00 to 0.36). However, there was no difference between honey and jam (mean voltage difference of honey versus jam 0.04 V, 95% CI −0.11 to 0.18).

Saline solution-treated segments had a mean macroscopic (gross) lesion surface area of 3.90 cm^2 (SD 1.03, n=6). In comparison, those treated with honey (n=12), jam (n=12), cola (n=6), and yogurt (n=6) had smaller areas of injury (Table 1, Figure 2C) (*P*<.0001 for honey, jam, and yogurt; *P*=.001 for cola) (Figure 2A and 3). The mean difference in macroscopic (gross) lesion surface area of saline solution versus honey and jam was 3.66 cm^2 (95% CI 2.53 to 4.79) and 3.53 cm^2 (95% CI 2.39 to 4.66), respectively. Honey- and jam-treated segments had smaller mean areas of macroscopic tissue injury compared to all other substances, including cola- and yogurt-treated samples (*P*=.0003 and *P*=.01, respectively, for honey; *P*=.001 and *P*=.03, respectively, for jam). There was no difference between honey and jam (mean difference honey versus jam=−0.13 cm^2, 95% CI −1.06 to 0.80). The remaining 2 products, orange juice and milk, performed similarly to saline solution (Table 1, Figure 2C).

Experiment 2: Intact Esophagus Model

At 120 minutes, honey (7.4, SD 1.0, *P*=.0004) and jam (8.0, SD 1.4, *P*=.0013) had lower mean final tissue pH compared to saline solution (11.4, SD 1.0). A similar result is seen across all timepoints (Figure 4A). At 120 minutes, the mean difference in pH of saline solution versus honey and jam was 4.0 (95% CI 2.08 to 5.96) and 3.4 (95% CI 1.50 to 5.38), respectively. Comparing honey to jam, there was no difference in final pH (at 120 minutes) with a mean difference in pH of −0.6 (95% CI −2.52 to 1.36). However, the discharge of voltage from the button battery was significantly different at 60 minutes for both jam and honey when compared to saline solution with a mean difference of 0.26 V (95% CI 0.16 to 0.36, *P*<.0001) and 0.14 V (95% CI 0.04 to 0.24, *P*=.006) respectively. At 60 minutes, the mean difference in voltage discharge comparing honey to jam was −0.12 V (95% CI −0.21 to −0.02) (Figure 4B). Samples treated with honey and

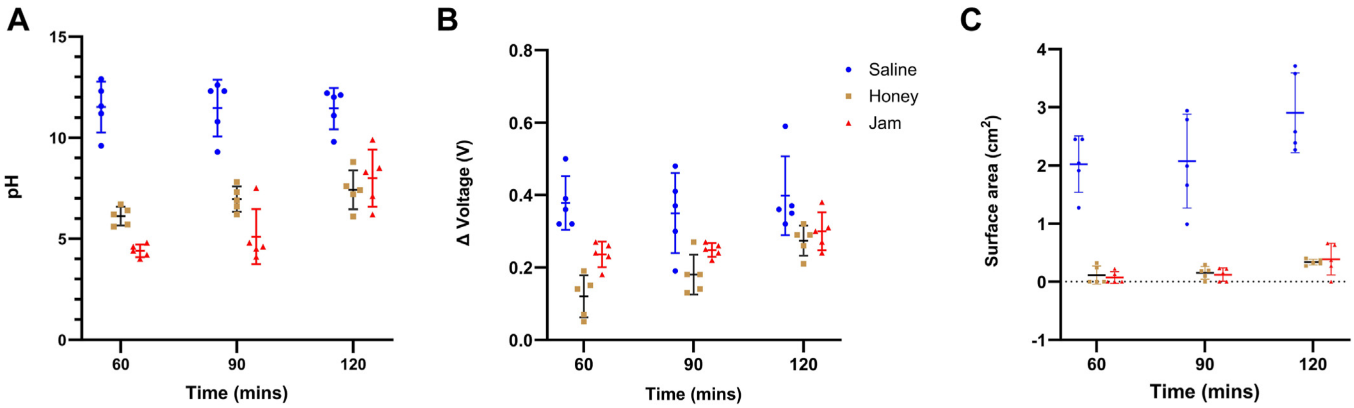

Figure 4. Experiment 2 results for saline solution (blue circle), honey (tan-brown square), and jam (red triangle) using an intact esophagus model at timepoints 60, 90 and 120 minutes after button battery insertion. *A*, Mean esophageal tissue pH. *B*, Mean voltage discharge of the button battery. *C*, Mean surface area of macroscopic mucosal lesion (cm^2). Bars represent standard deviation (n=5 for all treatments).

jam had markedly reduced areas of gross injury across all timepoints when compared to saline solution (Figure 4C). At 120 minutes, the mean difference in macroscopic (gross) lesion surface area of saline solution versus honey and jam was 2.57 cm^2 (95% CI 1.85 to 3.29) and 2.52 cm^2 (95% CI 1.8 to 3.24), respectively. Honey and jam were not different from each other across all 3 timepoints when comparing the gross area of injury (p=NS). At 120 minutes, the mean difference in area of gross injury between honey and jam was −0.05 cm^2 (95% CI −0.77 to 0.67).

