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MINIMALLY INVASIVE AND ROBOTIC PEDIATRIC SURGERY

APPLICATION OF THE P.I.RS. PRINCIPLE TO THE TREATMENT OF OTHER SURGICAL PATHOLOGIES

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1. Application of the P.I.R.S principle to the treatment of other surgical pathologies

1.1 Introduction

Surgery has changed dramatically over the last several decades. The emergence of MIS has allowed pediatric surgeons to manage critically ill neonates, children, and adolescents with improved outcomes in pain, postoperative course, cosmesis, and return to normal activity. Procedures that were once thought to be too difficult to attempt or even contraindicated in pediatric patients in many instances are now the standard of care. New and emerging techniques, such as single-incision laparoscopy, endoscopy-assisted surgery, robotic surgery, and techniques yet to be developed, all hold and reveal the potential for even further advancement in the management of these patients. The future of MIS in pediatrics is exciting; as long as our primary focus remains centered on developing techniques that limit morbidity and maximize positive outcomes for young patients and their families, the possibilities are both promising and infinite. [1]

In this futuristic, but contemporary scenario, herein we want to describe a novel application of the P.I.R.S principles in order to treat different surgical conditions.

1.1.1 P.I.R.S Technique

First described in 2006 by Patkowski et al, percutaneous internal ring suturing (PIRS) has been developed as an alternative surgical option for the correction of inguinal hernia.

Differently from the laparoscopic approach which is performed with three or rarely two trocars and requires intraperitoneal knotting [2], the PIRS technique necessitates only one umbilical port and the puncture of the skin with an 18-gauge injection needle, thus resulting with an almost invisible scar in the umbilicus.

Under laparoscopic-guided vision the 18-gauge injection needle with non-absorbable 2-0 monofilament thread inside the barrel of the needle is introduced into the body, through the abdominal wall into the abdominal cavity. With the movements of the tip of the needle the thread passes under the peritoneum, over half of the internal ring including a part of the ligament and adjacent tissue. The thread is pushed through the barrel of the needle into the abdominal cavity and eventually makes a loop. The needle is pulled out, leaving the loop of the thread inside the abdomen. From outside the patient's body, one of the thread ends is introduced again into the barrel of the needle and the needle passes through the same skin puncture point, to surround the other half of the internal ring with part of the round ligament. The end of the thread goes through the barrel of the needle into the thread loop and the needle is withdrawn. Next, the thread loop is pulled out of the abdomen with the thread end caught by the loop. In this way the thread is placed around the inguinal ring under the peritoneum and both ends exit the skin through the same puncture point. The knot is tied to close the internal ring and is placed under the skin. The umbilical wound is closed with absorbable stitches, while the skin puncture point in the inguinal region is left without any dressing. [3]

Main aim of this study is to describe the application, in our centre in Catania, of the PIRS principle for the minimally invasive correction of a rare pediatric surgical pathology: Gastric Volvolus.

We also describe a very small cohort of 3 patients affected with Morgagni Larrey Hernia who underwent surgical repair using the same technique.

1.2 Definition, Epidemiology, Classification and Pathogenesis

1.2.1 Gastric Volvolus

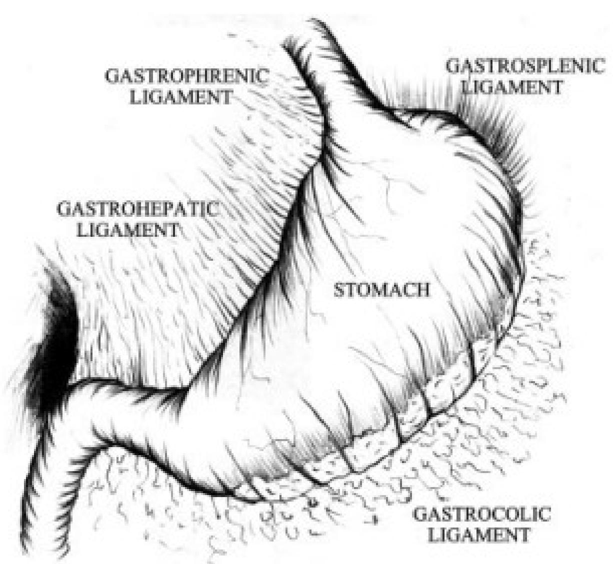
First described by Berti in 1866, Gastric volvulus is traditionally considered an uncommon cause of foregut obstruction and is usually described as having a peak incidence during the fifth decade of life. [4]

