Anesthetic Implications of Button Battery Ingestion in Children

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Foreign body ingestion is common in young children (those less than 5 yr of age).[1,2] Most ingested items pass uneventfully through the gastrointestinal tract, but certain items may prove dangerous due to their size, composition, or location.[3,4] The following Clinical Focus Review discusses the increasingly common problem of button battery ingestion, which, when left untreated can rapidly result in life-threatening complications, particularly in young children. The definitive management requires prompt recognition and endoscopic removal of batteries, often necessitating the use of general anesthesia. Awareness of the potential problems and recommended solutions for button battery ingestion is therefore of vital importance to practicing anesthesiologists.

Battery Background

Button batteries are round, flat batteries named for their resemblance to the button on an article of clothing. Sometimes referred to as disc batteries or coin cells, button batteries are increasingly common in small, portable electronic devices such as toys, hearing aids, watches, calculators, flashlights, and remote controls.[5,6] Unlike common household batteries that are typically long, insulated cylinders with conducting electrodes at each end, button batteries have a relatively large, flat surface area for conduction of an electrical current. One side of the button battery is the positive terminal and the opposite side is the negative terminal.

Button batteries vary in voltage, size, and chemical composition. The nomenclature for button batteries is important in the identification of these characteristics. The 3-volt CR2032 battery (fig. 1) is one of the most common button battery types. By convention, the "C" indicates the battery chemistry as being lithium-based. The "R" signifies the round shape of the battery. The battery has a diameter of 20 mm and a thickness of 3.2 mm, hence the "2032" moniker.[5] As the number and power requirements of small electronic devices have increased in recent years, a change to larger sized (greater than or equal to 20-mm diameter), lithium-based batteries with increased energy density (3 volt *vs.* 1.5 volt) has occurred. It is these larger, more powerful batteries that are associated with the most severe complications when ingested by children.[7–9]

Mechanism of Injury

Although button batteries can cause tissue damage when children put them in their ears or nose,[6] they are particularly dangerous when swallowed. Especially in young children, larger button batteries may become lodged in the esophagus.[6,7,10,11] Although a battery in the esophagus can be harmful in several ways, animal studies suggest that damage from lithium button batteries results from the generation of electrical current. With both poles of the battery in contact with the fluid medium of the esophageal mucosa, current can flow. The button battery's thin design and large surface area results in a low resistance circuit with high current flow driven by the power of the battery.[8] Within a few minutes, electrolysis generates hydroxide at the negative pole of the battery, resulting in an increase in tissue pH. An alkaline caustic reaction ensues causing esophageal tissue liquefaction necrosis,[8,12–14] beginning as soon as 15 min after battery contact.[12,15] Injury may extend beyond the esophageal mucosa into deeper esophageal tissue layers as the battery-driven reaction continues. Clinically significant tissue damage can occur within 2 h of battery impaction.[5,7,12,16] Esophageal perforation with extension into adjacent structures (mediastinum, trachea, vascular structures) may ultimately result, depending on the duration and the location of the battery within the esophagus.[9,13,14,16–19] Progression to esophageal perforation is usually associated with a duration greater than 12 to 24 h (occurring only 2% of the time before 24 h) and becomes increasingly more likely with prolonged impaction.[20] Importantly, even after battery removal, esophageal damage may continue to progress in the setting of a persistently high pH at the site of previous battery impaction,[7] with late presentation of symptoms and even death reported several weeks after battery removal.[17]

History/Incidence

Children are naturally curious about their environment. They often explore by placing foreign objects in their mouths and on occasion will accidentally swallow those items. The most commonly swallowed foreign bodies in the United States are coins, but shiny metallic button batteries are also appealing to children.[3,14] More than 3,000 cases of button battery ingestion are reported in the United States

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Fig. 1. CR2032 (20-mm diameter) lithium button batteries. (*A*) Size relationship to common U.S. coins. (*B*) Flat surface of positive battery pole (*black arrow*) on the left. Negative battery pole (*white arrow*) shown on the right with step-up to narrower flat surface.

per year and most of these occur in young children.[6,7,21] Although this represents a small percentage of overall foreign body ingestions, it remains a significant risk of morbidity and mortality.[3,7,14] The majority of fatalities and major complications associated with batteries lodged in the esophagus have been shown to occur in children less than 4 yr of age.[7]