Histopathology

In total, 28 esophageal samples from experiment 2 were evaluated (Table 2). One jam sample at 120 minutes was excluded and repeated as the battery was placed between the mucosa and submucosa and not in the lumen. Honey-treated specimens showed the least changes compared to saline solution and jam at 120 minutes (Table 2, Figure 5). The changes observed included varying extents of epithelial loss and necrosis and nuclear and cellular degeneration of the mesenchymal cells of the mucosal subepithelial stroma, submucosa and muscularis propria.

Additionally, the saline solution-treated specimens had changes evident in the mucosal and submucosal layers at the first time point (60 minutes) compared to no or minimal changes in the honey- and jam-treated specimens. In the saline group across all timepoints, the maximum changes extended to the submucosa in 5 of the specimens and to the mucosa in the remaining 4 specimens (Table 2). Overall, the least extent of histologic changes was seen in the specimens treated with honey, and the maximum depth of change was submucosal (minimally involved only) in 2 of the 9 specimens (Table 2, Figure 5). The remaining specimens showed no changes or splitting of the epithelium only. Of the specimens treated with jam, there were no changes until 90 minutes with 1 sample showing mucosal changes. At 120 minutes, 2 jam samples had evident changes with the maximum changes in 1 sample extending only minimally into the muscularis propria and another sample had changes into the submucosa (Table 2, Figure 5).

LIMITATIONS

This study was performed on a cadaveric model. The study parameters may not accurately reflect what happens

Table 2. Histopathologic changes seen in each trial in experiment 2 (intact esophagus).

Substance	Trial	60 Minutes	90 Minutes	120 Minutes
Saline solution	**1**	1a	2	1b
	2	2	1b	2
	3	1b	2	2
Honey	**1**	1a*	1a	0
	2	0	2†	0
	3	0	0	2†
Jam	**1**	0	0	3‡
	2	0	1b	Ex
	3	0	0	2
	4	-	-	0

Note: The following grading system was used: 0, no changes; 1, changes confined to the mucosa; 1a, changes not involving all layers of the mucosa; 1b, changes involving all layers of the mucosa; 2, changes extending to the submucosa; 3, changes extending to the muscularis propria.
Ex, Excluded as battery not placed in lumen.
*Split only.
†Changes extending minimally into the muscularis mucosa and submucosa.
‡Changes extending minimally into the muscularis propria.

