# What Physicians Need to Know About Water Beads: A Call To Action

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That Water Bead Lady

# Ear

**Key Points About Water Bead Insertion into the Ear:**

- Water beads in the ear can be difficult to remove.
- Persistent granulation in the ear may indicate water bead insertion.
- Children may insert water beads in their ears despite supervision.
- Misdiagnosis as an ear infection can lead to improper treatment with antibiotics.
- Avoid using ototopical drops or irrigation for removing malleable beads.
- Early recognition is crucial to prevent complications from water bead insertion.
- Complications can include perforation, ossificans, erosion, and permanent hearing loss.
- Use blunt tools for removal; seek an otorhinolaryngologist if difficult or fragmented.
- Surgery may be required.

**Symptoms of Water Bead Ear Insertion:**

- Ear pain
- Ear irritation
- A feeling of something in the ear
- Loss of hearing

Water bead insertion into the ear can be difficult to visualize and remove. In cases of persistent granulation in the ear, foreign body insertion should remain on the differential diagnosis (Sterling et al., 2016). Even with supervision, water beads can quickly be inserted into the ear in both school and home environments and since pediatric patients are not always reliable historians, it can be difficult to prevent such occurrences. Cases of foreign body water beads have been misdiagnosed as ear infections and treated with topical antibiotics, which can lead to enlargement of the foreign body. Irrigation techniques and topical medications should not be used, malleable beads in the ear should not be treated with ototopical drops and patients should be instructed to keep the ear dry (Sterling et al., 2016; Ramgopal et al., 2019). Early recognition of otologic foreign bodies is important, particularly if expansile water-bead is suspected in conjunction with severe otologic complications such as tympanic membrane perforation, labyrinthitis ossificans (a pathologic process where after the inner ear becomes inflamed it grows abnormal bone), ossicular erosion, and in a prolonged case, otic capsule erosion resulting in permanent auditory and vestibular loss (Sterling et al., 2016; Zalzal., et al 2022) . Research suggests blunt tools such as ear curettes and suction, may be best suited for bead removal; however,  if the item can not be removed or the bead breaks apart urgent consultation with an otorhinolaryngologist is recommended (Ramgopal et al., 2019; Zalzal., et al 2022) Surgical intervention is often required due to the highly destructive nature of water beads on the middle ear structures, depending on the duration of exposure (Zalzal., et al 2022).

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# Nasal Cavity/Airway/ Lung

**Key points About Water Bead Insertion Into The Nasal Cavity:**

- Water bead foreign bodies present unique diagnostic and treatment challenges
- Misdiagnosis and missed diagnosis are common
- Water beads cause nasal cavity complications
- Contain neurotoxic substances leading to systemic reactions
- Diagnosis involves endoscopic examination or nasal CT
- Require careful removal, often under anesthesia
- Removal is crucial to prevent complications and further injury
- Postoperative follow-up is necessary for addressing any sequelae

**Clinical Manifestations of Nasal Cavity Insertion:**

- Congestion
- Snorting
- Coughing
- Runny nose
- Swelling of the nasal cavity
- Nasal bleeding
- Injury to the nasal mucosa
- Development of a false membrane resulting from impingement, ischemia and necrosis.
- Chemical corrosion of the nasal mucosa

Note: If water beads remain in the nasal cavity for a prolonged period, patients can develop symptoms of agitation, refusal to eat and a high fever

Water bead foreign bodies have unique physicochemical properties that make the clinical diagnostic and treatment processes especially difficult. Due to the fact that children are unable to communicate their medical history effectively and their parents may not be aware of the incident that caused the issue, it is common for misdiagnosis and missed diagnosis to occur. "Superabsorbent polymer balls (water beads) are mainly made of polyacrylate-polyacrylamide copolymer and are able to absorb water. When exposed to water, they can expand to several times their original size. Therefore, they usually impinge on the nasal cavity, causing ischaemia and necrosis of the nasal mucosa. Furthermore, acrylamide is neurotoxic in nature. Although it loses its toxicity after being polymerized, it could still cause chemical corrosion of the nasal mucosa once introduced and may even enter the digestive tract and respiratory tract, where it is absorbed, entering the systemic circulation and causing toxic reactions" (Hans et al., 2021). Hans and their colleagues retrospectively analyzed the clinical data concerning 12 cases of superabsorbent polymer balls as nasal foreign bodies in children and summarized the corresponding clinical features, methods of diagnosis and treatment, and prognoses. The diagnosis of water bead insertion was made after transnasal endoscopic examination or nasal CT for confirmation when necessary. Twelve children had super absorbent polymer balls in their nasal cavities that remained in place for 4 hours to 7 days, causing symptoms such as congestion, runny nose, and nasal swelling. A biopsy of a patient's space-occupying lesion was performed, which indicated cellulose-like effusion combined with inflammatory necrotic changes and substantial neutrophil infiltration. Nasal mucosa appeared very swollen and eroded on the surface, with a white false membrane. When left in the nasal cavity for a long time, patients may experience discomfort such as agitation, poor appetite, and high fever. "Superabsorbent polymer balls (water beads) are prone to breaking into gel particles when touched. They are not only brittle but also too slimy to be gripped. Thus, they have to be suctioned out of the nasal cavity one at a time" (Hans et al., 2021). The foreign bodies caused significant swelling of the nasal mucosa as they expanded in size after absorbing water, leading to severe irritation. The transparent nature of the foreign bodies made it essential to carefully examine them to avoid missing the correct diagnosis. To remove the foreign bodies, most of the children required nasal endoscopy under general anesthesia. During the operation, the doctors found significant damage to the nasal cavity's lining. The researchers discovered that water bead foreign bodies in the nasal cavity should be removed safely and effectively to prevent complications and further nasal injury. Additionally, regular postoperative follow-up is necessary to promptly address any sequelae, such as nasal cavity adhesions (Hans et al., 2021). The peer reviewers' comments on the paper recommended advocating for the banning or removal of water bead toys for young children, or even banning them altogether.