The dangers associated with battery ingestion have been recognized for decades but have been evolving in recent years. For example, the number of emergency department visits related to battery ingestion has been increasing over time, rising from 0.14% of all foreign body ingestions in 1995 to 8.4% in 2015.[3] Although the majority of children suffer no permanent harm from battery ingestions,[6] outcomes have been worsening in recent years with a nearly sevenfold increase reported in the percentage of major or fatal outcomes associated with button battery ingestion.[7] This increase is thought to be due to two factors: (1) a greater number of ingestions of larger-diameter (greater than or equal to 20 mm) batteries that are more likely to become lodged in the esophagus; and (2) more lithium cell button batteries with a higher energy delivery (3 volt *vs.* 1.5 volt) that are likely to promote a more severe alkaline caustic reaction at the tissue level.[7] Regarding battery size, the diameter of an ingested button battery is the most important predictor of clinical outcome. Lithium batteries 20 to 25 mm in diameter account for more than 90% of major or fatal outcomes.[7] Importantly, severe injury can occur with battery exposure in the esophagus for only 2 h, suggesting the need for prompt removal.[7]

Diagnosis

Unfortunately, most of the fatal outcomes associated with button battery ingestion involve unwitnessed ingestions where a delay in diagnosis occurs.[7] The diagnosis is also simply missed in many of the reported fatal cases due to nonspecific symptoms (for example fever, cough, irritability, drooling, vomiting, unwillingness to eat, or dyspnea).[18,19] In the case of button battery ingestion, where rapid recognition and prompt removal is of paramount importance, this is particularly problematic.[7]

Radiographs are a necessary part of the diagnostic workup of a witnessed or suspected foreign body ingestion. If a button battery is found located in the esophagus, removal should be undertaken emergently.[7,10,11,17] The radiograph may help to determine the size of the battery and its location. Compared to coins, button batteries have a characteristic double ring or "halo sign" when viewed on a plain chest x-ray. The negative terminal side of the battery is also narrower when viewed laterally (fig. 2).[9,22,23] These findings may help differentiate a button battery from a coin but may also aid in determining the likely risk of complications if esophageal erosion were to occur by noting the level of the battery in the esophagus and its orientation. The "3 Ns" mnemonic (negative, narrow,

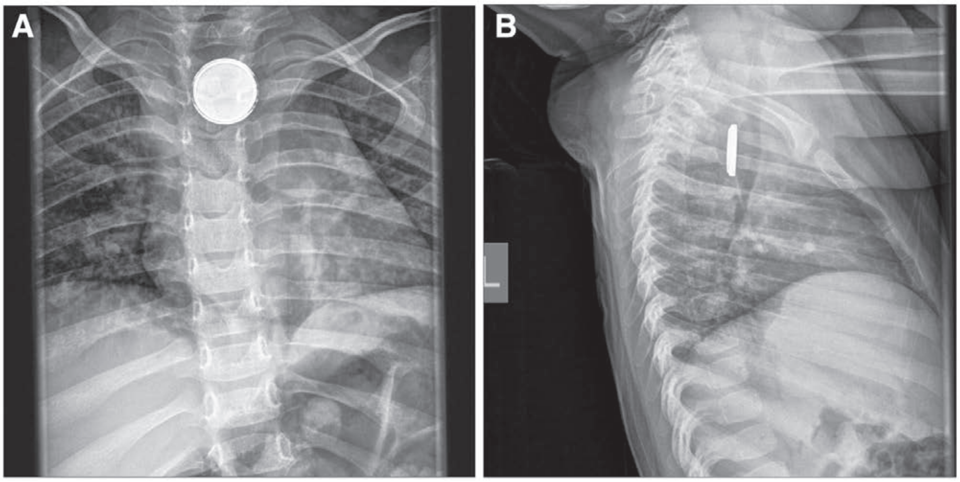

Fig. 2. Button battery in esophagus. (*A*) AP view radiograph demonstrating a "halo sign" noted by ring around outer edge of disc. (*B*) Lateral view radiograph demonstrating a "step-off" sign noted by the change in diameter between positive pole (anterior) and negative pole (posterior) of the battery. AP, anteroposterior. Reprinted from Sahn *et al.*[23] with permission from Elsevier, ©2014.

