Effectiveness and safety of ultrasound-guided hydrostatic reduction for children with acute intussusception

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Abstract
Objective This study aims to explore the effectiveness and safety of the new-type ultrasound-guided hydrostatic reduction for children with acute intussusception.
Methods The clinical data of 364 children with primary acute intussusception who underwent nonsurgical reduction in our hospital between January 2016 and May 2019 were retrospectively analyzed. Among the 364 children, 119 formed the hydrostatic reduction group. There were 89 males and 30 females, and the average age of admission was 25.13 ± 1.43 months. Among the pneumatic reduction group of 245 patients, there were 163 males and 82 females. The average age of admission was 22.47 ± 1.52 months. The reduction rate, length of stay, and perforation rate were compared between the two groups.
Results Univariate analysis showed that the reduction rate in the hydrostatic group (94.96%) was higher than in the pneumatic group (85.31%) (p = 0.007), and the hospital stay (2.76 ± 0.15 days) of the hydrostatic reduction group was shorter than that of the pneumatic reduction group (3.56 ± 0.35 days) (p = 0.038). In children with intussusception time >48 h, the reduction rate was 95.45% in the hydrostatic reduction group and 86.20% in the pneumatic reduction group.
Conclusion The new-type ultrasound-guided hydrostatic reduction has a higher reduction rate in the treatment of acute intussusception in children results in a shortened hospital stay. It is effective, safe, and avoids radiation exposure.

Keywords
Primary intussusception, ultrasound-guided, children, hydrostatic reduction

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Introduction

Acute intussusception is one of the most common acute abdominal emergencies in infancy and childhood. Clinical manifestations are paroxysmal abdominal pain, crying, vomiting, dark red-currant jelly stool, and a palpable sausage-like, slightly active, and tender mass in the abdomen. Primary intussusception accounts for about 90%. Acute intussusception progresses rapidly. Delayed diagnosis and treatment may lead to intestinal necrosis, peritonitis, and infectious toxic shock, endangering the affected child’s life. Non-operative reduction is the first choice for the treatment of intussusception. In general, X-ray-monitored pneumatic or barium reduction and ultrasound-guided hydrostatic reduction are used to treat acute intussusception in children. Compared with X-ray-monitored pneumatic reduction and barium reduction, ultrasound-guided hydrostatic reduction has the obvious advantage of avoiding radiation. Recently, a new type of ultrasound-guided reduction device with automatic pressure regulation and safety monitoring has been welcomed by clinicians for the treatment of children with acute intussusception. However, there is little relevant literature in this domain, and its effectiveness and safety are not well studied. The purpose of this study is to investigate the effectiveness and safety of the new-type ultrasound-guided hydrostatic reduction for children with primary intussusception to provide clinicians with a deeper understanding of the treatment. The approach is a retrospective analysis of 364 cases of primary intussusception in children.

Materials and methods

Inclusion and exclusion criteria

Inclusion criteria: (1) children aged 0–14 years; (2) children had one or more symptoms of abdominal pain, vomiting, rectal bleeding/red-currant jelly stool, and palpable mass; (3) ultrasound indicated “concentric circle sign” and “sleeve sign”; (4) children were in good condition; and (5) no obvious abdominal distension. Exclusion criteria: (1) children were in poor mental state; (2) obvious peritoneal irritation sign; (3) intestinal perforation of abdominal orthographs; (4) complicated with organic lesions; and (5) the guardian refused pressure enema reduction treatment.

Demographic information

From January 2016 to May 2019, 364 children (<14 years old) with primary intussusception were treated by enema reduction in the First Affiliated Hospital of Zhengzhou University. The most common presenting clinical features were abdominal pain (333, 91.48%), vomiting (247, 67.86%), rectal bleeding/red-currant jelly stool (161, 44.23%), and a palpable mass (325, 89.29%). The age ranged from 1 to 168 months. The average age was $23.76 \pm 1.32$ months. We did a segmented analysis of age, it is shown that the most common age is from 6 to 9 months. (Figure 1). The cases were divided into two groups. The hydrostatic group comprised 119 patients (89 male and
who were treated with the new-type ultrasound-guided hydrostatic reduction between January 2018 and May 2019. Their ages ranged from 1 to 137 months. The average age was $25.13 \pm 2.03$ months. The presentation time ranged from 2 to 192 h, and the average time was $32.33 \pm 2.98$ h. The pneumatic group comprised 245 children (163 males and 82 females) who underwent X-ray-monitored pneumatic reduction between January 2016 and December 2017. Their ages ranged from 2 to 168 months. The average age was $22.47 \pm 1.52$ months. The presentation time was from 3 to 144 h, and the average time was $29.06 \pm 2.43$ h (Table 1).