**Key Points About Water Bead Inhalation/ Aspiration/ Lung:**

- Age restriction and parent observation don't prevent water bead injuries effectively
- 30% of water bead injuries occur at school
- Inhaled and swallowed water beads can go undetected for long periods of time
- Water bead aspiration can cause severe pulmonary complications
- Diagnosis of water bead aspiration is challenging due to unclear presentation
- Recurrent chest infections and persistent wet cough may indicate water bead aspiration
- Extract with a basket as water beads are fragile
- Enlarged water beads in the larynx can be fatal
- Inhaled water beads can block airways and damage lung tissue

**Symptoms of Water Bead Inhalation/ Aspiration:**

- Choking
- Coughing
- Difficulty speaking
- No breathing or breathing trouble (respiratory distress)
- Turning blue, red or white in the face
- Wheezing
- Chest, throat or neck pain

Note: Sometimes, only minor symptoms are seen at first. The object may be forgotten until symptoms such as inflammation or infection develop.

Age restriction and parent observation are not very effective at preventing water bead injuries. Research has documented 30% of children who were later injured by water beads gained access to them at school (Alharbi & Dabbour, 2020). If swallowed the beads have the potential to remain undetected for long periods of time, sometimes over a year (Alharbi & Dabbour, 2020; Gardner et al., 2021). While the initial symptoms of water bead ingestion and aspiration may be asymptomatic, they can lead to severe pulmonary complications such as fibrotic tissue formation, bronchial erosion, atelectatic lung collapse, and lung damage both acutely and chronically over time (Alharbi & Dabbour, 2020; Gardner et al., 2021). Water bead aspiration can be a challenging condition to diagnose due to several factors, including the radiolucency of the beads, an unclear clinical presentation, and a slow and gradual decline in the patient's condition over time. “A 3-year-old boy was initially evaluated by his primary care provider for symptoms of gastroenteritis. Abdominal series x-rays were obtained and incidentally found opacification in the region of the left lung…concern for pneumonia, where chest x-ray revealed significant atelectatic collapse of the left lung, confirmed by computed tomography (CT) of the chest. Otolaryngology was consulted for assistance with management of the suspected foreign body, and the patient was taken to the operating room for a diagnostic bronchoscopy…Definitive management was achieved by rigid ventilating bronchoscopy. The fibrous tissue was incised with blunt and sharp instrumentation revealing green inorganic gel material. Further examination revealed evidence of erosion of most of the bronchus with exposed mediastinum and pericardium…Upon follow-up, the left lung has been noted to have stable atelectatic collapse via x-ray, although the patient is stable from a clinical perspective” (Gardner et al., 2021).

Another 3-year-old experienced recurrent chest infections associated with a persistent wet cough which resulted in four hospitalizations over the course of a year. The patient experienced respiratory difficulties, a worsened cough, and low oxygen levels, which necessitated frequent emergency visits, ICU stays, and a total of four hospitalizations spanning one year. Analysis of the patient's immune system revealed that immunoglobulin and lymphocyte levels were within the normal range . Efforts were made to extract the foreign object with the use of a flexible scope and retrieval basket. However, this resulted in the crushing and fragmentation of the object into smaller segments, necessitating the removal of each piece using the retrieval basket. Eventually, all of the pieces were successfully extracted. During the procedure, it was noted that granulation tissue had developed, obstructing the airway of the posterior segment of the left lower lobe to the point where the scope could not pass through it (Alharbi & Dabbour, 2020). Researchers and clinicians have expressed concerns that the enlargement of a water bead or beads lodged in the larynx, could lead to the death of a child. This concern holds merit, as the literature on occupational medicine documents the case of a 26-year-old man who inhaled polyacrylamide gel while cleaning it from a tank truck. This resulted in severe airway blockage and lung tissue damage, ultimately leading to the patient's death. An autopsy revealed the presence of numerous polyacrylamide particles in the lungs, along with significant damage to the bronchioles and alveoli (Jubran et al., 1992).

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# Water Bead Ingestion

**Key Points Water Bead in the GI Tract:**

- Nearly 40% of all foreign body swallowing incidents are unwitnessed
- Water beads should not be marketed or given as toys to children due to their chemical and mechanical risks
- The attractive colors and small size of water beads can lead children to mistake water beads for edible products
- Ingestion of water beads poses a public health concern
- Diagnosis of water bead ingestion can be challenging, especially in young children who have limited communication abilities
- Healthcare professionals should proactively ask parents about the use of water beads in the home or school
- In over 70% of obstruction cases the water bead swallowing was undisclosed upon hospital admission
- Different visualization methods have pros and cons for diagnosing water bead ingestion, as detailed below
- Water beads left in the gastrointestinal tract can cause complications
- Adhesion in the bowel causes ischemia and necrosis
- Early removal of water beads is recommended to prevent complications
- Water beads can collect and form bezoars in the gastrointestinal tract without obvious symptoms
- Partial and complete obstructions can result from water bead ingestions
- Prompt endoscopic removal is recommended for beads if in the upper GI tract
- Surgical consultation should be sought immediately if signs of bowel obstruction are present
- Physicians should be aware of complications and limitations in accessing information on the chemical composition of toy products
- Widespread access to blood tests for chemicals in consumer products is not available to clinicians

**Water Bead Ingestion Symptoms:**

- Water Bead Ingestion Symptoms
- Wheezing/Coughing
- Constipation
- No appetite
- Lethargy
- Drooling
- Rash
- Hiccuping
- Abdominal swelling
- Abdominal soreness
- Complaining of something in their throat or chest.
- Stomach pains

**Water Bead Obstruction Clinical Manifestations:**

- Partial or complete blockage
- Bowel discoloration and thinning
- Focal ischemic change
- Friable distended bowel susceptible to damage
- Edematous, swollen bowel mucosa
- Relocation of gut flora
- Sprawled posture
- Acute hyponatremia
- Seizures
- Resected bowel
- Perforation peritonitis
- Pressure necrosis
- Cytotoxic cerebral edema
- Toxic brain encephalopathy
- Bowel necrosis
- Infection
- Sepsis, septicemia, septic shock
- Multi-organ failure
- Death

