


Management of magnetic foreign body ingestion in children

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Abstract

Magnetic foreign bodies ingestion is a special cause for attending emergency department. Here, we aim to analyze the characteristics and treatments of children who ingested magnetic foreign bodies (Buckyballs). Data were collected from children who ingested Buckyballs between February 2017 and October 2019. A retrospective analysis was performed to summarize the experiences of conservative treatment, gastroscopy and surgery when dealing with Buckyballs ingestion.

A total of 49 patients with buckyballs ingestion were identified, of whom 11 underwent conservative treatments, 6 underwent gastroscopy, and 32 underwent surgery. Among such individuals, eight patients (72.7%) had a successful conservative treatment (number of Buckyballs [NB]: 3.5[IQR: 2.0–4.0]); four patients (66.7%) had Buckyballs successfully removed by gastroscopy (NB: 3.5 [IQR: 3.0–5.5]); 16 asymptomatic (50%) patients (NB: 4.0[IQR: 3.0–8.0]) and 16 symptomatic (50%) patients (NB: 8.5 [IQR: 6.25–11.75]) received emergency surgery. Compared to patients who received conservative treatment, the number of ingested Buckyballs was significantly higher in patients who received surgery or gastroscopy (7.0 [IQR: 3.0–10.75] vs 3.5 [IQR: 2.0–4.0], $P < .05$). The risk of intestinal perforation was significantly higher in symptomatic patients ($P < .05$) compared to asymptomatic patients.

Gastroscopy is recommended when Buckyballs are in the stomach or esophagus. In asymptomatic patients, conservative treatment can be considered for 4 to 6 days. Patients failing conservative treatment, or those who are symptomatic should undergo emergency surgery.

Abbreviations: ADT = abdominal drainage tube, FB = foreign body, IQRs = interquartile ranges, NB = number of Buckyballs.

Keywords: buckyball, conservative treatment, gastroscopy, magnetic foreign body, surgery

1. Introduction

Foreign body (FB) ingestion in children is a common cause for attending the emergency department with a high incidence in patients between 6 months and 6 years of age.^[1] The most commonly ingested FBs are small household objects such as coins, pins, and toy parts.^[2] Over the last two decades, the incidence of

magnetic FBs ingestion has increased rapidly.^[3,4] As a special FB, magnets have the ability to attract each other across the loops of bowels causing intestinal necrosis, ileus, and perforation.^[5–8] Among magnetic FBs, powerful rare-earth neodymium magnets (Buckyballs, Fig. 1A) are more hazardous items than traditional magnets for children.^[9] Compared to traditional magnets, the round, powerful Buckyballs attract each other with a smaller stress area, which often result in intestinal complications.

The high incidence of complications in magnets ingestion has forced companies to recall certain magnetic toys in some countries.^[10,11] However, Buckyballs remain widely available online and established warning labels are no effective strategy of injury prevention. In the present study, we performed a retrospective analysis of 49 patients who ingested Buckyballs. We aimed to summarize the experiences and develop a management algorithm of Buckyballs ingestion.

2. Materials and methods

2.1. Patients

Forty-nine patients (39 males and 10 females) with Buckyballs ingestion were treated at the Department of General Surgery, The Children's Hospital, Zhejiang University School of Medicine were included within the period of February 2017 to October 2019. Criteria of patient selection:

1. A history of magnetic foreign bodies ingestion;
2. An abdominal X-ray or CT scan indicated foreign bodies in the digestive tract;
3. Buckyballs were confirmed after conservative treatment, surgery, or laparoscopy.

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All data generated or analyzed during this study are included in this published article [and its supplementary information files].

