Clinical Characteristics and Interventions for Ingested Magnetic Foreign Bodies in Children: A Systematic Review and Meta-analysis

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Background: Ingested foreign materials are a common cause for hospital emergency department visit. Foreign objects such as magnets found in the gastrointestinal tract can cause serious problem because magnets attract to each other across the intestinal wall, often resulting in severe damage. We aimed to review the magnitude of the problem, the clinical characteristics and the interventions related to this problem.

Methods: A systematic review and meta-analysis of the retrospective studies published in PUBMED, MEDLINE, Web of Science, Embase and Cochrane was conducted. The search was limited to studies published from Jan 1, 2000 to July 31, 2022, with the last search done on August 1, 2022. No publication restrictions or study design filters were applied.

Results: Data from 24 retrospective cohort studies with 2014 patients were included in the review. 63.6% (95% CI 59.9%-67.3%) of children who had swallowed foreign bodies were male, and 43% (95% CI 29.3%-57.3%) children presented with non-specific symptoms or had a complete absence of symptoms. Only 74.7% (95% CI 58.7%-88%) of the children has clear history of ingested foreign bodies. Abdominal surgery was the most prevalent interventions (43.3%, 95%CI 32.5%-54.1%) among the inpatients, while conservative treatments were the second common intervention (40.3%, 95%CI 27.8%–52.9%) among the inpatients and outpatients. Intestinal perforation or fistula occurred in 30.2% (95%CI 22.5%–37.8%) children.

Conclusions: Despite significant heterogeneity among primary studies, our results detail the morbidity, clinical characteristics and interventions associated with ingested magnetic foreign bodies in children.

Keywords: *Emergency department, Management, Outcome, Surgery*.

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Ingestion of foreign bodies in young children is a common cause for emergency department visit. In recent decades, high-powered magnets were widely used in commercial and various areas [1]. As a result, the incidence of ingestion of more hazardous items such as high-powered magnets has increased rapidly in the last decade [2]. Magnetic foreign bodies consumed into the gastrointestinal tract or squeezed into the upper respiratory tract, may cause obstruction in nasal, tracheal, auricular and anal area. Ingested magnets travel through the esophagus and stomach into the intestine. Multiple magnets in the gastrointestinal tract adhere to each other across the intestinal wall, often resulting in severe damage [3], which was previously called "the force within." To understand the extent of the problem, this review was conducted to describe the clinical characteristics and the interventions related to the problem.

METHODS

Our study reporting followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [4]. The study was registered on PROSPERO. A systematic review of retrospective studies published in PUBMED, MEDLINE, Web of Science, Embase and Cochrane was conducted. The search had a cap on date from Jan 1, 2000 to Jul 31, 2022, with the last search done on August 1, 2022. No publication restrictions or study design filters were applied. The search strategy for the databases was as follows: ((magnetic foreign body) [all fields]) AND ((children) [all fields]OR (child) [all fields]). Reference lists from related articles were also scanned to broaden the search. A hand search was performed in all five databases.

The study inclusion criteria were *i*) case series reporting the pediatric operations related to the magnetic foreign bodies; *ii*) study reported at least one of the following outcomes: clinical symptoms, interventive method, perforation or fistula, witnessed ingestions, postoperative complications, length of hospital stay, and geographic regions; *iii*) study provided appropriate statistical

estimates or counts; and *iv*) only studies that were reported in English. The study exclusion criteria were; *i*) case reports (<5 cases); *ii*) review articles; *iii*) the foreign body was not in the digestive tract; *iv*) conference abstracts; and *v*) studies with no comparative outcomes in the paper.

The following information was extracted and entered in the database: name of first author, year of publication, type of study, mean age, gender, number of populations, history of ingesting foreign bodies and primary outcomes, including clinical symptoms, interventive method, perforation or fistula, witnessed ingestions, postoperative complications, length of hospital stay, and geographic regions. The Newcastle Ottawa scale (NOS) score [5] for those studies focused on three categories: selection, comparability and outcome. The maximum stars of NOS score is nine stars. An article assessed ≥6 stars was considered to be of high quality and was adopted in the study.