The ingestion of water beads can be particularly hazardous because most often swallowings occur unbeknownst to parents, and obvious symptoms of distress are delayed, making it difficult for caregivers to associate the ingestion with their child's illness (Jung & Lee, 2022). "Young children typically cannot communicate well about the swallowing events. Thus, ingestion of water beads is prone to delayed diagnosis and consequent intestinal obstruction" (Kim et al., 2020). Water beads' attractive colors and small sizes make them easily mistaken by young infants as edible products (Faytrouni et al., 2021). Foreign body ingestion is a frequent concern in the emergency department regarding children, as they tend to explore their surroundings with their mouths especially during early childhood; children with developmental disabilities and sensory processing differences often participate in this behavior for longer than their typically developing peers. This instinctive behavior can often result in the accidental swallowing of objects. It has been reported that nearly 40% of all foreign body ingestions in children are unwitnessed (Ramos-Mercado et al., 2019). A literature review on water bead obstructions revealed that in 76.74% of such cases, ingestion of water beads was not disclosed by family members upon hospital admission; only 10 out of 43 cases were reported (Caré et al., 2022). Clinicians should be conscious of the fact that often the issue is not that the impacted child themselves played with water beads, or that parents provided inadequate supervision, but instead that the water beads were simply in the home or school, being used as a sensory toy for an older child or for gardening purposes.

Water beads are radiolucent, and CT signals often can not distinguish water beads from intestinal fluid, making them almost impossible to visually detect in the absence of information through medical history before surgery. This complicates the diagnostic process and each visualization method has pros and cons that physicians should be aware of. X-Ray will only show the complications of foreign body ingestion such as obstruction but not the beads themselves (Singh et al., 2016; Faytrouni et al., 2021). Ultrasound can miss smaller beads leading to the underestimation of the number of water beads. The beads can produce a hypoechoic shadow and tend to appear as cystic pathology, such as enteric duplication cyst, mesenteric cyst, twisted ovarian cyst (Faizah et al., 2016; Kim et al., 2020). Water beads have the ability to collect inside the body and can form a conglomerate (Shangareeva et al., 2019a). CT can suffer from similar limitations as x-ray such as producing hypodense nature and can simulate a cystic structure or a filling defect in obstructed patients (Singh et al., 2016; Shangareeva et al., 2019; Faytrouni et al., 2021). Furthermore, if a patient is already experiencing vomiting prior to a CT scan with contrast, it may interfere with the completion of the imaging series and prevent clear visualization.

The swelling size of a water bead can be influenced by a number of factors, including salt content, ph, and temperature (Lee et al., 2019). Ultrasound has shown that the size of the beads can increase significantly after 12 hours of immersion in water. In-vitro studies have also shown that water beads can expand up to five times their original diameter 96 hours after ingestion in simulated small intestine conditions (Lip et al., 2017; Kim et al., 2020). Researchers have concluded that polyethylene glycol (PEG) administered to promote intestinal transit of water beads may paradoxically result in increased bead diameter (Ramos-Mercado et al., 2019). Their water absorbance capacity and relative volume expansion depend on both the properties of the fluid that comes in contact with the beads and the nature of the gel ball polymer (Faytrouni., 2021). Super absorbent polymer is a generic term; as such, specific SAP compositions tend not to be readily available to physicians at the point of care. "Ingestion of crystal jelly balls could be lethal both in children and also in the adult population causing intestinal obstruction due to its highly water absorptive and expansive properties" (Dissanayake et al., 2018). Left in the gastrointestinal tract, water beads have been reported to cause obstruction, bowel perforation, hypovolemia, seizures, cytotoxic cerebral edema, renal failure, infection, multiple organ failure, sepsis, and death (Mirza et al., 2011; Mirza & Sheikh 2012; Faytrouni et al., 2021; Shangareeva et al., 2019; Han et al., 2021; Caré et al., 2022; Govindarajan el al., 2023).

Water bead ingestion requires a high degree of suspicion. Management should not conform to standard protocols of foreign body removal, and early removal whenever possible should be attempted in order to prevent complications (Lip et al., 2017). "The recommendation following witnessed ingestion of gel balls in a well young infant or a child is for prompt endoscopic removal presuming they are in the upper GI tract: esophagus, stomach or duodenum. If the beads are not endoscopically accessible and the patient is asymptomatic then we recommend watchful management with monitoring for signs of bowel obstruction in the ensuing 96 hours. If the patient is presenting with signs of bowel obstruction, particularly with bilious emesis, immediate surgical consultation should occur. Early discussion and consultation with the pediatric GI and surgical teams is appropriate" (Faytrouni et al., 2021). Water bead obstructions can mimic duplicate cysts and an enterocolitis-like picture, and ingestion complications may result in nausea and vomiting, constipation, partial or complete blockage, bowel discoloration and thinning, edematous, swollen bowel mucosa, relocation of gut flora, sprawled posture, acute hyponatremia, seizures, resected bowel, perforation peritonitis, pressure necrosis, intoxication, cytotoxic cerebral edema, bowel necrosis, infection, sepsis, multi-organ failure, and death (Mirza et al., 2011; Mirza & Sheikh, 2012; Muthukumaran & Vivek, 2014; Lee et al., 2019; Shangareeva et al., 2019a; Shangareeva et al., 2019b; Govindarajan & Arasappan, 2023)

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# Information about Toxicity

**Key Points About Toxicity:**

- Water beads are often made of polyacrylamide-polyacrylate copolymers, which can contain neurotoxic acrylamide as a residual monomer
- Children are particularly vulnerable to acrylamide
- Polyacrylamide has a longer lifespan and is cheaper compared to alternatives, contributing to its widespread use
- Historical cases demonstrate the use of cheaper but more harmful chemicals to maximize profit
- Acrylamide exposure can occur through oral, dermal, or inhalation routes
- Current regulations do not have specific restrictions on residual acrylamide monomers in polyacrylamide for the toy and decor product categories
- Clinical blood and urine tests for acrylamide exposure are not widely available to clinicians
- Tests to assess the residual acrylamide content in a polyacrylamide toy suffer from issues of interference and reliability
- Monomers with known hazards can transfer under realistic conditions
- Measuring only migration levels is insufficient to assess health risks
- A full health risk assessment depends on both residual monomer content and migration levels
- Multiple factors can contribute to monomer release