necrotic) may be useful in anticipating potential risk since the *negative* pole is the *narrow* side of the battery on the lateral radiograph where an increase in local pH and tissue *necrosis* is most likely to occur.[7] For example, if a button battery is located in the proximal esophagus with the negative pole facing anteriorly toward the adjacent trachea, there is a greater risk of developing a tracheoesophageal fistula.[13,16,24,25]

When button batteries are located in the stomach, the acidic environment and decreased likelihood of impaction compared to the esophagus make focal tissue damage in that area less likely.[5] Clinicians may therefore elect to simply observe patients with gastric batteries.[7,10,17] However, since esophageal damage can occur before reaching the stomach,[16] symptomatic patients (pain, vomiting, or evidence of bleeding) may require a more urgent battery removal and evaluation for tissue damage.[10,17,26]

Possible Complications

A number of complications have been reported in cases of button battery ingestion. Damage to the esophageal mucosa itself can result in long-term scarring and esophageal stricture formation. Perforation of the esophagus can lead to pneumothorax, pneumomediastinum, mediastinitis, or tracheoesophageal fistula formation.[7,19] One of the more dreaded complications is erosion into the aorta or other major blood vessel, resulting in massive hemorrhage and death. Other complications include vocal cord paralysis from damage to recurrent laryngeal nerves, thyroid parenchymal hemorrhage, and spondylodiscitis of the spine, among others.[16,27]

Prevention

Major efforts have been undertaken to inform the public of the hazards of button battery ingestion. Multiple government, industry, and academic entities throughout the world have issued public warnings and educational information on the hazards of button battery ingestion, many with recommendations for how to minimize the risk of exposure through prevention.[27] Several highly publicized cases have also appeared in the press and have helped increase public awareness of the problem.[28]

In 2012, the Button Battery Task Force, was formed with a mission statement: "A collaborative effort of representatives from relevant organizations in industry, medicine, public health and government to develop, coordinate and implement strategies to reduce the incidence of button battery ingestion injuries in children."[27] A multi-pronged approach from the Button Battery Task Force has promoted several improvements aimed at prevention. This includes child-resistant packaging of batteries with warnings on the outside of the packages, as well as on the batteries themselves. For example, Energizer button batteries (Energizer Holdings, Inc., USA) include a warning sticker on the negative terminal side that must be removed before use.[27] Enhancements in battery compartment design on devices have also been recommended to include more secure housing in toys intended for young children, (*e.g.,* they may require a tool to open them).[27] These efforts may be helpful since most swallowed button batteries in children are taken directly from devices rather than from new battery packages.[5] Legislative efforts have also been promoted by the Button Battery Task Force to address the problem. Unfortunately, despite these extensive efforts, button battery ingestions with associated complications continue to occur.[3]

Treatment

The National Battery Ingestion Hotline (1-800-498-8666) at the National Capital Poison Center in Washington, D.C., provides information and guidance to both the public and clinicians regarding battery ingestions. Data from the hotline has been useful in identifying mechanisms to reduce the hazards of battery ingestion and in the creation and refinement of treatment guidelines. Analogous to the Malignant Hyperthermia Hotline, clinicians are urged to contact the hotline 24/7 for consultation and assistance with management in the care of patients with known or suspected battery ingestion. Detailed historical clinical information on outcomes and fatalities as well as safety tips and an up-to-date treatment algorithm for button battery ingestion are also available at the National Capital Poison Center website: http://www.poison.org/battery (accessed August 2, 2019).