**Equipment**

Hydrostatic group: The disposable reduction device for children with intussusception was produced by Shenzhen Yixinda Medical New Technology Co., Ltd (Figure 2(a)). Pneumatic group: The computer-controlled enema restoration instrument was produced by Guangzhou Jinjian Medical Instrument Co., Ltd (Figure 2(b)).

**Method**

For the new-type ultrasound-guided hydrostatic reduction, the child was laid on the operating bed and ultrasound was used to confirm the position of the head and the length of the intussusception (“concentric circle sign” and “sleeve sign”) (Figure 3(a)). A digital
rectal exam was conducted to check whether there were other diseases of the anal canal. Then, the device was connected, and the following were checked: the pipeline was smooth and the safety valve was good and leak-free. The initial pressure was then adjusted to 8 kPa, under ultrasound guidance, normal saline (36 to 39°C) was injected into the intestinal tract. Pressure gauge monitored the pressure on the head of intussusception in real-time. While the pressure exceeded the preset value, normal saline would be drained through the discharge pipe. According to the child’s age and tolerance during the reduction, the reduction pressure was slowly increased, but to no more than a maximum pressure of 16 kPa. The water flowed gradually from the rectum to the head of the intussusception, which showed an “isolated island sign” (Figure 3(b)), and then

Table 1. Comparison of general data between the two groups of children.

| Characteristics                  | All, n (%) | Hydrostatic group, n (%) | Pneumatic group, n (%) | p-Value |
|----------------------------------|------------|--------------------------|------------------------|---------|
| Age (months)                     | 23.75 ± 1.32 | 25.13 ± 2.03             | 22.47 ± 1.52           | 0.307   |
| Sex                              |             |                          |                        |         |
| Male                             | 252 (69.23) | 89 (74.79)               | 163 (66.53)            | 0.109   |
| Female                           | 112 (30.77) | 30 (25.21)               | 82 (33.47)             |         |
| Symptoms                         |             |                          |                        |         |
| Abdominal pain                   | 333 (91.48) | 107 (89.92)              | 226 (92.24)            | 0.455   |
| Vomiting                         | 247 (67.86) | 73 (61.34)               | 174 (71.02)            | 0.806   |
| Bloody stool                     | 161 (44.23) | 46 (38.66)               | 115 (46.94)            | 0.136   |
| Palpable mass                    | 325 (89.29) | 103 (86.56)              | 222 (90.61)            | 0.24    |
| Duration of symptoms             |             |                          |                        |         |
| ≤48 h                            | 313 (85.99) | 97 (81.52)               | 216 (88.16)            | 0.086   |
| >48 h                            | 51 (14.01)  | 22 (18.49)               | 29 (11.84)             |         |

DOS: duration of symptoms.

p > 0.05 was used to establish no statistical significance.

Figure 2. (a) The hydrostatic reduction device: ① inlet pipe; ② safety valve; ③ pressure regulation; ④ drainage pipeline; ⑤ pressure monitor; ⑥ anal tube. (b) The pneumatic reduction device.
gradually retreated to the ileocecal region. When water flowed through the ileocecum into the intestine, which showed a “crab claw sign” and “honeycomb sign” (Figure 3(c) and (d)), the reduction was successful. If dyspnea occurred or the child’s condition was poor during the reduction, the enema reduction would be stopped immediately, a safety valve would be opened with intestinal pressure reduced and intestinal perforation avoided.

For the X-ray-monitored pneumatic reduction, the child was laid on the digital photography examination bed, and the initial pressure of the reduction was adjusted to 8 kPa. Under X-ray monitoring and distal intestine filling, the typical “cup mouth sign” appeared on the X-ray. During the reduction, the reduction pressure was slowly adjusted according to the child’s age and tolerance, but to no more than a maximum pressure of 16 kPa. When the intestine was developed and filled with air, the reduction was a success.

If intestinal perforation or dyspnea occurred or the child’s condition was poor during the reduction, the enema reduction was stopped immediately, and a rescue surgery was initiated immediately. Children with successful nonsurgical reduction were asked to stay in the hospital for at least 24 h for evaluation of recurrence and complications.

**Observation indicators**

The following observation indicators were noted: (1) reduction rate: successful rate of reduction; (2) length of stay; (3) recurrence rate: recurrence within 24 h after successful reduction; (4) rate of intestinal perforation.