**Clinical Manifestations of Acrylamide Poisoning:**

The toxic effects of acrylamide depend on the duration, total dose, frequency of contact, and rate of exposure. Patients should be closely observed, as a seemingly good condition on arrival at the hospital can be misleading. Both chronic and acute forms of acrylamide poisoning can be insidious at first and then become suddenly serious. Poisoning symptoms may not appear immediately after ingestion. Therefore sudden and rapid decline should be anticipated, as the effects of acute high-dose exposure may be delayed in onset for several hours. In a fatal case of acute acrylamide poisoning resulting from oral ingestion of 13 grams, the patient exhibited central neurological symptoms including delirium and hallucinations, with the rapid onset of metabolic acidosis, circulatory failure, renal failure, and hepatic failure.

Polyneuropathy and peripheral neuropathy, primarily affecting motor and proprioceptive function, may develop several weeks after exposure. Sub-acute toxicity, occurring over days to weeks may result in neurological symptoms preceded by a dermatitis, exfoliative, erythroderma type, red rash. At high concentrations dermal contact, a frequent route of exposure, can cause skin irritation, numbness, tingling, blistering, excessive sweating, and peeling. Visual impairment and eye irritation may occur with significant exposure. Inhalation of acrylamide can lead to a cough and sore throat. Severe poisonings can lead to encephalopathy.

Ingestion, the least common route, may result in abdominal pain. Complete recovery over a few weeks to months may be expected with mild presentation, including prolonged weakness, but in cases of severe presentation, gradual and incomplete recovery may occur with residual ataxia, loss of reflexes, distal extremity weakness, and sensory disturbances. In chronic exposure of sufficient concentration, effects are predominantly sensorimotor and proprioceptive neuropathy with loss of deep tendon reflexes, muscle weakness and wasting, distal extremity numbness, and paresthesias. Excessive sweating and an exfoliative rash are also common with chronic exposure. Traditional lab work may be unhelpful; acrylamide poisoning is typically a clinical diagnosis. Evidence of peripheral neuropathy on nerve conduction studies supports the diagnosis of acrylamide neurotoxicity. Normal studies do not exclude the diagnosis.

When it comes to working up a differential, there should be an understanding there can be some overlap of symptoms between acute and chronic exposures. Comprehending both presentations enables the identification and elimination of aspects exclusive to each, while also determining the ongoing care needs of the patient.

Link to additional information on the health effects of acrylamide:
https://drive.google.com/file/d/1cLmlpbIEwxG-Y9r7AKReYVFnvGzP6SR9/view?usp=sharing

**ACUTE EXPOSURE WITH POISONING/EXPOSURE:**

**Acute ingestion poisoning cases from medical literature:** nausea, vomiting, clinical manifestations may be similar to a severe sepsis with acute nervous, cardiac, pulmonary, renal, and hepatic effects. Severe multiple organ failure with renal, liver, respiratory and circulatory failure, and signs of disseminated intravascular coagulation, rhabdo-myolysis, ascites, diffuse edema of the intestinal wall, ischemia of the small bowel, gastric erosive lesion, decreased level of consciousness, seizures, hypotension, and acute adult respiratory distress syndrome. Delayed onset of delusion, hallucination, gate disorders, and speaking difficulties. Management of these patients consists of conservative and palliative therapies to reduce the oxidative effects (Joo et al., 2012;  Banagozar Mohammadi et al., 2015).

**CHRONIC EXPOSURE WITH POISONING/EXPOSURE:**

**Chronic ingestion poisoning cases from medical literature:** Progressive in nature for as long as exposure above a certain critical dose continues. Following removal from further exposure, dermatitis resolves relatively quickly and the peripheral neuropathy resolves over a period of weeks to months. Central effects such as truncal ataxia may take much longer to resolve and, in severe cases, complete recovery may never occur. Acrylamide intoxication is a clinical diagnosis and should be strongly suspected whenever truncal ataxia with peripheral neuropathy is detected in an acrylamide-exposed worker. The presence of excessive sweating and rash makes the diagnosis even more likely (Mulloy, 1996; Igisu et al., 1975).

**Water Beads and Acrylamide Poisoning**

An idealized super absorbent polymer material possesses functional features such as the highest absorption capacity in saline, desired rate of absorption based on particle size and porosity, highest absorbency under load, lowest soluble content and residual monomer, lowest price, highest durability and stability in the swelling environment and during storage, highest biodegradability without toxic species formation, pH-neutrality after swelling in water, colorlessness, odorlessness, absolute non-toxicity, photostability, and re-wetting capability if required (Zohuriaan & Kabiri, 2008). It is not feasible for a superabsorbent polymer material to simultaneously meet all the required features mentioned above. The reality is, optimizing the synthetic components to achieve the maximum level of certain features may result in the inefficiency of others. Therefore it is crucial that in practice, the production reaction variables be optimized to strike an appropriate balance of the super absorbent polymer material's properties (Zohuriaan & Kabiri, 2008). The final properties of a superabsorbent polymer are significantly influenced by various reaction variables, including the type and concentration of the cross-linker, the type and concentration of the initiator, the type and concentration of the monomer(s), the type, size, and amount of inorganic particles incorporated (if any), the polymerization method, the polymerization temperature, the amount and type of surfactant used, the stirrer/reactor geometry and rate of stirring, the porosity generating method or the amount and type of porogen (if used), the drying method, temperature, and time, as well as post-treatments such as surface cross-linking to enhance the swollen gel strength (Zohuriaan & Kabiri, 2008; Meshram et al., 2020). To ensure consistent and defect-free final products, manufacturers must closely monitor and structure the production process, consider final product usage specifications, and properly work with the involved chemical materials.