A quick diagnosis and rapid removal of the battery can be challenging. Even in circumstances where the ingestion is known and a prompt diagnosis is made, battery removal in children usually requires general anesthesia in a facility equipped to perform endoscopy or esophagoscopy in pediatric patients. This may involve consultation with subspecialists or transfer to another facility, both of which take time. The clock is ticking, but in many cases, the goal of avoiding injury by removing an impacted battery within 2h is simply not realistic. Understanding these limitations to rapid removal of button batteries, recent efforts have been aimed at potentially mitigating the local effects of battery impaction in the esophagus by reversing the increased pH at the battery site while efforts to remove the battery are underway. One such strategy is for children with a known or suspected battery impaction to drink small amounts of a weakly acidic liquid in order to neutralize the alkaline environment at the battery site. To investigate this possibility, Jatana *et al.*[12] took cadaveric sections of piglet esophagus and positioned the most commonly ingested button battery (CR2032) against isolated esophageal tissue to simulate battery impaction and allow current to flow. Several common household beverages (lemon juice, orange juice, water, or cola) were irrigated over the batteries every 5min. pH and temperature were measured regularly for 2h. The results showed that lemon juice and orange juice were most effective in neutralizing the pH and in reducing the visible tissue injury, compared to control. Temperature was unchanged, suggesting that any possible exothermic reaction associated with pH neutralization was minimal.[12]

Similar studies using acidic liquids with greater viscosities (honey and sucralfate) have also demonstrated effective pH neutralization at the battery site using an *in vitro* piglet esophagus model.[14] These thicker liquids may effectively coat the battery (thereby limiting contact with the mucosa) and potentially provide greater mitigation of the pH-related changes compared to thinner liquids. They are also more likely to be acceptable to young children compared to lemon or orange juice. To test the effectiveness of this concept *in vivo*, Anfang *et al.* anesthetized piglets and after testing the voltage of a new 3-volt lithium button battery, placed it manually in the proximal esophagus. Serial irrigations were then performed at the battery impaction site using either saline (control), honey, or sucralfate every 10min for 1h. The batteries were subsequently removed and the animals were awakened and allowed to resume a typical diet for 7 days. The results showed that the batteries in both the honey and sucralfate groups had discharged less than in the saline group, suggesting a protective effect. Both honey and sucralfate were associated with effective pH neutralization at the battery impaction site compared to saline control. Grossly, half the control animals experienced esophageal perforation compared to none in the honey or sucralfate groups. Additionally, histologic examination of the esophageal tissue 7 days after battery exposure revealed a greater degree of tissue damage in the control group.[14]

Clinical experience suggests that the tissue destruction from a battery impacted in the esophagus can continue to progress even after the battery has been removed with delayed presentation of symptoms days to weeks later. In some cases, late exsanguination and death have occurred from continued erosion into deeper tissue layers and blood vessels.[16,17] Because the alkaline environment at the esophageal tissue level may persist even after battery removal, another mitigation strategy is to irrigate with an acidic solution (dilute acetic acid 0.25%) endoscopically at the impaction site in the esophagus at the time of battery removal. This has been shown to effectively lower the tissue pH in an animal model and may be undertaken to help minimize the progression of tissue damage after button battery impaction.[12]

As a result of the animal studies suggesting the benefits of pH-lowering mitigation strategies, the button battery treatment guidelines from the National Capital Poison Center were updated in 2018 (fig. 3).[26] Added was a recommendation that those with suspected battery ingestion consume honey at home or on the way to the hospital. Exceptions include children less than 12 months of age (due to the rare risk of botulism with honey consumption) and those with battery ingestion of more than 12h (due to higher risk of esophageal perforation).[26] Patients should otherwise be kept *non per os*. Once in the hospital setting with an x-ray confirming esophageal location of a button battery, sucralfate suspension may be administered instead of honey. Regardless of these strategies, battery removal by endoscopy should not be delayed and should still ideally occur within 2h of button battery ingestion. Importantly for those providing anesthesia, recent consumption of honey or sucralfate should be anticipated and regardless of recent consumption of any other food or drinks, anesthesia