Statistical analysis: This was conducted by STATA version 16.0. The pooled proportions of foreign bodies were calculated using the DerSimonian and Laird approach [6]. All studies with missing values or zero counts were excluded from the analysis. First, a test for homogeneity of proportions among the different studies was performed using the Cochran method. Thus, the pooled proportions of foreign bodies were estimated along with the corresponding 95% confidence intervals (CI), and the DerSimonian-Laird random effects weighting scheme for the studies was included in the analysis. Some study outcomes were reported as medians with ranges or mid-quartiles with ranges. According to the methods intro-duced by Luo, et al. [7] and Wan, et al. [8], those data were converted to means with deviations, thus the results for each group are presented as the mean (SD). The I^2 statistic was used to test the degrees of heterogeneity, the P value of I^2 <0.05 was used to indicate high heterogeneity and vice versa. The random-effects model was applied to pool the high heterogeneity results and the fixed-effects model was used for low heterogeneity (P value of I^2 >0.05). Begg test and Egger test were performed to assess the risk of bias; a P value <0.05 was considered to have a high risk of publication bias.

RESULTS

We identified 556 papers through the literature search. After removing duplicates, 331 records were excluded from title and abstract evaluation, and 201 records were excluded after full-text review because they did not meet the inclusion criteria (**Fig. 1**). Finally, data from 24 retrospective cohort studies with 2014 patients were included in our study.

Table I summarizes the characteristics of 24 records with 2014 patients enrolled in the meta-analysis. The baseline characteristics of the 24 records are listed in **Table II**. The NOS scores ranged from 6 to 8 stars, reflecting the quality of cohort studies. Pooled proportions of dichotomous variables are presented in **Table III**. The pooled effect size (95% CI) for age in years [5.08 (4.29, 5.87); I^2=99%; P<0.001] was based on 2014 cases from 24 articles with a random effect model. The pooled effect size (95% CI)

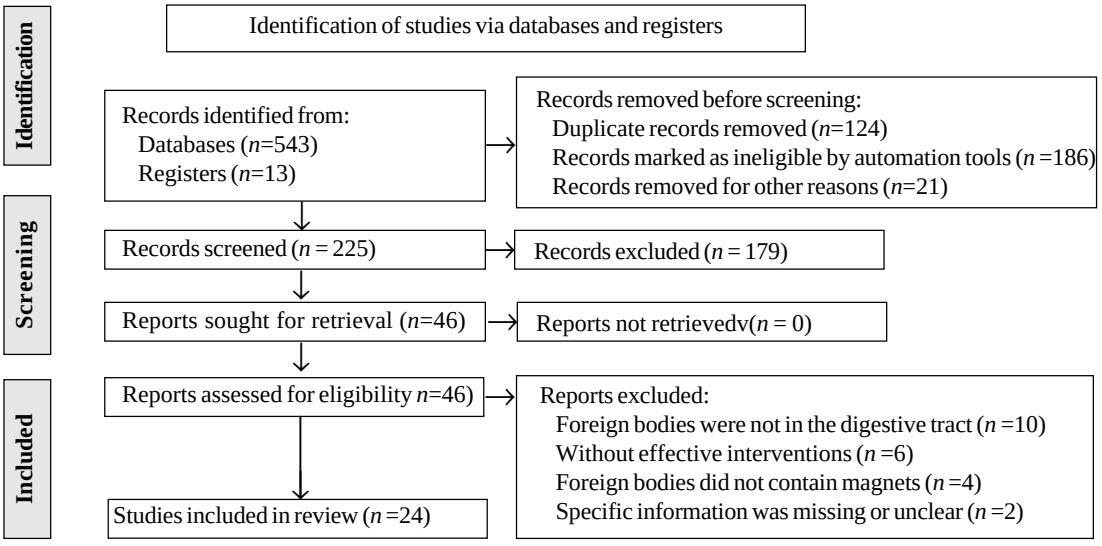

Fig. 1 Adapted PRISMA flow diagram, showing the number of papers identified in the initial search, numbers excluded for various reasons and the final number of papers which are the basis of the data presented.

Table I Characteristics of 24 Records Included in the Meta-Analysis (*N*=2014)

Clinical characteristics	*No. of cases (%)*
Male gender	1250 (62.1)
Geographic region	
North America	1301 (64.6)
Asia	591 (29.3)
Oceania	23 (1.1)
Europe	99 (4.9)
History of ingesting foreign bodies	
Witnessed ingestions	868 (43.1)
Unwitnessed ingestions	699 (34.7)
Not reported	447 (22.2)
Clinical symptoms[a]	
Abdominal pain	211 (10.5)
Vomiting	150 (7.4)
Fever	37 (1.8)
Excessive crying	34 (1.7)
Obstructive symptoms	13 (0.6)
Coughing and chocking	10 (0.5)
Decreased oral intake	5 (0.25)
No symptoms	524 (26.0)
Clinical interventions	
Abdominal surgery	655 (32.5)
Endoscopic removals	393 (19.5)
Conservative treatments[b]	890 (44.2)
Perforation or fistula	364 (18.1)
Postoperative complications[c]	
Wound infection	11 (0.5)
Intestinal obstruction	4 (0.2)
Anastomotic leak	5 (0.25)

[a]melena in 2 children and chest pain in 1 child. [b]including inpatients and outpatients; [c]One child had fever, and another died after hemorrhage from an esophago-aortic fistula.

for days of hospital stay [8.70 (6.51, 10.9); I^2=99.6%; P<0.001] was based on 1225 cases from 12 articles with a random effect model.