Gastric volvulus in infants, children, or adolescents is a rare pathological entity, with an estimated incidence not clearly reported in literature, often diagnosed with delays as its presenting symptoms are similar to more common conditions such as pyloric stenosis and gastroesophageal reflux. [5] [6]

The term “volvulus” is derived from the Latin verb volvere, which means to turn or roll. “Gastric volvulus” refers to the revolution of all or a portion of the stomach at least 180° about an axis that causes an obstruction of the foregut.

In terms of onset the obstruction may be acute, recurrent, intermittent, or chronic. A twisting or turning of the stomach of 180° that results in only partial foregut obstruction is best defined as “gastric torsion. [7] [8]

The stomach is normally fixed to the abdominal cavity by 4 ligaments: the gastrocolic, gastrohepatic, gastrophrenic, and gastrosplenic (Fig 1).



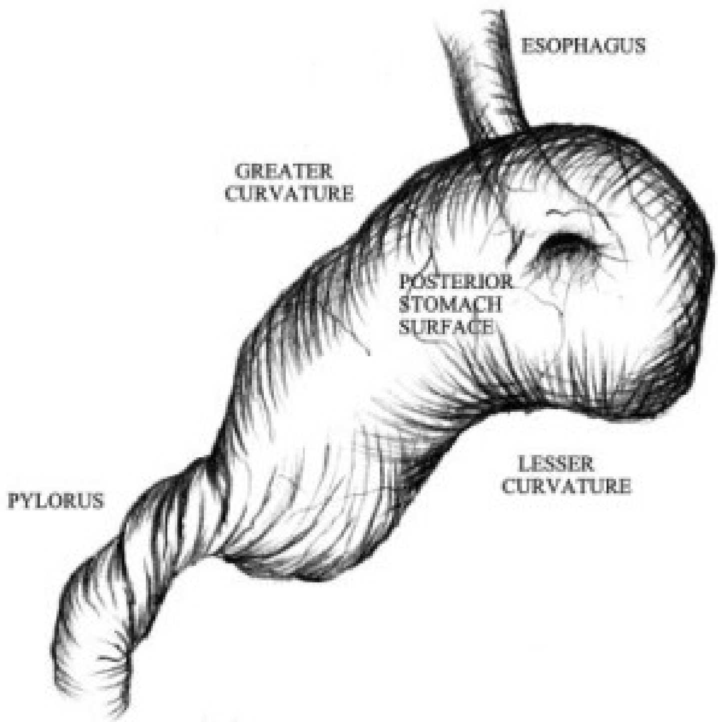
Together with the pylorus and the gastroesophageal junction, these ligaments normally anchor the stomach and prevent volvulus. Failure of these normal attachments may be the result of agenesis, elongation, or disruption of the gastric ligaments, which results in idiopathic or primary gastric volvulus. Disorders of gastric anatomy or gastric function or abnormalities of adjacent organs such as the diaphragm or spleen may result in secondary gastric volvulus (Table 1).

TABLE 1 Anatomic Etiology of Gastric Volvulus

Primary volvulus: absence, failure of attachment, or elongation of gastric fixation
Gastrocolic ligament
Gastrohepatic ligament
Gastrophrenic ligament
Gastrosplenic ligament
Secondary volvulus
Disorders of gastric anatomy or function
Acute or chronic distention (gastric outlet obstruction, hypomotility, or massive aerophagia)
Peptic ulcer disease
Neoplasm of the stomach
Hourglass stomach
Gastric ptosis
Abnormalities of adjacent organs
Diaphragm (hernia, rupture, eventration, phrenic nerve palsy)
Spleen (asplenia, polysplenia, splenomegaly, wandering spleen)
Transverse colon (volvulus, displacement into chest)
Intestinal malrotation
Liver (dislocation or hypoplasia of left lobe)