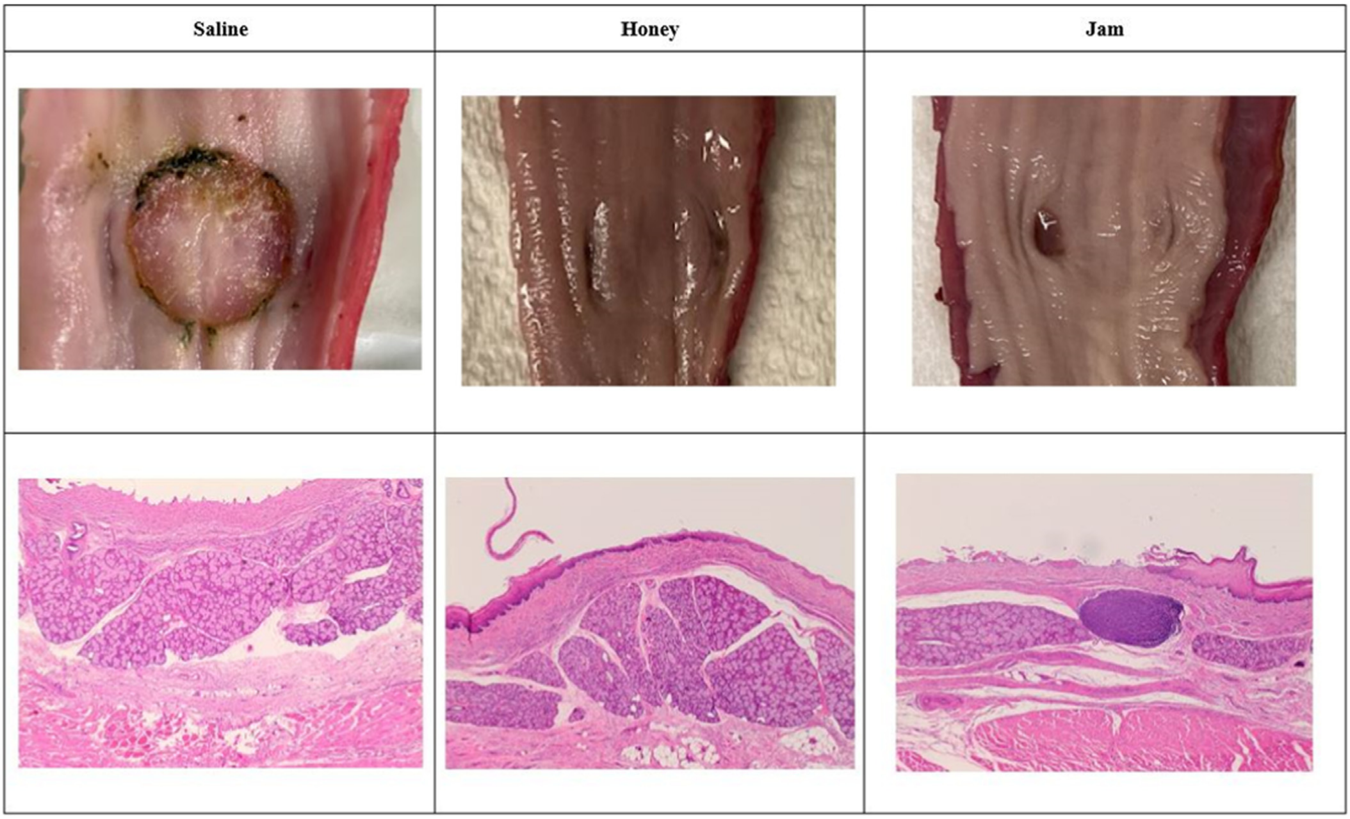

Figure 5. Representative examples of gross macroscopic specimens and H&E staining of button battery-containing esophageal tissues treated with saline solution, honey and jam after 120 minutes of button battery application (40X magnification). Microscopic samples show changes extending to the submucosa in saline solution-treated samples, changes extending minimally into the muscularis mucosa and submucosa in honey-treated samples, and changes extending minimally into the muscularis propria in jam-treated samples.

in a patient. For instance, peristaltic contraction and saliva production as well as their contribution to injury could not be explored.[13] Moreover, the bodily response to injury, including granulation tissue formation, inflammatory cell response and capillary dilation, was not taken into account.

Other limitations included the process of having to lift the button battery to measure tissue pH, which disrupts the circuit temporarily. Experiment 2 attempted to resolve this issue by using intact esophagi. Lastly, the investigators and histopathologist were not blinded to the treatment arm, which may have resulted in detection bias. However, the outcomes were all well-defined (ie, pH, voltage, and predefined histopathologic grading) and based on previous studies.[9,12]

DISCUSSION

Button battery ingestion is a significant and potentially life-threatening issue. Given the severity and rapid onset of injury, developing effective early treatment strategies is of clinical importance. This study investigated whether common household substances could be used in such strategies by neutralizing tissue pH, reducing voltage discharge, and mitigating injury. Honey and jam were found to effectively neutralize tissue pH and decrease the extent of macroscopic injury. Honey is recommended as a first-aid treatment, and the results suggest that jam may be an alternative to mitigate early stage button battery injury.[6,11]

In the intact esophageal model (experiment 2), both honey and jam appeared to protect esophageal mucosal tissue at 60 and 90 minutes with minimal microscopic changes. In comparison, saline solution samples had changes evident in the mucosa and submucosa layers at 60 minutes. At 120 minutes (60 minutes after the last irrigation), the honey samples had the least damage, with the jam samples having varying degrees of damage. One reason for this could have been that in experiment 2 it was more difficult to irrigate the jam through the esophageal lumen than honey, as jam contained pieces of preserved fruit. Hence, not all the irrigated jam may have entered the lumen and coated the battery.

The protective effect of honey may be attributed to its acidic nature and high viscosity; jam has similar proprieties.[9,14,15] Honey is thought to prevent electrolysis by reducing hydroxide formation and lowering alkalinity, thereby limiting the extent of caustic injury.[9] The higher viscosity of jam and honey may also allow them to serve as a physical barrier disrupting electrolysis for longer than less viscous substances.[9,10] This may explain why other acidic food substances that are less viscous (eg, cola, orange juice and yogurt) performed similarly to saline control. Furthermore, honey and jam are also common household substances that are easily accessible and palatable, making them well suited as potential first-aid treatment strategies.