Web Table I exhibits the Begg and Egger test for publication bias of clinical characteristics, such as gender, age, witnessed ingestions, clinical symptoms, interventive method, perforation or fistula, length of hospital stay. Egger funnel plots were drawn for the enrolled 24 records (**Fig. 2**).

DISCUSSION

Among all the ingested inorganic foreign bodies, magnets are recorded to be in the highest proportion. Ingestion of magnets warrants specific attention, because it can be particularly destructive to the local tissue [33], especially when multiple magnetic foreign bodies adhere to each other. In 2007, the Consumer Product Safety Commission (CPSC) issued the first warning, noting the possibility of high-powered magnets detaching from children's toys causing injury and even death, if swallowed [34]. In October, 2014, the CPSC published its final rule, Safety Standard for Magnet Sets, prohibiting sales of these small high-powered magnet sets [35], which was later overturned, resulting in a resurgence of these magnets on the market in the later years [36]. From 2011 to 2016, a mean of 1.6 patients per year attended with multiple magnet ingestions vs 9.5 patients per year from 2017 to 2020 in some parts of Europe [37]. North America and Asia appeared to be the regions with the highest number of reports about these foreign bodies. Data showed increase incidence of ingested magnetic foreign bodies commonly in boys.

The North American Society of Pediatric Gastroenterology, Hepatology, and Nutrition (NASPGHAN) algorithm [34] published in 2012, should be applied in clinical evaluation and surgical treatment of the affected pediatric patients. If one single magnet was ingested, observation is an appropriate intervention, same treatment as with other smooth, small foreign bodies (except batteries). Magnetic foreign bodies are "*innocent in solitude, harmful in groups*"; however, if numerous magnets were swallowed, thorough evaluation is warranted. If ingestion was recent and the particles are still in the stomach, the magnets should be retrieved by endoscopy using a magnetic probe [38,39]. If signs of intestinal distress develop, prompt laparotomy should be considered to prevent serious gastrointestinal complications [40], especially in multiple magnetic foreign bodies ingestion.

The clinical interventions of ingested magnetic foreign bodies were surgical interventions and/or conservative treat-ments. Surgical interventions include laparotomy, laparoscopy and endoscopic removals among the inpatients. Conservative treatments were also common among the inpatients and outpatients. Multiple magnets adhered together can easily be misinterpreted as a single entity in the single bowel lumen [41], while they are actually located in different bowel sites and attracted to each other causing intestinal wall perforation or fistula. The foreign bodies were mainly found in the jejunum and ileum, followed by colon, duodenum, stomach and esophagus, which are also the predilection sites for bowel perforation or fistula. Approximately, the average hospital stay was 8.7 (95% CI 6.51-10.9) days indicated in 12 articles with 1225 cases recorded.

Although, foreign bodies type was usually reported, only a relatively small proportion of articles provided detailed information on clinical characteristics, diagnostic

Table II Baseline Characteristics of 24 Records Included in the Meta-analysis

Study (year)	*Country*	*No. of patients*	*Gender (M/F)*	*Age (y)*[a]	*NOS score*
De Roo, et al. (2013) [9]	America	72	39/33	2.7 (3.0)	6
Brown, et al. (2013) [10]	America	56	28/28	7.8 (1.3)	8
Agbo, et al. (2013) [11]	America	112	60/52	6.1 (1.3)	6
Tavarez, et al. (2013) [12]	America	38	22/16	5.2 (2.2)	6
Strickland, et al. (2014) [13]	Canada	72	47/25	6.3 (5.0)	8
Waters, et al. (2015) [14]	America	99	66/33	4.2 (3.0)	7
Sola, et al. (2018) [15]	America	89	50/39	7.9 (1.6)	6
Li, et al. (2020) [16]	China	24	17/7	3.5 (1.7)	8
Cai, et al. (2020) [17]	China	56	45/11	4.7 (3.0)	8
Zhang, et al. (2020) [18]	China	49	39/10	3.3 (1.3)	7
Huang, et al. (2020) [19]	China	35	24/11	5.6 (4.0)	7
Lai, et al. (2020) [20]	China	13	10/3	5.5 (3.2)	6
Wang, et al. (2020) [21]	China	74	50/24	3.1 (0.9)	7
Yireh, et al. (2020) [22]	Korea	9	3/6	3.9 (2.9)	6
Mostafa, et al. (2021) [23]	England	46	28/18	6.8 (2.3)	8
Huang, et al. (2021) [24]	China	14	12/2	4.9 (3.1)	8
Miyamoto, et al. (2021) [25]	Japan	104	62/42	2.7 (2.1)	6
Zheng, et al. (2021) [26]	China	51	36/15	4.8 (1.9)	8
Price, et al. (2021) [27]	England	53	27/26	7.2 (3.1)	6
Ding, et al. (2022) [28]	China	71	48/23	2.7 (2.5)	7
Jin, et al. (2022) [29]	China	91	66/25	3.6 (0.8)	6
Nataraja, et al. (2022) [30]	Australia	23	10/13	5.8 (3.6)	8
Middelberg, et al. (2022) [31]	America	596	362/234	7.7 (2.6)	7
Shaul, et al. (2022) [32]	America	167	99/68	6.0 (1.1)	8