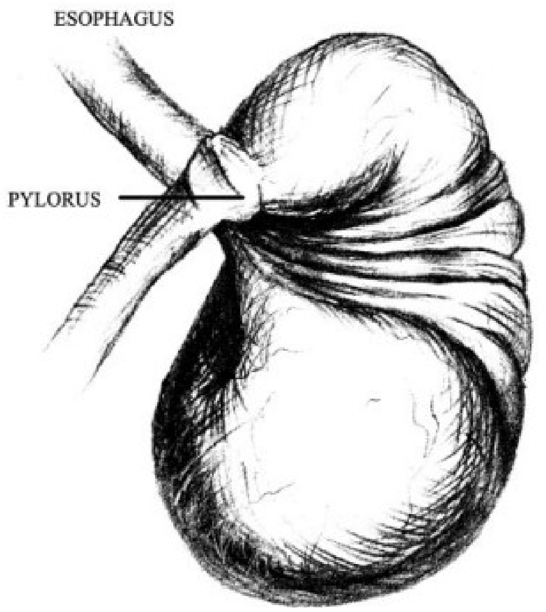
Adapted with permission from Scherer J III. Peptic ulcer and other conditions of the stomach. In: Grosfeld J, O'Neill J, Coran AG, Fonkalsrud E, eds. *Pediatric Surgery*. 6th ed. Philadelphia, PA: Mosby; 2006:1234.

The stomach may rotate on a longitudinal axis that extends from the gastroesophageal junction to the pylorus. Rotation about this axis causes the greater curvature of the stomach to rest superior to the lesser curvature, resulting in an “upside-down” stomach. This is called “organoaxial volvulus” (Fig 2).

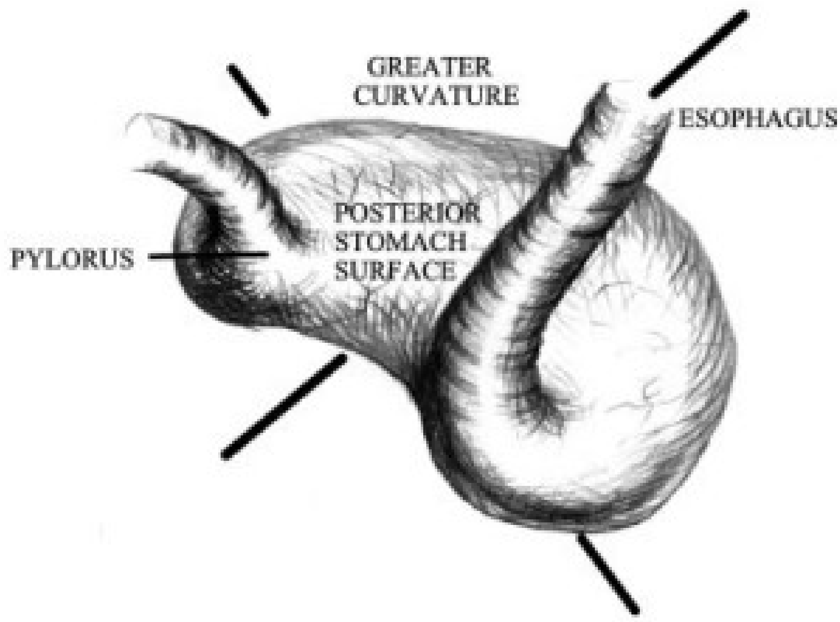


The stomach in organoaxial volvulus tends to lie in a horizontal plane when viewed in plain radiography of the abdomen and chest, which is a distinguishing feature that may aid in early diagnosis.