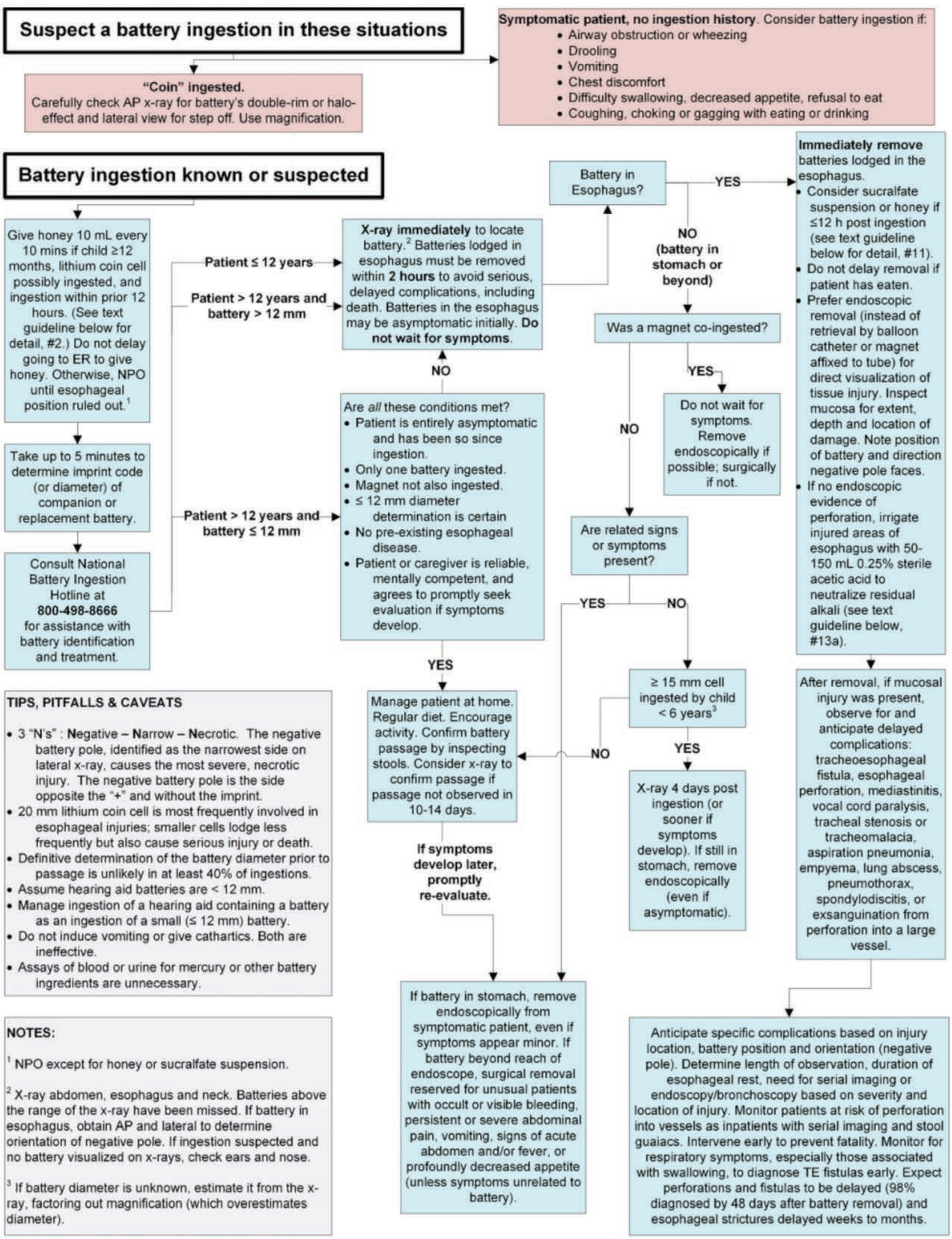

Fig. 3. National Capital Poison Center. Button Battery Ingestion Triage and Treatment Guideline,[26] updated June 2018. Reproduced with permission ©2010-2019.

should not be delayed due to *non per os* status in the case of button battery ingestion.

Although it is hoped that new treatment strategies will decrease the risk of esophageal damage and the potential for perforation, this has yet to be evaluated. As such, urgent battery removal should remain a priority. Hospitals and treatment teams should consider creating their own local protocols for the care of patients with button battery ingestion based on published guidelines and in consideration of their own resources. This might include simply designating button battery ingestion level 1 trauma status in order to expedite treatment.[29] A more thorough approach could involve convening a multidisciplinary team of primary care and emergency physicians, gastroenterologists, otolaryngology specialists, surgeons, radiologists, and anesthesiologists, among others, to develop a comprehensive institutional guideline for management of complicated button battery ingestion.[17] In developing local protocols, delays in care should be minimized through effective planning and communication. Some hospitals have put in place special notification systems that immediately alert relevant on-call specialists (including anesthesiology) when the emergency department is expecting or evaluating a patient with button battery ingestion. This notification includes patient name, age, location of battery, and estimated time of arrival in order for the various teams to prepare. Anesthesiologists should play a key role in the expeditious management of patients once that announcement is made. For hospitals that are not well-equipped to care for a child with an esophageal button battery, the local protocol could establish a clear mechanism for rapid transfer to a designated center while mitigation techniques are underway, if that is determined to be safe based on the patient's condition.