M: Male; F: Female; NOS: Newcastle-Ottawa Quality Assessment Scale. [a] *mean (SD). All studies were retrospective studies.*

Table III Pooled Proportions of Clinical Characteristics of Ingested Foreign Bodies in Children

Characteristics	*No. of studies*	*Cases (n)*	*Total cases (N)*	*Pooled proportion (95% CI)*	I^2	*P value*
Gender						
Male	24	1250	2014	0.636 (0.599 - 0.327)	61.9%	<0.001
Female	24	764	2014	0.364 (0.673 - 0.401)	61.9%	<0.001
Witnessed ingestions	15	868	1567	0.747 (0.587 - 0.880)	97.4%	<0.001
Clinical symptoms						
Abdominal pain	11	211	620	0.382 (0.202-0.562)	96.5%	<0.001
Vomiting	11	150	678	0.272 (0.179-0.364)	90.3%	<0.001
Fever	8	37	520	0.068 (0.028-0.108)	76.6%	<0.001
Excessive crying	4	34	167	0.216 (0.016-0.415)	91.2%	<0.001
No symptoms	18	524	1041	0.430 (0.293-0.573)	95.0%	<0.001
Perforation or fistula	21	364	1755	0.302 (0.225-0.378)	95.0%	<0.001
Clinical interventions						
Abdominal surgery	24	655	2014	0.433 (0.325-0.541)	97.8%	<0.001
Endoscopic removal	24	393	2014	0.124 (0.083 - 0.172)	86.3%	<0.001
Conservative treatments[a]	24	890	2014	0.278 (0.403-0.529)	98.2%	<0.001

[a] *including inpatients and outpatients. Random effects model used for all pooled proportions.*