In contrast, rotation of the stomach along an axis perpendicular to its longitudinal axis has been described with many names. Originally termed “mesenterio-axialis” by Buchanan [9], it was shortened to “mesentero-axial” by Singleton in 1940 [10]. The stomach in mesenteroaxial volvulus typically lies in a vertical plane, with the antrum and pylorus rotated anterior and superior to the gastroesophageal junction. (Fig.3)



Rotation of the stomach about both the organoaxial and mesenteroaxial axes is termed “combined volvulus”. (Fig 4)



2. Materials and Methods

We performed a retrospective review of clinical and operative notes of patients presenting to a single Tertiary Center for Pediatric Surgery—ARNAS Garibaldi, Catania, Sicily, Italy—between January 2015 and March 2022, with ACGV. Data on demographics, comorbidities, clinical presentation, symptoms and their duration were reviewed. Operative notes were examined, and the surgical approach used was described including patient decubitus, as well as the instruments used and operative time. Descriptive data analysis was performed. Any intra- and post-operative complications were reviewed. The revision of the published literature on the management of acute and chronic gastric volvulus was performed via Pubmed, Embase, Medline, Google Scholar and Cochrane database.

3. Results

3.1 Demographics

From January 2015 until March 2022, 13 patients presented to our Emergency Department with symptoms of gastric outlet obstruction requiring hospital admission and further investigations.

Our center is a referral tertiary hospital for pediatric surgery, covering an estimated population of 1.5 million habitants from six different cities (Catania, Siracusa, Enna, Agrigento, Ragusa and Caltanissetta).

Overall, 7/13 (54%) were female, median age at surgery was 57 days (6–122 days), median weight—4840 g (3220–6000 g). Data on comorbidities were available for 9/13 patients: 4/9 (44%) presented associated anomalies (PFO, PDA, ileal duplication); all of the comorbidities were known prior to the surgery except for the ileal duplication, which was diagnosed intraoperatively and addressed separately. Seven (54%) patients were admitted with vomiting and regurgitation, 1/13 (8%) presented with feeding difficulties and failure to thrive and 1/13 (8%) presented with sudden abdominal distension. Data on clinical presentation on admission were not available for 4/13 patients. Overall, the duration of symptoms varied from 24 h (sudden abdominal distension) to 2 weeks (feeding difficulties, failure to thrive) [Table 2].

Gender	Gestational Age	Age at Surgery (Days)	Weight at Surgery	Presenting Symptoms	Type of Volvulus
F	38 + 5	102	5650	Vomiting and retching	Organo-axial
F	39 + 0	122	4840	Vomiting and retching	Organo-axial
F	38 + 5	57	4600	Abdominal distension	Organo-axial
M	39 + 1	36	3220	Vomiting and retching	Organo-axial
F	39 + 2	6	3680	Vomiting and retching	Organo-axial
M	38 + 2	57	5280	Vomiting and retching	Organo-axial
M	38 + 0	78	6000	Vomiting and retching	Organo-axial
M	39 + 0	43	3890	Vomiting and retching	Organo-axial
F	N/A	N/A	N/A	N/A	Organo-axial
M	40 + 4	69	4980	Feeding difficulties/failure to thrive	Organo-axial
F	N/A	N/A	N/A	N/A	Organo-axial
M	N/A	N/A	N/A	N/A	Organo-axial
F	N/A	180	N/A	N/A	Organo-axial

All of the patients received adequate resuscitation with endovenous administration of normal saline 0.9% and glucose 5% and NG tube. Nine (70%) underwent US abdomen to exclude pyloric stenosis as cause of gastric outlet obstruction. No data were available for 4/13 patients in regard to the US findings. All of the patients underwent an upper GI contrast study showing enlarged and rotated stomach with delayed or absent emptying and pylorus looking downward, suggestive and diagnostic of organo-axial volvulus. [Fig. 6 and 7]

Figure 6. Upper GI contrast study: 4 months old infants presenting with thrive. The contrast report showed an enlarged stomach, the gastric bubble cardias, a more elevated left hemidiaphragm and the gastric antrum higher than the pylorus as for organo-axial volvolus.