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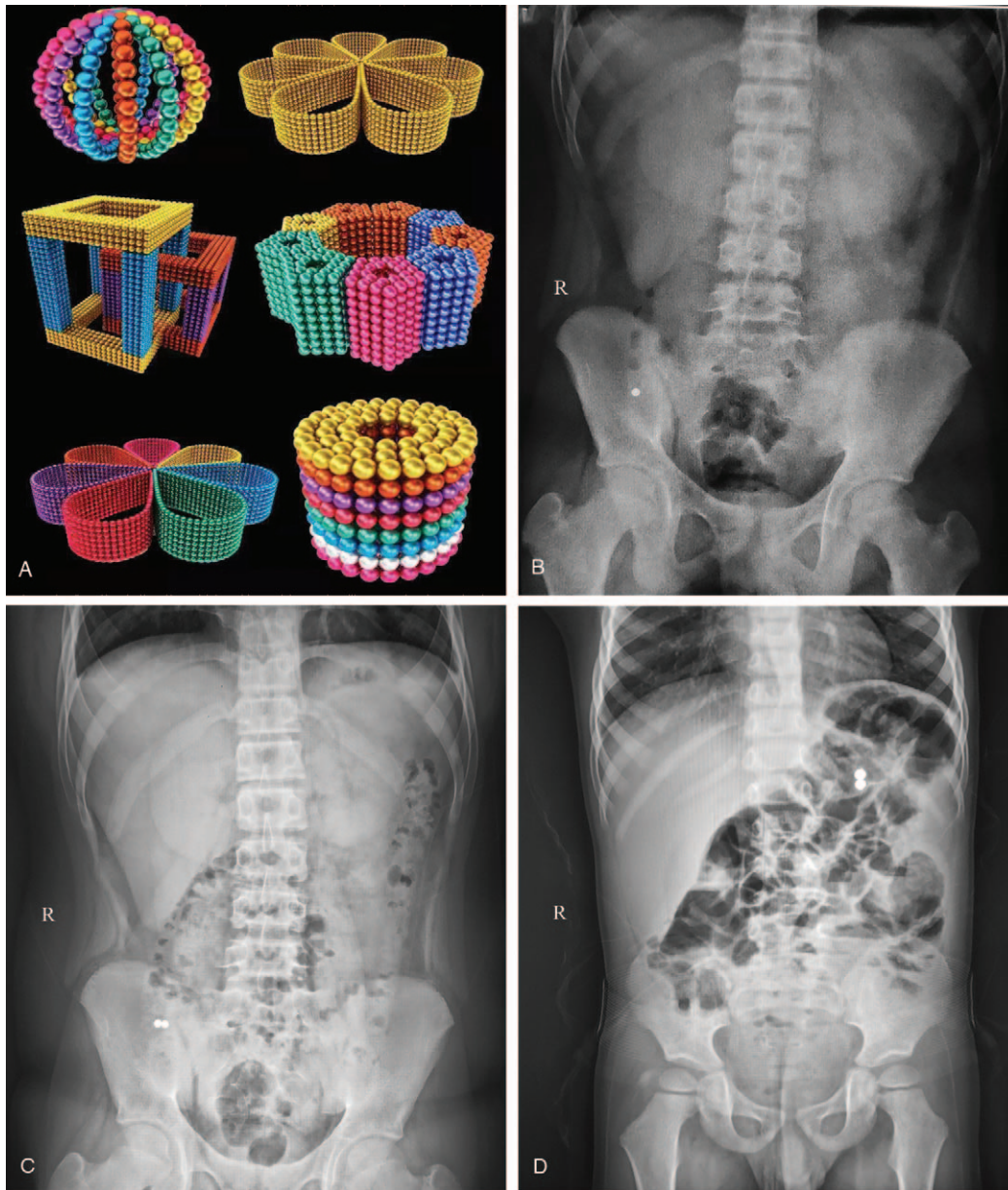


Figure 1. Imaging of Buckyballs ingestion. (A) Rare-earth neodymium magnets (Buckyballs). (B) Two Buckyballs overlapped on a single view and were misdiagnosed as a single Buckyball. (C) Another abdominal radiography of the same patient shown in (B). (D) Buckyballs in the stomach and colon attracted each other appeared as all the Buckyballs were still in the stomach.

Eleven patients received conservative treatment, six patients received gastroscopy, and 32 patients received emergency surgery. Clinical data including sex, age, pre-operative symptoms, effective time span of conservative treatment, length of hospital stay, and gastrointestinal perforation are provided in Table 1. The numbers of ingested Buckyballs according to different treatment groups were provided in Table 2. This study was approved by the Ethical Committee of The Children's Hospital, Zhejiang University School of Medicine (No. 2020-IRB-120).