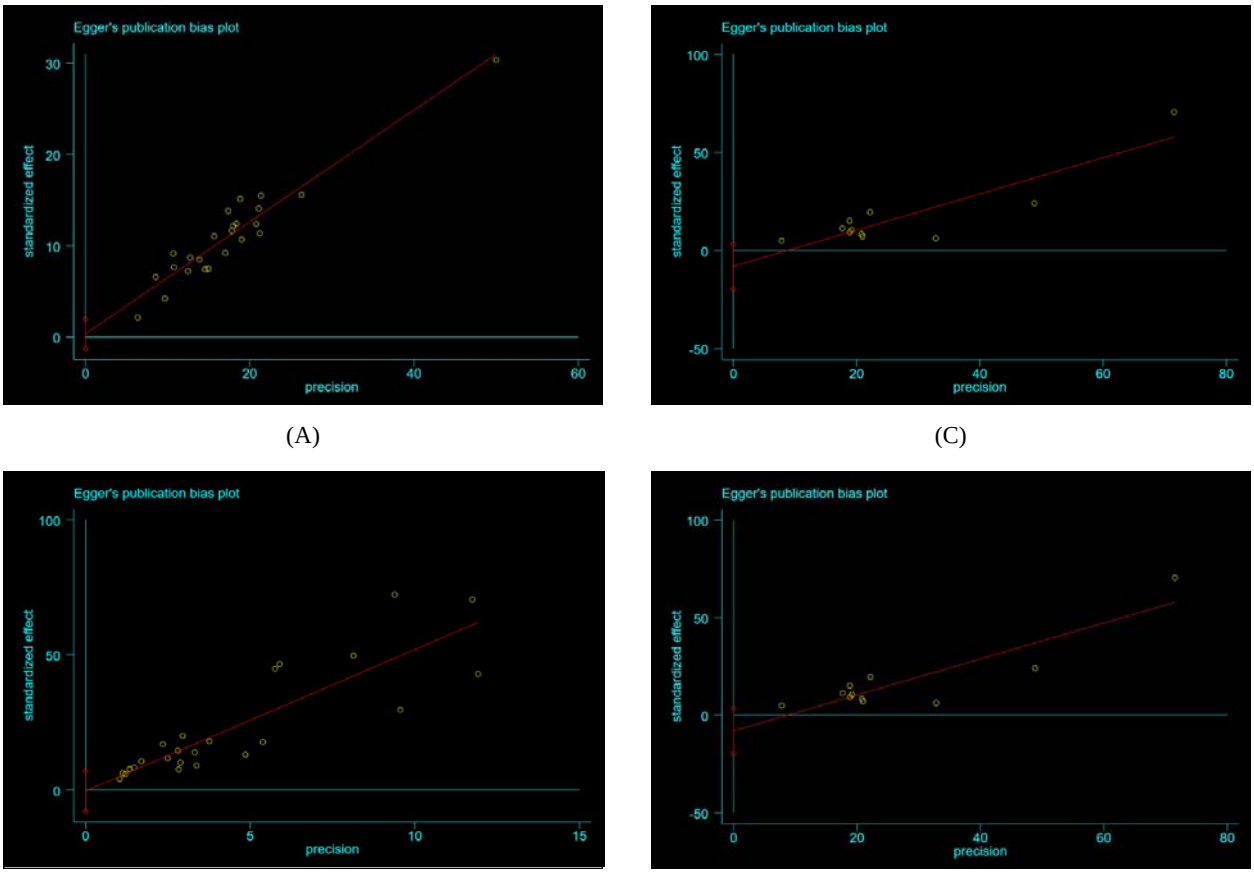

Fig. 2 Publication bias plot (Egger test) for ingested magnetics foreign bodies in children with respect to: *a*) male gender, *b*) age, *c*) witnessed ingestions, and *d*) abdominal pain.

procedures, and complications; suggesting there is a lack of attention in post treatment follow-ups after foreign bodies extraction, and there is insufficient focus on long-term outcomes.

There are limitations in our meta-analysis. Firstly, only data from observational studies or retrospective cohort studies are available, selection bias was inevitable. Secondly, the surgical teams were also the report authors, and there might be a certain risk of bias. Thirdly, only 24 records were analyzed, some clinical presentation and postoperative outcomes were significantly hetero-geneous. Fourthly, there was indication of high risk of publication bias. In addition, long-term follow up data is limited for further analysis.

Ingested foreign bodies in children have become one of the imperative problems that merit special attention in the pediatric emergency, especially the magnetic foreign bodies because it can induce serious consequences. Strict legal regulations should be in place to prevent the use of magnets in pediatric products and the importance of preventive measures needs to be emphasized to parents and caregivers. More importantly, protocols on vigilant diagnostic procedures and standardized treatments should be established when encountered ingested magnetic foreign bodies. Although the extreme diversity of epidemiological study designs and characteristics could make it challenge to analyzing research summaries, meta-analyses of observational studies remain to be one of the few methods to resolve crucial problems in clinical and public health.

Though an enormous heterogeneity among primary studies may impair study comparability, our study results confirmed the relevant morbidity, clinical characteristics and interventions associated with ingested magnetic FBs in children. Protocols for more vigilant diagnostic procedures, treatment and post treatment follow up should be developed; lastly, preventive measures such as parental education and legislation should be emphasized in protecting the pediatric population.

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Contributors: SX, JB: systematic search, data extraction, Formal analysis, article writing; YH, SL, HZ: formal analysis, quality assessment; YF: quality assessment; BZ: corresponding author who determined the main idea of the manuscript. All authors designed, reviewed and approved the manuscript.
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Web Table I Begg and Egger Test of Publication Bias of Clinical Characteristics

	Number of studies	*P value*[a]	
		Begg Test	*Egger Test*
Male	24	1.000	0.650
Age (yrs)	24	0.862	0.917
Witnessed ingestions	15	0.350	0.149
Clinical symptoms			
Abdominal pain	11	0.436	0.984
Vomiting	11	0.087	0.002
Fever	8	0.035	0.013
Excessive crying	4	0.734	0.229
No symptoms	18	0.964	0.491
Perforation or fistula	21	0.001	0.001
Clinical interventions			
Abdominal surgery	24	0.206	0.000
Endoscopic removals	24	0.065	0.372
Conservative treatments	24	0.785	0.070
Postoperative stay (days)	12	0.193	0.001

P value < 0.05 was considered to have a high risk of publication bias.