**Statistical analysis**

SPSS Version 22.0 was applied for statistical analysis. Student’s t-test was used to compare the groups for normal distribution data. Comparisons between the groups were performed using Pearson’s chi-square test for categorical variables. Results were considered statistically significant if analysis yielded a p-value <0.05.
Results

A total of 364 pediatric patients with primary intussusception were admitted between January 2016 and May 2019. The baseline characteristics of all the pediatric patients are shown in Table 1. There was no significant difference between the two groups. The average reduction pressure in the hydrostatic group was 10.56 ± 0.13 kPa and the average reduction time was 9.57 ± 0.46 min. The average reduction pressure in the pneumatic group was 10.61 ± 0.09 kPa and the average reduction time was 10.31 ± 0.43 min. There was no significant difference in the reduction time or pressure between the two groups. The reduction rate in the hydrostatic group was 94.95% (113/119). Six cases underwent surgical treatment after a failed hydrostatic reduction. Four of them had successful reduction during surgery, and two had an enterotomy and enterostomy. The average hospitalization time for the hydrostatic group was 2.76 ± 0.15 days. The rate of recurrence within 24 h in the hydrostatic group was 4.42% (5/113). All were successfully repositioned under the guidance of ultrasound, and no intestinal perforation or delayed perforation occurred. The reduction rate in the pneumatic group was 85.31% (209/245). Thirty-six children with failed pneumatic reduction underwent surgical treatment. Thirty had successful reduction during surgery, and six were found to have intestinal necrosis and underwent enterotomy or enterostomy during the surgery. The average hospitalization time of the pneumatic group was 3.56 ± 0.35 days. The recurrence rate within 24 h in the pneumatic group was 5.26% (11/209). Re-pneumatic reduction was successful in 8 of 11 children. The reduction rate and the hospitalization time were statistically significant between the two groups ($p < 0.05$). The hydrostatic group was superior to the pneumatic group. There were no perforations in this study (Table 2).

In the hydrostatic group, there were 97 cases with a presentation time of ≤48 h. The reduction rate was 94.85%. There were 22 cases with a presentation time of >48 h in the hydrostatic group. The reduction rate was 95.45%. In the pneumatic group, 216 cases had

| Table 2. Comparative analysis of the clinical index of the two groups of children [case (%)]. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Clinical index                  | All, n (%)      | Hydrostatic group, n (%) | Pneumatic group, n (%) | p-Value |
| Total reduction rate            | 322 (88.46)     | 113 (95.0)       | 209 (85.3)       | 0.007 |
| DOS ≤48 h                       | 276 (88.18)     | 92 (94.85)       | 184 (85.19)      | 0.014 |
| DOS >48 h                       | 46 (90.20)      | 21 (95.45)       | 25 (86.20)       | 0.271 |
| Length of stay (d)              | 3.18 ± 0.16     | 2.76 ± 0.15      | 3.56 ± 0.35      | 0.038 |
| Recurrence rate within 24 h     | 16 (4.97)       | 5 (4.42)         | 11 (5.26)        | 0.741 |
| Reduction pressure (kPa)        | 10.60 ± 0.07    | 10.56 ± 0.13     | 10.61 ± 0.09     | 0.737 |
| Reduction time (min)            | 10.07 ± 0.33    | 9.57 ± 0.46      | 10.31 ± 0.43     | 0.245 |
| Perforation rate                | 0               | 0                | 0                |      |

DOS: duration of symptoms.

$p < 0.05$ was used to establish statistical significance.

Recurrence rate: recurrence within 24 h after successful reduction.
a presentation time of $\leq 48$ h. The reduction rate was 85.16%. There were 29 cases with a presentation time of $>48$ h in the pneumatic group. The reduction rate was 86.20%. The reduction rate in the cases with a presentation time of $\leq 48$ h in the hydrostatic group was higher than in the pneumatic group ($p < 0.05$). The reduction rates with presentation times $>48$ h were high in the two groups, although there was no significant difference between the two groups ($p > 0.05$) (Table 2).

**Discussion**

Intussusception is a common acute abdominal emergency that involves the invagination of one segment of the intestine into a distal segment, often leading to bowel obstruction. The disease is most common in children under 2 years of age, especially those aged 4–10 months. The annual average incidence of intussusception in the world is about 50–250/100,000, and the ratio of males to females is about 2–3:1. While the disease can occur at any time of the year, it occurs mostly in spring, secondly in summer and winter, and rarely in autumn. Intussusception develops rapidly. If it is not diagnosed and treated in time, it can lead to intestinal ischemia, necrosis, perforation, peritonitis, septic shock, and even death.