2.2. Study design

Patients were divided into surgical group, conservative group, and gastroscopy group. Patients who failed to recover uneventfully from conservative treatment or gastroscopy further received

surgery. Surgical group: patients received emergency surgery upon admittance to the hospital. Patients were divided into A1 group (patients without pre-operative symptoms) and A2 group (patients with pre-operative symptoms, such as vomiting, fever or abdominal pain). We then compared the post-operative complications and treatments between the two subgroups. Conservative group: patients received in-patient observation upon admittance to the hospital. Patients were divided into B1 group (Buckyballs were defecated without medical intervention) and B2 group (surgery was required). We then analyzed the clinical features of patients who received conservative treatment. Gastroscopy group: patients received emergency gastroscopy upon admittance to the hospital. Patients were divided into C1 group (Buckyballs were successfully removed by gastroscopy) and C2 group (surgery was required). We then summarized the clinical

Table 1**Clinical characteristics.**

Group	Surgical group		Conservative group		Gastroscopy group	
	Symptomatic (n=16)	Asymptomatic (n=16)	Successful (n=8)	Unsuccessful (n=3)	Successful (n=4)	Unsuccessful (n=2)
Subgroup						
Sex (female: male)	5: 11	2: 14	2: 6	1: 2	0: 4	0: 2
Age (year)	3.13 (1.52–5.56)	2.83 (2.27–4.25)	7.04 (5.54–8.57)	4.1	8.02 (2.82–12.94)	5.0
With or without symptoms (n)	16	0	0	0	0	1
Length of hospital stay (LOS; days)	11.0 (9.25–14.0)	10.0 (9.0–11.75)	2.0 (1.0–3.0)	22.33	4.5 (2.5–5.75)	11.0
Effective conservative time (days)	–	–	1.0 (0.85–2.2)	–	–	–
Perforation (n)	16	10	0	3	0	1

Data were shown as the medians \pm inter-quartile ranges (IQRs).

Effective conservative time is defined as the time that the ingested Buckyballs reach the lower abdomen or pelvic cavity.

characteristics of using gastroscopy for the treatment of magnetic FBs ingestion.

Criteria of high-grade antibiotics use (Tienam or Meropenem):

1. Severe preoperative clinical symptoms (e.g., septic shock, peritonitis);
2. Abnormal blood routine (WBC $> 20 \times 10^9/L$ or CRP > 100 mg/L or progressive increase of CRP);
3. Severe abdominal infection (purulent ascites or massive leakage of intestinal contents).

Criteria of abdominal drainage tube use:

1. Severe abdominal infection (purulent ascites or massive leakage of intestinal contents);
2. Severe intestinal necrosis necessitating intestinal resection and anastomosis.

2.3. Statistical analysis

Statistical analysis was performed with SPSS18.0 and Graphpad Prism 6. Data were shown as the medians \pm interquartile ranges (IQRs) or the means depending on the data characteristics. The Mann–Whitney test was utilized for continuous variables. Pearson's chi-square and Fisher's exact tests were used for categorical variables. *P*-Values $< .05$ were considered statistically significant. All *P*-values reported were two-tailed.

3. Results

3.1. Surgical group

Sixteen asymptomatic patients (14 males and 2 females) received emergency laparotomy upon admittance to the hospital. The average age was 2.83 years (IQR: 2.27–4.25), the average

number of ingested Buckyballs was 4.0 (IQR:3.0–8.0), and the average length of hospital stay was 10.0 days (IQR: 9.0–11.75; Table 1). Among the patients, 10 were complicated with gastrointestinal perforations, 5 received an ADT, and 3 were administered with high-grade antibiotics. Notably, one patient did not show symptoms 2 weeks after ingestion, but received intestinal resection because of severe gastrointestinal perforations. During this operation, we saw magnets attracted each other across the loops of bowels, and the intestinal adhesion stopped the intestinal contents from leaking into the abdominal cavity.