Anesthesia Management

In most circumstances, the operating room is the preferred location for button battery removal since patients usually require general anesthesia, the operating room is accustomed to emergencies, and the treatment of potential complications is more readily accomplished in that setting. Some hospitals may utilize a "hybrid" operating room with additional endoscopic, endovascular, and imaging capabilities. Ideally, the patient should be brought directly to the operating room from the emergency department or helipad in order to expedite treatment. In consideration of the potential for a full stomach and the need to secure the airway with an endotracheal tube for safe retrieval of a foreign body, a rapid sequence induction of anesthesia may be appropriate. Anesthesia induction agents should be chosen based on the hemodynamic stability of the patient upon presentation to the operating room.

If diagnosed early, most button battery removal procedures are likely to proceed uneventfully. However, recognition of the risk of esophageal perforation (especially with erosion into vascular structures) remains a key element in planning for anesthesia care. The location and orientation of the battery in the esophagus should be considered in assessing risk but ultimately, when esophageal perforation is known or suspected, particularly when there is evidence of bleeding, a number of additional steps should be taken. Specialists from general and/or thoracic surgery, interventional cardiology, and/or radiology should be in attendance, depending on the hospital's available resources.[16,17,30] The need for massive transfusion should be anticipated and the operating room prepared accordingly. Banked blood should be immediately available. Large bore IV access should be obtained. Intra-arterial blood pressure monitoring and the availability of a rapid infusion device should be considered. Depending on the circumstances, central venous access may also be appropriate, although placement should not appreciably delay battery removal unless absolutely necessary. Of note, children with a history of a previous sentinel bleed, even if hemodynamically stable and without evidence of active bleeding, are at increased risk for subsequent bleeding and should be treated as such.[17]

In cases of massive hemorrhage, especially after development of an aortoesophageal fistula, definitive treatment might include either primary surgical or endovascular repair. A Blakemore tube has been employed in some reported cases of esophageal hemorrhage to minimize bleeding while definitive treatment is undertaken.[16,17] Regardless of the technique utilized, it should be recognized that the historical survival rate from hemorrhage associated with esophageal button battery ingestion is low.[7]

In uncomplicated cases where esophageal damage is minimal and the esophageal pH has been neutralized with acetic acid after battery removal, patients may be extubated at the end of the procedure and observed in the inpatient hospital setting. Patients with complications, including those with esophageal perforation, may be more appropriately cared for in the intensive care unit and may need to remain intubated and sedated. Evaluation after initial battery removal may include computed tomography angiography or magnetic resonance imaging if vascular injury is suspected.[10,16] Repeat endoscopy or other subsequent evaluation, as well as the duration of inpatient observation, will be guided by the severity of injury and in recognition that complications (including bleeding) may not become apparent for days to weeks after battery removal.[16,17]

Future Directions

Most efforts aimed at prevention of injury from button battery ingestion have focused on public education, battery packaging and warning labels, and mitigation strategies, as well as improvement in the battery housing design on devices. One additional mechanism may be the design of the battery itself. Updated button batteries that only allow current to flow when solidly placed in the housing of an electronic device have been considered as a way to potentially improve safety.[27] One such design is the quantum tunneling composite coated battery, which, by incorporating a specialized coating on the negative terminal of the battery, allows current to flow freely in the high pressure environment of the battery housing of a device, but reduces conductivity in the relatively low-pressure environment of the esophagus.[31] Future work with this and other changes in battery design may help to decrease the risk of button battery ingestion.

Conclusion

Despite numerous ongoing efforts to decrease the incidence and associated complications from ingestion of button batteries, it remains a significant potential source of morbidity and mortality, especially in young children. Recognition of the importance of rapid removal of batteries lodged in the esophagus within 2 h and of the potential complications associated with button battery ingestion is of vital importance to all who care for these children, including anesthesiologists.

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Competing Interests

The authors declare no competing interests.

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