Water beads are typically made of polyacrylamide- polyacrylate copolymers. "Although acrylamide loses some toxicity after polymerization, it can still cause chemical corrosion of the nasal mucosa and may even enter the digestive tract and respiratory tract, where it is absorbed, entering the systemic circulation and causing toxic reactions" (Han et al., 2021). Sol fraction and residual monomer have typically been neglected areas of super absorbent polymer academic research (Zohuriaan & Kabiri, 2008). While a pure polyacrylamide is considered non-toxic, polyacrylamide is made from the polymerization of neurotoxic acrylamide and can contain residual acrylamide monomers (Spencer & Schaumburg, 1974, Part I; Mulloy, 1996; Zimmermann et al., 2022; Wang et al., 2023; Environmental health & safety: Acrylamide, n.d.). "Polymerization reactions are rarely complete and therefore residual monomers might still be present in plastics" (Zimmermann et al., 2022). "Depending on the polymer type, the polymerization process, and the technique used for reducing residual monomer content, monomers can still account for up to 4% by weight in the final material" (Zimmermann et al., 2022). Polyacrylamide solid gels can contain high concentrations of residual and extremely toxic acrylamide monomers, ranging from 10% to 30% (Chen & Chrambach, 1979). According to the Albert Einstein College of Medicine, polymerized acrylamide gels should be treated with the same caution as acrylamide monomers themselves to avoid accidental repeated exposure to neurotoxic acrylamide monomers (Environmental health & safety: Acrylamide, n.d.). During flocculation, the release of acrylamide can occur due to structural, conformational, modifications in the polymer chain, resulting in its liberation from confinement. If a similar process of clustering or aggregation occurs in the human gastrointestinal tract, it can lead to an increased risk of acrylamide exposure, which can potentially have adverse health effects. Children are particularly vulnerable to the adverse effects of acrylamide due to their low body weight and high consumption of food products containing acrylamide. It has also been demonstrated that the toxic effect of acrylamide increases with an increase in both the dose and exposure time (Karpiesiuk et al., 2023).

People can be exposed to acrylamide through oral, dermal, or inhalation routes (Murray, 1996). "Exposure is a function of the quantity of free acrylamide present. Historically, under uncontrolled manufacturing conditions, exposures have been very high, such as 1 – 3 mg/m3 in China" (Acrylamide monograph - National Toxicology Program, 2005). "Uptake from cosmetics, consumer products, some gardening products, paper and pulp products, coatings, and textiles is possible because of contact with polyacrylamide containing free acrylamide" (Acrylamide monograph - National Toxicology Program, 2005). The EPA and FDA have implemented regulations that limit the quantity of both residual acrylamide monomer in polyacrylamide and the amount of polymer used in specific applications. This restriction is designed to reduce the exposure of the general public to acrylamide through various means such as water, food-contact materials, medical products, and cosmetics (FDA, 1977; King & Noss, 1989; Amended final report on the safety assessment of polyacrylamide and acrylamide residues in cosmetics, 2005). The assumption has been that uptake of acrylamide is unlikely to exceed trace levels because of strictly regulated limits on acrylamide content for individual products, but currently, the Consumer Product Safety Commission does not have restrictions on the amount of residual acrylamide monomer in polyacrylamide, the polymerization process, or polymer specific applications standards set for the toy product and decor categories. Additionally, though commercial toy manufacturers receive safety data sheets from suppliers, which may contain some relevant information on chemical hazards, it cannot be assumed that toy manufacturers and retailers know the exact chemical content of all the components of their products. In the absence of strict specifications regarding chemical content, there may be batch-to-batch variation in chemical mixtures used for toys. Furthermore, the chemicals used in toys may change rapidly in response to market forces (Toys and Chemical Safety A Thought Starter, 2006; Glynn, 2012). It should be noted, polyacrylamide has a longer life span and is cheaper compared to alternatives such as sodium polyacrylate

(IvyPanda, 2020). The Aqua Dots/ Bindeez recall in the toy industry is a clear instance of cheaper and more harmful chemicals being utilized in products to boost profit margins, which is a trend seen in numerous historical cases (Suchard et al., 2009).

In the EU, toy safety is regulated by Directive 2009/48/EC Toy Safety Directive, which prohibits the use of chemicals that are carcinogenic, mutagenic, or toxic to reproduction (CMRs) in toys. However, some CMRs may still be present in toys as long as their concentration is below the level classified by CLP regulation for Food Contact Materials (FCM). According to Annex II, Part III-Chemical properties, toys that are themselves substances or mixtures must comply with CPL Regulation (EC) No 1272/2008, The Classification, Labeling and Packaging (CLP), harmonizing the two standards (Zimmermann et al., 2022). Monomers, known to be hazardous, are permitted for use in polymer production for FCMs on the premise that they are converted into polymers through a chemical process. This is based on the assumption that the resulting polymers' molecular weight is too large to be taken up by the gastrointestinal tract, enter cells, and cause toxic effects, but, as Zimmermann and colleagues' study demonstrates FCMs can contain unpolymerized residues of several monomers of high concern and empirical data has shown that monomers with known hazard properties can transfer under realistic conditions (Zimmermann et al., 2022). The polymerization process may be incomplete, or the chemical was used for a different purpose, or the polymer is degrading, causing the release of the monomer (Zimmermann et al., 2022). Research reveals that unreacted monomers can still be found in the polymeric materials of finished FCMs and recognizing this fact is a very important step to move forward towards safer toy products. It is also important to note that testing for monomer migration is different from testing for residual monomer content.

The Ministry of Environment and Food of Denmark: Environmental Protection Agency, in 2019, found that data regarding the residual content of acrylamide in polyacrylamide was lacking and though they intended to investigate the residual acrylamide content of polyacrylamide used for "grow in water toys" it was not possible for them to complete their investigation because of the difficulty in analyzing for residual acrylamide in solid polyacrylamide materials. According to their investigation Eurofins, in 2018, did not perform this analysis due to issues with interference and limitations in accurately quantifying residual acrylamide content during the analysis (Poulsen, 2019). If the migration of a monomer from a product is known, but the residual monomer content is not, it is not always possible to accurately assess the total potential health risks associated with using the product. Migration levels of monomers do not provide information about the total amount of monomers that is present in the product. It is important to measure both the residual monomer content and the migration levels to accurately assess a product's potential health risks. By understanding both measurements, manufacturers and regulators can make informed decisions about the safety of a product with full knowledge about potential issues with manufacturing process effectiveness, product risks to consumers over time, and health harms a product can cause under various exposure scenarios, such as exposure through different routes. This information allows stakeholders to take appropriate measures to mitigate any potential risks to human health. Even though water beads may pass CPSIA testing standards for heavy metals and phthalates, they can still pose a chemical risk to children.