Another 16 patients (11 males and 5 females) presented with fever, abdominal pain or vomiting upon admittance to the hospital. The average age was 3.13 years (IQR: 1.52–5.56), the average number of ingested Buckyballs was 8.5 (IQR: 6.25–11.75), and the average length of hospital stay was 11.0 days (IQR: 9.25–14.0; Table 1). Among the patients, all 16 of those patients were complicated with gastrointestinal perforations, 11 received an ADT, and 6 were administered with high-grade antibiotics. The risk of intestinal perforation for symptomatic patients was significantly increased ($P=.018$) compared to asymptomatic patients (Fig. 2A). One symptomatic patient was complicated with severe peritonitis and septic shock, this patient was discharged after receiving antibiotic therapy for 15 days. All sixteen patients who received ADT were discharged without incisional infection.

3.2. Conservative group

A total of 11 asymptomatic patients received conservative treatment. Eight of which (6 males and 2 females) successfully defecated the Buckyballs without medical interventions. The average age was 7.04 years (IQR: 5.54–8.57) and the average length of hospital stay was 2.0 days (IQR: 1.0–3.0). The average number of ingested Buckyballs of those patients were significantly lower compared to patients who received surgery and gastroscopy (3.5 [IQR: 2.0–4.0] vs 7.0 [IQR: 3.0–10.75], $P=.0156$; Table 2 and Fig. 2B). All the eight patients received serial abdominal X-rays to confirm the location of the Buckyballs. The Buckyballs of three patients were in the lower abdomen after 19 h, 1 day, and 1.3 days, respectively. The Buckyballs of another five patients were in the pelvic cavity after 13 h, 1 day, 1 day, 2.5 days, and 4.4 days, respectively. The effective conservative time was 1.0 day (IQR: 0.85–2.2; Table 1). And patients who received conservative treatment for more than 1.65 days (Youden index=1.65, AUC=0.826) had a higher risk of intestinal perforation (Fig. 2C). The effective conservative time was defined as the time required for the ingested Buckyballs to reach the lower abdomen or pelvic cavity, as indicated by serial abdominal X-rays.

Table 2**The numbers of ingested Buckyballs.**

Groups	Numbers of Buckyballs (n)	
Surgical group	A1 (n=15)	4.0 (3.0–8.0)
	A2 (n=16)	8.5 (6.25–11.75)
Conservative group	B1 (n=8)	3.5 (2.0–4.0)
	B2 (n=3)	4.3
Gastroscopy group	C1 (n=4)	3.5 (3.0–5.5)
	C2 (n=2)	11.0
Operative patients	D (n=41)	7.0 (3.0–10.75)

Data are shown as the medians \pm inter-quartile ranges (IQRs), B2 and C2 group are shown as the mean.

D group (A1+A2+B2+C1+C2): patients received surgery or gastroscopy.

In one patient of group A1 we lost the detailed number of Buckyballs.