Various in vivo and in vitro studies have assessed the potential for household products to neutralize button battery injury.[1,9,10,12,16] Most studies utilized a model of placing a button battery onto porcine esophagus sections and irrigating with various substances.[1,9,10,12,16] Porcine specimens were selected due to the anatomic similarities to human esophagi, including size, thickness of esophageal layers and response to injury.[17,18] Across these studies, the number of irrigations, timing and volume of substance irrigated varied, ranging from 5 to 10 mL every 5 to 15 minutes for 2 to 6 hours. We performed 6 irrigations of 10 mL every 10 minutes per current guideline recommendations.[11] Many studies used litmus paper to measure pH; we utilized a pH probe to increase accuracy.[10,19,20] Most studies repeated each substance in duplicate or triplicate, whereas we performed a minimum of 6 trials per substance for increased precision.[1,9,10,12] In these in vitro studies, honey, olive oil, edible oils (colza, peanut, olive), lemon juice and sucralfate (Carafate®) have all been shown to be effective at neutralizing pH and reducing visible macroscopic injury.[1,9,10,12,16] Jam was not a substance tested.

Our results differed from Jatana et al,[1] who utilized a cadaveric model and applied 5 mL irrigations every 5 minutes to samples for 2 hours. They found that lemon juice was most effective at neutralizing tissue pH and reducing visible injury followed by orange juice, cola and Pepsi, which were all partially effective when compared to a saline solution. In contrast, we found that orange juice and cola were ineffective in attenuating injury and performed similarly to saline solution. Our designs differed in that their samples were vertically suspended whereas ours were placed on a 30° incline, and we ceased irrigation at 60 minutes.

Jia et al[12] investigated edible oils (rapeseed, peanut, olive) as possible protective insulating substance. In this study, 5 mL was irrigated into vertically and horizontally positioned esophageal segments every 5 minutes for over 6 hours. They showed these oils were effective at neutralizing the alkaline environment and minimized injury by limiting battery discharge. They argued that edible oils were effective given that their nonelectrolyte composition and viscosity were unaffected by saliva, which helped the oils coat the battery and provide longer protection.[12] However, an issue with edible oils is their unpalatability compared to alternatives like honey and jam.

Porcine in vivo (live) studies have been performed to examine the effect of honey, sucralfate, olive oil and a mixture of olive oil and honey.[9,10] In a live pig model (1 hour button battery application), Anfang et al[9] found that honey and sucralfate (irrigated every 10 minutes) was effective at neutralizing the alkaline environments caused by button batteries with a lower tissue pH, reduced voltage discharge and yielded fewer signs of macroscopic and microscopic injury. Jia et al[10] confirmed that honey reduced button battery injury in a similar live animal model (1 hour button battery application) and also tested the effect of olive oil (insulating liquid) and a mixture of olive oil and honey. Although they found olive oil irrigations demonstrated better protective effect compared to honey or sucralfate for button battery-induced esophageal damage in vitro, this did not translate in the in vivo model that showed that olive oil alone exacerbated esophageal injury. The authors hypothesized this was because olive oil has low viscosity and did not remain around the button battery after irrigation into the esophagus. However, a combination of olive oil and honey showed a protective effect.[10] Although in vivo models have demonstrated benefit, these substances were not swallowed by the animals but instead administered through syringes under anesthesia. Therefore, the amount of substance that coats the battery if swallowed is unknown.

Button battery ingestion has the potential to cause severe esophageal injury. Although definitive removal remains the clinical standard, there is in vitro evidence that the use of first-aid strategies, such as honey and jam, prior to removal may decrease the extent of injury. The results of this cadaveric porcine esophageal model suggest that jam performed similarly to honey at mitigating injury, as evidenced by its ability to neutralize tissue pH, reduce macroscopic ulceration and minimize microscopic histologic changes at 60 and 90 minutes. However, at 120 minutes, honey exhibited the least histologic changes. Jam should therefore be considered as an alternative first-aid treatment option. This could prove useful in settings where honey is not readily available or must be avoided due to allergy or risk of infant botulism (in individuals <1 year old). The potential applications of this study are twofold. First, honey and jam can be administered as first aid to manage suspected button battery ingestion. Second, it may be useful for patients when definitive removal is delayed, as may occur in rural settings. Honey is already recommended in many treatment guidelines, and jam should be considered as an alternative.

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Author contributions: AC and BC conceived the study concept and design, AC, CL, DN, FS, AS performed the study. AC, CL, AS, BC performed the interpretation of the data with AC, CL performed the statistical analysis. AC, CL, AS drafted the manuscript and all authors contributed to its revision. AC takes responsibility for the paper as a whole. The authors acknowledge Jasmine Saha for completion of the pilot study.

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