Woodrow and colleagues in 2008 found that sunlight, ferric ions, and ethylenediaminetetraacetic acid (EDTA), in an acidic environment resulted in polyacrylamide degradation to acrylamide monomers. The study used polyacrylamide with the strict EPA limit for allowed residual acrylamide in drinking water for their experiment; however no such limit has been set for polyacrylamide used in toys or decor products. Denmark's survey found they could not investigate for residual acrylamide due to interference issues with testing for residual acrylamide in a solid polyacrylamide, and as of 2018 though Eurofins does have a migration test (outlined in EN-71), they did not have a test for residual acrylamide in polyacrylamide. Though EDTA does not occur naturally inside the human body there are compounds with similar structures like amino acid histidine, and metallothionein proteins that are present. Typically simulated gastric juices do not contain ferric & ferrous ions or structures similar to EDTA. However it is important to understand these types of compounds are found in the human body during digestion; for testing purposes, this information and these compounds are relevant. Woodrow and colleagues made it clear the extent of degradation would depend on various factors such as the chemical composition, concentration of $Fe^{+3}$, EDTA similar human compounds, duration of sunlight exposure, and the environmental conditions under which the experiment is conducted. In addition a 2019 paper found, "It has been shown that anaerobic digestion of polyacrylamide by a mixed population of microbes results in accumulation of significant amounts of the acrylamide monomer" (Nyyssölä & Ahlgren, 2019). The human stomach and intestines can create a dangerously similar environment.

The theory put forth by Mirza et al in 2011 suggested that in the case of their patient, intestinal perforation resulted from either chemical damage to the intestinal wall or gradual enlargement of the water-absorbent beads, leading to pressure necrosis of the intestinal wall (Mirza et al., 2011; Tewari et al., 2021). The reason they considered the second theory the most probable was that the crystal balls, which were initially very small in size, easily passed the esophagus, pylorus, and duodeno-jejunal junction. When it reached the mid-ileum, their size gradually increased by absorbing water from intestinal juices. This, they theorized, resulted in pressure necrosis of the intestinal wall and perforation followed. Mirza et al, 2011 and their colleagues concluded the second theory was the most plausible explanation of the intestinal perforations encountered in their patient, because they assumed the super absorbant material was subject to strict regulation and is inert to the human body. Authors cited Wikipedia as the source for their information about the water beads; it does not appear they consulted with an occupational environmental physician. Authors did not seem to consider the potential for monomer release and patient exposure either due to the incomplete polymerization process (residual monomer), or the release of monomer due to conformational changes in the polymer chain (active monomer particles released from polymer structures acting as haptens (Kucharczyk et al., 2021)), or the polymer undergoing degradation due to the environment inside the human body.

A study from the French Poison Control Centers in 2021 stated "Risk of obstruction does not seem to concern all kinds of SAPs beads. SAPs swelling capacity is highly variable and depends on cross-linking density, affinity between polymers and water, and electrolytes-generated osmotic pressure" (Caré et al., 2021). Authors stated water bead injury cases were different from the poisoning cases involving the Aqua dot beads because, “No systemic toxicity, i.e. toxicity linked to the passage of one of the components of the product in the blood, after SAPs bead ingestion was observed, as expected. Most of the marketed SAPs are cross-linked sodium polyacrylate. In rats, the oral median lethal dose is very high (>40,000 mg/kg), and oral administration does not result in any kind of toxicity” (Caré et al., 2021). “It cannot be assumed toy manufacturers know the exact chemical content of all of the components of their products in the absence of strict specifications regarding chemical content” (Toys and Chemical Safety: A Thought Starter, 2006). In a laboratory setting, there is greater control over the synthesis process, ensuring precise knowledge of the quality and chemical composition of items created for a specific experiment. It is fundamentally dangerous to assume consumer grade polymers are consistently of the same quality and purity as technical grade polymers. When it comes to toys, the chemicals used can experience swift changes in response to market forces or may be safeguarded as proprietary information. “Toys manufactured by smaller companies, at home, or in cottage industries may have less rigorous control and documentation over the chemicals used” (Toys and Chemical Safety: A Thought Starter, 2006). The reality is there are not widely available blood tests for many of the hazardous chemical components that can result from exposure to deficiently manufactured and designed water beads.

While there is limited data on acrylamide poisoning in children, the Agency for Toxic Substances and Disease Registry (2012) states that “Acrylamide is expected to have the same effects on children as it does on adults,” and animal studies have clearly demonstrated the toxic effects of acrylamide. “Children are not little adults, they are a unique subpopulation that needs to be considered in risk assessment due to differential exposure patterns, immaturity in physiological development, or differential toxicant metabolism” (Carroquino et al., 2012). Children should be recognized as a unique class of workmen participating in the occupation of play due to the distinct nature of their activities, exposures, and vulnerabilities. While occupational environmental medicine primarily focuses on adults, the information and research in this field can serve as a valuable starting point when examining injury patterns in children. Although children engage in different activities and encounter specific environmental risks during play, there are often similarities in the mechanisms of injury or exposure pathways between adults and children. By drawing from the existing knowledge in occupational environmental medicine, researchers and healthcare professionals can gain insights into potential hazards and preventive measures for children. While acknowledging the need for a specialized approach to account for the unique characteristics of children, leveraging the literature on adult occupational health can provide a valuable foundation for understanding and addressing health issues related to childhood play and activities. When examining the pattern of injury observed in children following water bead incidents, particularly cases involving obstructions after water bead ingestion, a concerning trend becomes evident.