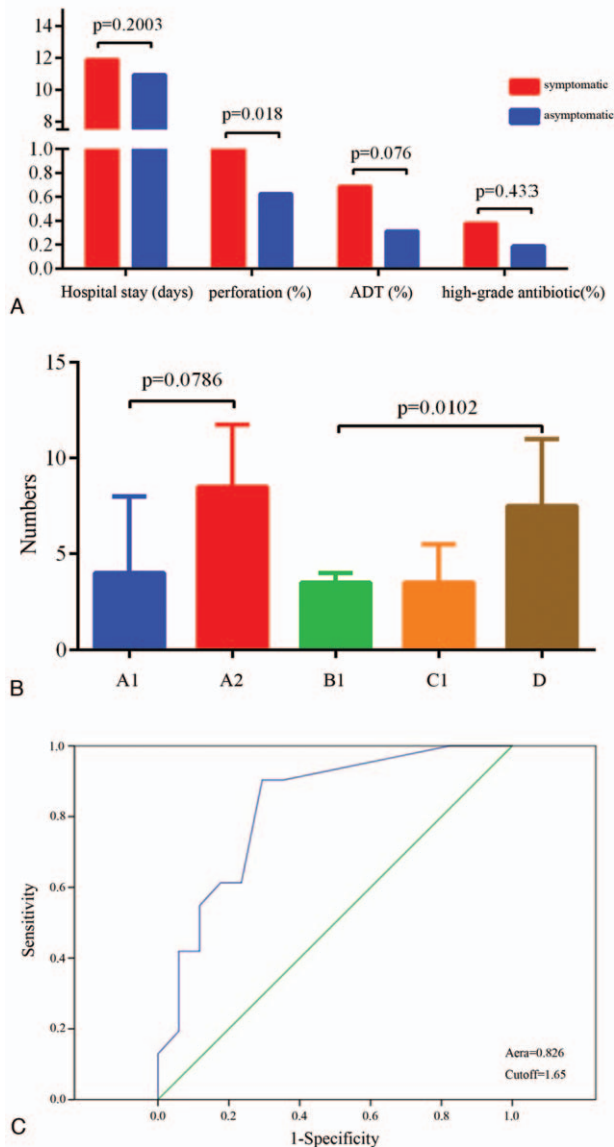


Figure 2. Numbers of ingested Buckyballs and clinical characteristics. (A) Clinical characteristics between the A1 and A2 groups (ADT=abdominal drainage tube). (B) The numbers of ingested Buckyballs in the A1 (asymptomatic patients received emergency surgery), A2 (symptomatic patients received emergency surgery), B1 (patients received conservative treatment successfully), C1 (Buckyballs were removed by gastroscopy successfully) and D (patients received surgery and gastroscopy) groups. (C) Univariate ROC curve analyses of the conservative time of 49 patients were performed to determine the optimal cutoff (Youden index).

Three patients (2 males and 1 female) received surgery after an average conservative time of 7.3 days. The average age of those patients were 4 years and their average length of hospital stay was 22.3 days (Table 1). All of those patients were complicated with gastrointestinal perforations. One of those patients received an ADT, and two were administered with high-grade antibiotics.

3.3. Gastroscopy group

A total of six patients (6 males) received gastroscopy. Among them, four asymptomatic patients had Buckyballs successfully removed. The average age of those patients was 8.02 years (IQR:

2.82–12.94), the average number of ingested Buckyballs was 3.5 (IQR: 3.0–5.5), and the average length of hospital stay was 4.5 days (IQR: 2.5–5.75; Table 1). The first patient had four Buckyballs removed from the stomach 1 day after ingestion without any complications. The second patient had three Buckyballs removed from the gastric fundus and esophagus 4 days after ingestion, and was complicated with gastric fundus perforation. This patient was discharged after receiving fasting and antibiotic therapy for 6 days. The third patient had six Buckyballs removed from the gastric antrum and posterior gastric wall 1 day after ingestion, and was complicated with gastric antrum ulcer. The final patient had three Buckyballs removed from the stomach 5 h after ingestion, and was complicated with gastric ulcer.

Two patients first received general anesthesia for gastroscopy, and finally received general anesthesia with tracheal intubation for surgery. The average age was 5 years, and the average length of hospital stay was 11 days. One symptomatic patient had ten Buckyballs removed from the stomach by gastroscopy and two Buckyballs removed from the transverse colon by surgery. That patient was complicated with gastrointestinal perforations. Another asymptomatic patient had five Buckyballs removed from the stomach by gastroscopy and five Buckyballs removed from the terminal ileum by surgery.

4. Discussion

Ingestion of Buckyballs is hazardous for children, and requires special medical attention and prompt management. Clinically, some patients require emergency surgery for acute complications including ileus, gastrointestinal perforation and peritonitis; however, some patients may defecate Buckyballs without any medical interventions.^[12] Therefore, it is particularly important to perform a comprehensive evaluation on patients' clinical conditions and examinations before determining the appropriate medical interventions.

A cluster of Buckyballs attract each other across the loops of bowels may lead to massive intestinal adhesion, which can localize intestinal contents and inflammatory exudates. In the present study, such a patient remained asymptomatic for 2 weeks while gastrointestinal perforations developed. Thus, it remains a challenge for pediatric surgeons to perform medical interventions at an appropriate time.^[13] When patients are admitted to hospital, an abdominal X-ray should first be performed to quantify the number and location of the Buckyballs. However, multiple Buckyballs attract each other tightly may appear as a single ball on X-ray (Fig. 1B and C). If necessary, a lateral radiograph can assist in this evaluation.^[14] For Buckyballs in the esophagus or stomach, gastroscopy is the preferred choice to remove them (better <12 h).^[14,15] The North American Society for Pediatric Gastroenterology, Hepatology, and Nutrition (NASPGHAN) divide the time of removing buckyballs in the esophagus or stomach into categories of emergent (<2 h from presentation), and urgent intervention (<24 h from presentation).^[16] Here, we suggest that if the ingestion time is <24 h or the Buckyballs are not in the pelvic cavity, as indicated by abdominal X-rays, gastroscopy should be considered first. It is worth noticing that even if the magnets are removed from the stomach timely, gastric ulcers may still occur within 8 h.^[9] Our findings are in agreement with their observation (Fig. 3C and D). In asymptomatic patients who were not successfully treated by gastroscopy physicians still consider conservative treatment.