With the progress of medical technology, image-guided nonsurgical reduction methods have been improved, such as X-ray-monitored pneumatic (or barium) reduction and ultrasound-guided hydrostatic reduction. According to some literature reports, ultrasound-guided hydrostatic reduction has the following advantages compared to barium or pneumatic reduction: (1) It avoids exposing medical staff, children, and their families to X-rays; (2) The pressure of hydrostatic reduction is mild and persistent, which reduces the incidence of intestinal perforation; (3) Should perforation occur, the saline would not stimulate the abdominal cavity, which would avoid the occurrence of chemical peritonitis, unlike with barium reduction, and tension pneumoperitoneum with pneumatic reduction. (4) The type of intussusception and pathological leading point can be checked by ultrasound; (5) The success rate of reduction is high. In this study, the success rate of reduction in the hydrostatic group (95.0%) was higher than in the pneumatic group (85.3%). The difference was statistically significant ($p < 0.05$).

Compared with the self-made simple ultrasound-guided hydrostatic reduction device, the new-type device of ultrasound-guided hydrostatic reduction has the following advantages: (1) with a pressure detection device and safety water valve, the pressure can be adjusted (8–20 kPa). In addition, the pressure gauge can accurately monitor the real pressure at the head of the intussusception in real-time. When the pressure exceeds the preset value, saline can be discharged from the drainage pipe of the device to keep the pressure at the head of the intussusception stable and safe; the discharged saline water can be recycled. (2) The device is disposable. It reduces the possibility of cross-infection of intestinal diseases. (3) The manual pressing water balloon and pulse pumping of warm saline help to wash out intestinal inflammatory mediators and reduce fever after the reduction. (4) When the pressure of the intestinal cavity is too high and dangerous, or an intestinal perforation occurs in children, the artificial spillway rod of the device can be pulled out quickly to discharge the intestinal contents.
and, hence, lower the risk of intestinal rupture or avoid excessive contamination of the abdominal cavity.\textsuperscript{15} (5) The hydrostatic reduction device is a set of equipment, is simple to operate, and reduces the preparation time and workload of doctors.\textsuperscript{18} (6) This device avoids contaminating medical staff and operating platforms with intestinal contents. It is noteworthy that no perforation or delayed perforation occurred in our two groups, which may be related to the rich experience of the clinicians in this study.\textsuperscript{13}

In textbooks, symptoms with a duration exceeding 48 h are a contraindication for attempted enema reduction. In the report of Raymond ZML, there was no significant correlation between the presentation time and the enema reduction rate, and the reduction rate of cases whose duration of symptoms was more than 72 h still reached 82.4\%.\textsuperscript{14} In this study, patients whose symptoms exceeded 48 h were provided an enema reduction while they were in good general condition and had no signs of peritonitis. The guardian approved and signed the written consent. The reduction rate of the hydrostatic group was 95.45\%, while the pneumatic group was 86.20\%. The reduction rate was high, and there were no perforations in the two groups. It is suggested that symptoms lasting more than 48 h can be an indication for enema reduction, provided that the patient is in good general condition and has no signs of peritonitis.

The hospitalization time in the hydrostatic group was shorter than the pneumatic group in this study. The difference was statistically significant ($p < 0.05$). The warm saline helps to discharge the intestinal contents, which reduces the absorption of toxins, relieves fever after the reduction, and shortens the hospitalization time.\textsuperscript{14} These advantages promote the application of ultrasound-guided hydrostatic reduction. Ultrasound scanning can monitor the process of reduction, evaluate the blood supply of the intussusception and the degree of ileocecal valve edema, and detect other abdominal diseases.\textsuperscript{14} In this study, the recurrence rate in the hydrostatic group (4.4\%; 5/119) was lower than in the pneumatic group (5.3\% 11/245) and lower than that reported in the literature, which may be related to the small sample size of recurrent children in this study.\textsuperscript{7}

In this study, the age span of the children treated was large. With the maximum age being 168 months, the average age of the children was higher. The age composition ratio between the two groups was not compared, and we will discuss it in our future work. In addition, we will expand the sample cases in the future study to go beyond 48 h of presentation time and increase the number of cases.

**Conclusion**

This study shows that the new-type ultrasound-guided hydrostatic reduction with automatic pressure regulation and safety control is superior to pneumatic reduction in terms of rate of reduction and a shortened hospital stay. It is effective, safe, and avoids radiation exposure. It can be used as the first choice for nonsurgical reduction of intussusception and is worthy of clinical promotion.

**Compliance with ethical standards**

The authors declare that they have no conflicts of interest. Informed consent was obtained from all participants included in the study. All the procedures performed involving
human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics Committee of the First Affiliated Hospital of Zhengzhou University.

Declaration of conflicting interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the National Natural Science Foundation of China (grant number 81902471), Key Scientific Research Projects of Higher Education Institutions in Henan Province (20B320023), Joint Co-construction Project of Henan Provincial Medical Science and Technology Research Plan (LHGJ20200323) and Provincial and Ministry Co-construction Project of Henan Provincial Medical Science and Technology Research Plan (SB201904003).

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