What we know from gastrointestinal, pharmaceutical, and medical device research is that the most prominent strategies for achieving gastric retention are density mismatching, geometry-based, and bioadhesive doses (Laulicht et al., 2010; Talukder & Fassihi, 2004). Water beads can operate as duplicate cyst type lesions along the gastrointestinal tract and may achieve gastric retention because of their inherent swelling behavior, ability to collect together and modify geometric shape, density mismatch, mucoadhesiveness, and chemical composition.

Water bead obstructions can lead to various pathologies and the risk of complication is increased the longer the water beads are in the child’s system. If medical attention is provided quickly, the water bead is removed, the patient is given treatment that is supportive, and attempts to restore homeostasis, overall recovery tends to be good. This is similar to acute cases of acrylamide poisoning in animals and humans in the medical literature (Banagozar Mohammadi et al., 2015; Igisu, et al., 1975). Spencer and Schaumburg remarked in Part II of their 1974 paper: “If animals survive the effects of acute poisoning, recovery may be rapid and complete.” Kuperman found through animal experiments in 1958, with regards to acrylamide the nature of the syndrome depended upon the dose magnitude, rate of administration, and the length of time during which the agent was given. Igisu and colleagues later demonstrated that route of exposure can also impact the syndrome (Kuperman, 1958; Igisu, et al., 1975). Though the exact mechanism of acrylamide toxicity is not known we do know that acrylamide poisoning is insidious. Joo et al. 2012 reported a case of a 40-year-old man who reported to the hospital completely asymptomatic after ingesting acrylamide and within 40 hours he was dead. Ingestion of acrylamide can lead to various gastrointestinal pathologies, such as gastroerosive lesion, gastroenteritis, difficulty defecating, bowel ischemia, ascites, necrosis, and diffuse edema of the intestinal wall (Mulloy, 1996; Joo et al., 2012; Banagozar Mohammadi et al., 2015; Wang et al., 2023).

“In acute poisoning, changes are seen in the nerve cell bodies, and in chronic poisoning, changes are seen in the axons, but this is consistent with the fact that central neurological symptoms are most prominent in acute poisoning, while peripheral neurological symptoms are primary in chronic poisoning. Moreover, the neurotoxicity is considered to be due to neurotrophic disorders caused by the inhibition of glycolytic enzymes” (Joo et al., 2012). While neurotrophic disorders primarily affect the nervous system as a whole rather than specifically targeting the GI tract it is important to note that disturbances in neurotrophic factors or the nervous system can potentially have indirect effects on GI function. For example, abnormalities in neurotrophic factors or neuronal signaling may contribute to gastrointestinal dysmotility (impaired movement of the digestive tract), alterations in intestinal permeability, or dysfunction in the enteric nervous system (the network of nerves within the GI tract). These effects can lead to symptoms such as constipation, diarrhea, abdominal pain, or other GI disturbances. Joo et al observed that their patient’s CT scan findings suggested necrosis of the intestinal tract, and that it was likely direct corrosive action on the intestinal mucosa led to acidosis versus convulsions alone. Moreover, because acrylamide inhibits the glycolytic pathway, it may have promoted anaerobic metabolism and induced lactic acidosis (Joo et al., 2012). Complications associated with clinical manifestations of acrylamide poisoning appear similar to severe sepsis, including acute effects on the nervous, cardiac, pulmonary, renal, hepatic systems, and death (World Health Organization International Programme on Chemical Safety, n.d; National Institutes of Health, n.d; Joo et al., 2012; Banagozar Mohammadi et al., 2015).

Acrylamide is known to be a neurotoxin for both the peripheral and central nervous systems, although its precise mechanism is not yet fully understood. The neurotoxic mechanism of acrylamide can be summarized as involving axonal degeneration, neuronal deficits, DNA-protein adduct formation, oxidative stress, mitochondrial dysfunction, calcium dyshomeostasis, apoptosis, autophagy, inflammation, gut- brain axis homeostasis, and circadian rhythms. Animal studies have shown that acrylamide can increase intestinal permeability and interfere with brain-gut axis communication (Zhao et al., 2022). "Indeed intestinal tissue is one of the main targets of acrylamide-induced toxicity. Acrylamide has been reported to cause gastric and intestinal mucosal injury by increasing the inflammatory responses, oxidative stress and apoptosis" (Amirshahrokhi, 2021). In 2022, Bulc et al. conducted a study showing that exposure to acrylamide led to quantitative changes in neurons expressing SP, VAChT, nNOS, GAL, and SP. Their findings demonstrated that even at low doses, acrylamide can exert a toxic impact on enteric neurons. Furthermore, Ige et al. (2021) found that increased oral exposure to acrylamide can impair gastric emptying, intestinal motility, mucus secretion, digestive and absorptive functions of the small intestines, gastric protective factors, and gastric mucosal integrity, while also reducing the abundance of beneficial bacteria and increasing pathogenic bacteria in a dose-dependent manner. This may be attributed to acrylamide-induced impaired neuronal signaling, autonomic neuropathy, oxidative stress, inflammation, and cell necrosis. In addition, acrylamide exposure reduces gastric protective factors and can cause dose-dependent degeneration of gastric mucosal integrity, putting the patient's mucosa at risk for erosions and lesions (Ige et al., 2019). Acrylamide exposure can cause an imbalance in intestinal flora, reducing the abundance of some beneficial bacteria and significantly increasing the abundance of pathogenic bacteria (Zhao et al., 2022). It is therefore alarming that cases of water bead obstruction have reported focal discoloration and thinning of the resected bowel, intestinal tissue which is friable and susceptible to damage, ascites, focal ischemia, compromised barrier function of the intestine, relocation of gut flora with accompanying morbidity including bacteria infection, sepsis, acute renal shutdown, multi-organ failure, brain injury, and death ( Mirza & Sheikh, 2012; Mirza et al., 2011; Muthukumaran & Vivek, 2014; Shangareeva et al., 2019; Jung & Lee, 2022; Govindarajan & Arasappan, 2023).