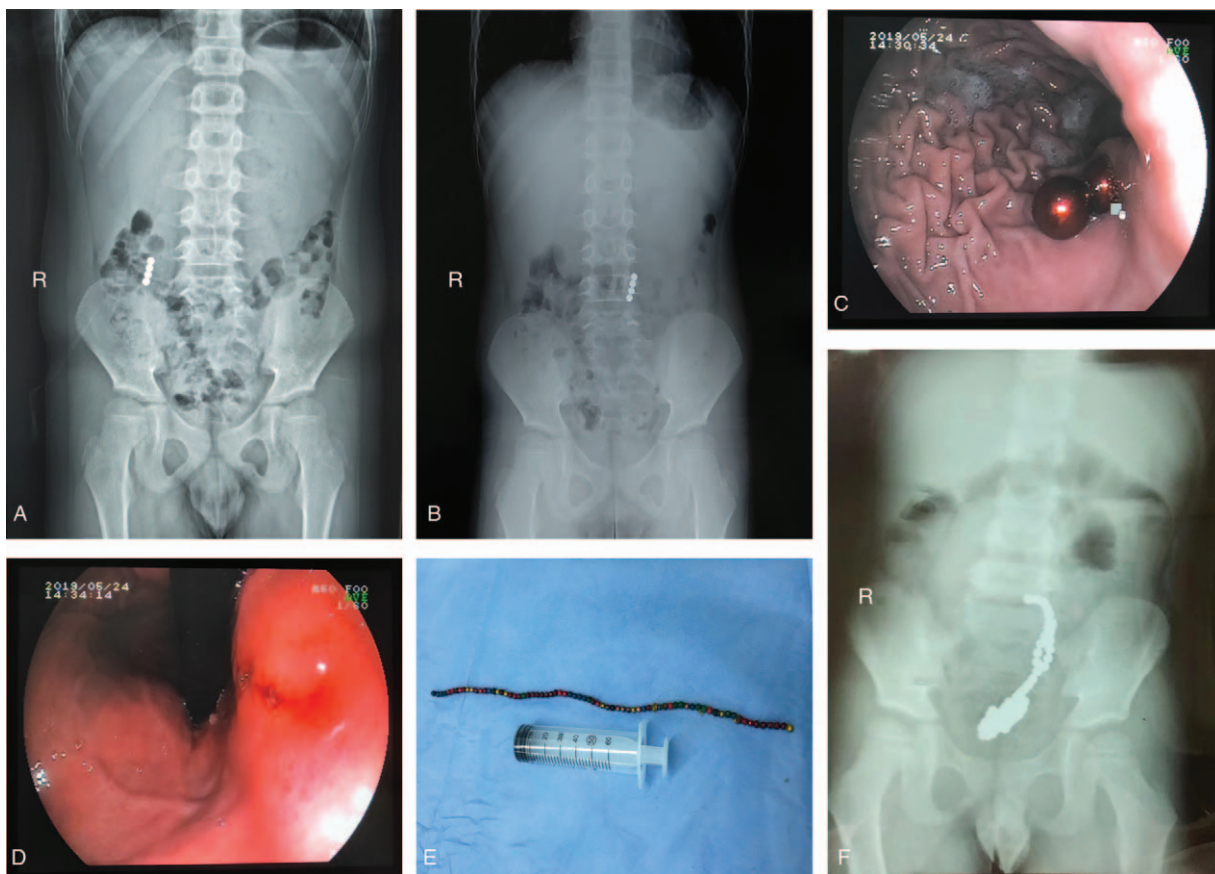


Figure 3. Imaging of Buckyballs ingestion. (A) and (B) Buckyballs attracted each other across the loops of the bowels and moved from side-to-side along with the intestines for several days. (C) and (D) Buckyballs were removed by gastroscopy within 5 h, gastric ulcer still occurred. (E) and (F) A patient ingested 73 Buckyballs.

Patients usually experience good recovery if the Buckyballs are removed timely; however, the use of gastroscopy is still infrequent in our hospital. We conclude the reasons as followed: first, patients are relatively young and their parents often fail to provide the exact medical history. Second, small and round Buckyballs can easily pass through the pylorus. In addition, for patients with severe gastrointestinal perforations, surgery is necessary.

Experts from NASPGHAN came to a consensus that patients who ingested magnets, should be observed in a controlled situation if conservative treatment was adopted.^[16] Patients with a single Buckyball or patients who ingested a few Buckyballs consecutively could first consider conservative treatment if they were asymptomatic. It should be noted that Buckyballs attract each other across the loops of bowels may lead to the displacement of the gastrointestinal tract. In this situation, the location of Buckyballs may remain unchanged (Fig. 1D) or move from side-to-side at the same abdominal level within several days (Fig. 3A and B). The frequency of reviewing an abdominal X-ray depends. As previously reported, asymptomatic patients with post-pylorus magnets may receive serial X-rays in emergency department to check for progression every 4 to 6 h, which can be extended to every 8 to 12 h gradually.^[16] We found that patients who were cured by conservative treatment generally ingested significantly fewer Buckyballs than patients who required surgery. Additionally, the Buckyballs in those patients mostly arrived at the lower abdomen or pelvic cavity early. Besides, patients who experienced a conservative time for more than 1.65

days tended to face a higher risk of intestinal perforations. Therefore, we suggest that asymptomatic patients who are not suitable for gastroscopy, or are unwilling to receive gastroscopy can follow serial X-rays for 2 days. If the Buckyballs arrive at the lower abdomen within this period, patients would probably defecate the Buckyballs within 4 to 6 days,^[17] or else, medical interventions are recommended. If at any time patients become symptomatic or the location of Buckyballs do not change within 48 h,^[18] surgery should be considered.

The treatment of post-pyloric magnets is still under controversy: some researchers recommend surgical management for all post-pyloric magnets,^[8,4] while NASPGHAN suggest endoscopy for post-pyloric magnets if patients are asymptomatic.^[16] In our hospital, we generally perform laparotomy for post-pyloric magnets for the following reasons. First, it is difficult for laparoscopy and endoscopy to achieve a comprehensive exploration of the complete digestive tract, especially for patients with massive intestinal adhesion. Second, intestinal adhesion can localize the intestinal contents and inflammatory exudates around the perforations to relieve abdominal contamination, and it is difficult for surgeons to timely repair multiple perforations when they are evaluating and separating intestinal adhesion by laparoscopy. Additionally, a long time is required for surgeons to remove a large number of Buckyballs using laparoscopy in patients with severe abdominal contamination (Fig. 3E and F). Thus, we argue that the use of laparotomy to treat post-pyloric Buckyballs can significantly shorten the operative