In animal research and human cross sectional and in vitro studies, chronic exposure to acrylamide at levels relevant to human exposure has been linked to learning, memory, and developmental and cognitive problems (Lee et al., 2018; Lauvås, 2022; Meng et al., 2022). In cases of acute poisoning, research has shown if the animal survives, recovery can be rapid and complete (Spencer & Schaumburg, 1974, Part II). In less severely poisoned individuals, signs of peripheral neuropathy gradually disappear when they are removed from the source of exposure (Spencer & Schaumburg, 1974, Part I).

Although gastric lavage is typically ineffective for acrylamide monomer poisoning, it is worth noting that in reported cases of acrylamide ingestion poisonings, acrylamide was first dissolved in water or a liquid medium, and therefore rapidly absorbed and was distributed throughout the body's organs. It is important to acknowledge that in cases of high-dose acute acrylamide poisoning, the time until symptoms manifest may be shortened due to rapid exposure; however, progression is notably insidious until it becomes rapidly serious. The severity of acrylamide toxicity is influenced by factors such as the dose, speed, and duration of exposure. Hence, it is reasonable to hypothesize that exposures resulting from structural or chemical modifications to the polymer, can result in the release of residual acrylamide monomer or degraded polymer byproducts such as monomers, oligomers, or inclusions, and have an impact on the dose, speed, and duration of exposure. Consequently, this has the potential to lead to variations in various aspects of the timeline and clinical manifestation of poisoning among affected individuals. The gastrointestinal environment, encompassing factors such as mucosa, intestinal tissue, pH, temperature, salt content, ferric ion content, gut flora, variability in the anatomy of the GI tract, transit time, and anaerobic metabolism, can play a significant role in facilitating the release of potentially hazardous substances from a polymer matrix. In order to fully comprehend the implications of these exposure scenarios on the presentation and outcomes of poisoning cases, further investigation is required. Therefore, it is crucial to undertake additional research and investigations to enhance the understanding of water bead poisonings.

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# Conclusion

- Water beads can be toxic and are unsuitable as toys for children.
- Water bead injuries pose severe risks, comparable to magnets, button batteries, and sharp objects.
- Timely diagnosis and assurance of removal of water bead material from children's respiratory and gastrointestinal tracts are crucial for better outcomes.
- Assessing only the swelling capability of water beads is insufficient; measuring residual monomer content and migration levels is essential for accurate risk assessment.
- Children's vulnerability to chemical exposure and foreign body ingestion raise public health concerns about water beads.
- Heightened awareness, prompt diagnosis, and treatment are necessary to address water bead injuries and poisonings.
- Reporting cases when toy products are found in children's bodies is crucial for monitoring safety concerns.
- Healthcare professionals should incorporate reporting as a standard practice to collect data on hazardous toy incidents.
- Radiolucent products need specific warnings, and toys mistaken for candy should have stricter testing specifications and warnings.
- Strengthening enforcement can prevent transportation and distribution of hazardous products.
- Raising awareness about water bead dangers is crucial until stricter safety measures are implemented for child well-being

In our pursuit of protecting the innocent lives of our children, we cannot ignore the harsh reality that water beads can be toxic and pose great dangers as toys. Armed with this knowledge, we must rise together and take decisive action to prioritize the safety and well-being of our precious little ones. The risks associated with water bead injuries are extensive and severe, encompassing a range of health issues from nasal cavity injury to brain injury and even death. These risks are comparable to those posed by multiple magnets, button batteries, and sharp objects. To improve patient outcomes, it is crucial to prioritize timely diagnosis and swift removal of water beads from children's gastrointestinal and respiratory tracts.

Merely assessing the swelling capability of water beads is insufficient in addressing the potential risks posed by their chemical composition, specifically in relation to the creation of obstructive and gastrointestinal retentive encouraging environments. The respiratory and gastrointestinal systems of a child cannot be reduced to predictable machines; multiple variables need to be evaluated in the testing standard setting processes to account for numerous environmental factors within the human body. To accurately evaluate the potential health risks associated with a product that may be swallowed or inhaled by children during play, tests should take into account not only the obvious mechanical impact of the product, but also how its chemical composition impacts processes within the body. A product's toxicity could first manifest as a physical inhibition dependent on various parameters. While swelling tests provide some insights into the physical characteristics of water beads, they fail to consider how the chemical composition influences behavior within the body. The chemical composition of the beads can play a significant role in their interactions with bodily fluids, mucosal surfaces, tissues, biological and physicochemical factors, leading to prolonged retention and obstruction.

Children's vulnerability to chemical exposure and their tendency to ingest foreign objects raise significant public health concerns regarding water beads. Heightened awareness of the risks associated with water bead injuries, particularly water bead poisonings, is necessary. Healthcare providers should be vigilant in considering the possibility of water bead ingestion. Ask caregivers if there are water beads present in their child's home or school and actively listen to caregivers' reports to enable prompt diagnosis and treatment. The reporting of cases where toy products are discovered in the respiratory and gastrointestinal tracts of children is crucial for monitoring and addressing safety concerns. Healthcare professionals should incorporate reporting as a standard practice of care to ensure the systematic collection of data related to such incidents. Doing so will enhance collective understanding of the risks associated with hazardous toy products and allow appropriate measures to be implemented more quickly, preventing future injury occurrences and safeguarding children's health.

Radiolucent products should carry a specific warning. Products that pose significant and unusual risks if swallowed, inserted, or inhaled should bear a warning instructing parents to seek immediate medical attention if these situations occur. There is a pressing need to implement stricter specifications pertaining to toys that may be mistaken for candy. Furthermore, enforcement and interdiction measures should be strengthened to prevent the transportation and distribution of hazardous products that fail to meet these new safety standards. By proactively taking measures, we can join forces to pave the way for protecting the well-being of our children and reducing the potential harm caused by products with hidden dangers. Until such measures can be fully realized, it remains imperative that we continue to raise awareness about the grave perils posed by water beads, spreading the crucial message far and wide. Let us unite in our resolve, ensuring that the innocence and joy of childhood are safeguarded, free from the lurking hazards that should never mar their precious lives.