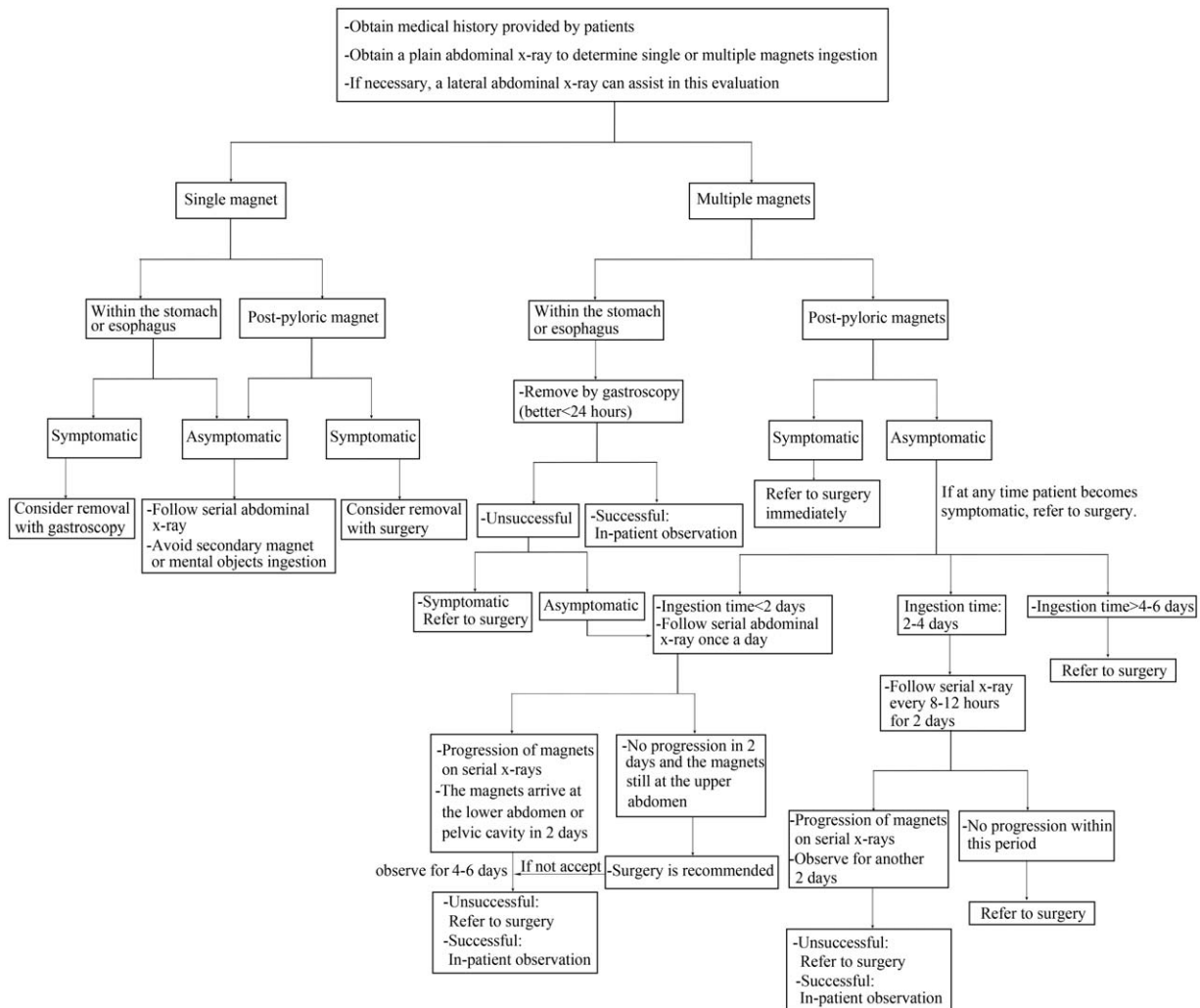


Figure 4. The management algorithm of Buckyballs ingestion.

time, timely repair the perforations and thoroughly explore the complete digestive tract. For the high incidence of perforations among asymptomatic patients in our study, we recommend surgery for those patients who already surpassed the optimal time for conservative treatment (i.e., ingestion time > 4–6 days). For the high risk of gastrointestinal perforations and other severe complications, including acute diffuse peritonitis and septic shock, symptomatic patients should receive emergency surgery after admission.

Finally, the limitations of this study should also be considered. Our results are from a single center and include only 2 years of follow-up, thus our experiences could only be considered as a medical advice. Besides, we mainly focus on how to reduce the risk of abdominal infection caused by inappropriate operation. Although laparoscopy not only prolongs the time of operation but also increases the risk of abdominal infection, it is still a worthwhile project in this problem. In future research, we are planning to study how to select appropriate indication for laparoscopy.

5. Conclusion

In conclusion, strict in-patient observation should be carried out for every pediatric patient with magnetic ingestion, especially

Buckyballs. Gastroscopy is recommended if the Buckyballs are in the stomach or esophagus. A failure of gastroscopy to treat asymptomatic patients is not an absolute indication for surgery, and conservative treatment for 4 to 6 days is recommended. Asymptomatic patients with post-pyloric magnets also can receive conservative treatment for 4 to 6 days. If at any time these patients become symptomatic or conservative treatment fails, surgery is recommended. Patients who have clinical symptoms or have surpassed the optimal time of conservative treatment before hospitalization should receive emergency surgery (Fig. 4).

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