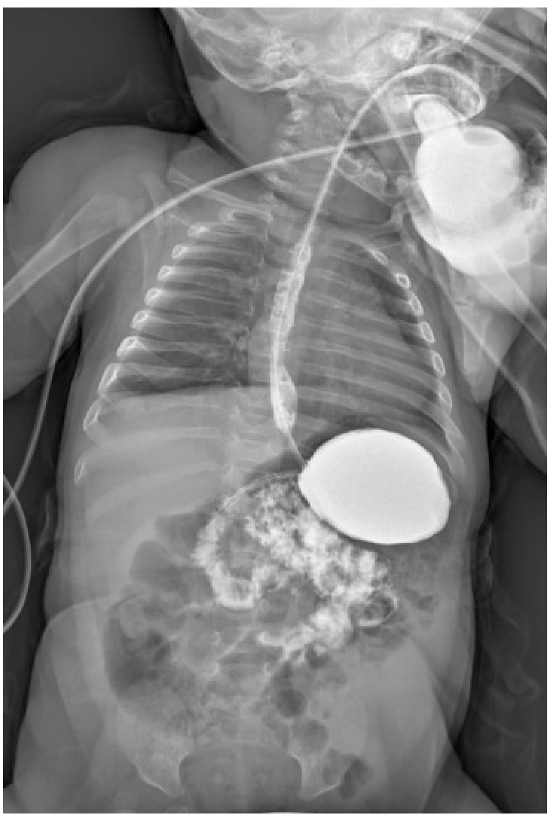


Figure 7.
Upper GI contrast study: 6 months old girl presenting with ongoing vomiting and failure to thrive. The contrast study shows an enlarged stomach horizontally orientated, the antrum cranially displaced to the pylorus as per organo-axial gastric volvolus

3.2. Operative Technique

A standard supine position was used for all of the patients (Fig.8). Patients were positioned at the end of the bed with the legs in frog position properly secured. We used a 5 mm infra-umbilical port and a 5 mm 30◦ scope. Pneumoperitoneum was established with an intra-abdominal pressure of 8–10 mmHg and 1–1.5 lt/min was used. A stab incision within the right upper quadrant was performed to accept a 3 mm instrument inserted under direct vision, without using a trocar.

Figure 8. Intraoperative image: patient decubitus

Under direct vision, a 14 Gauge injection needle containing a non-absorbable suture (2-0 monofilament thread non-reabsorbable) was inserted through the abdominal wall within the abdominal cavity and a seromuscular bite was passed through the anterior wall of the stomach.

Figure 9. Intraoperative image: suture insertion via 14 G

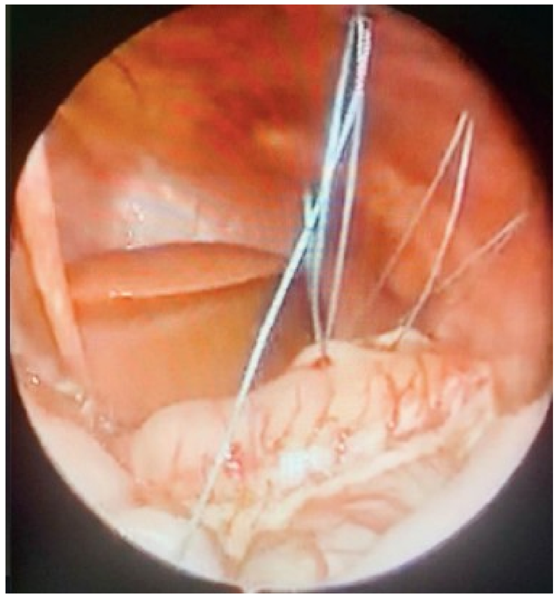


Figure 10. Intraoperative image: positioning of seromuscular thread within the stomach's greater curvature and the anterior abdominal muscle

The needle was pulled out leaving the loop inside the seromuscular aspect of the stomach. Another thread end was then introduced again into the barrel of the needle and the needle passed through the same skin puncture point, the end of the thread goes through the barrel of the needle into the loop of the thread loop and the needle was then withdrawn. The knot was tied to secure the anterior gastric wall to the abdominal wall under direct vision.

The procedure is repeated twice on the anterior gastric wall within the greater curvature. We did not position gastrostomies and did not perform anti-reflux procedures.

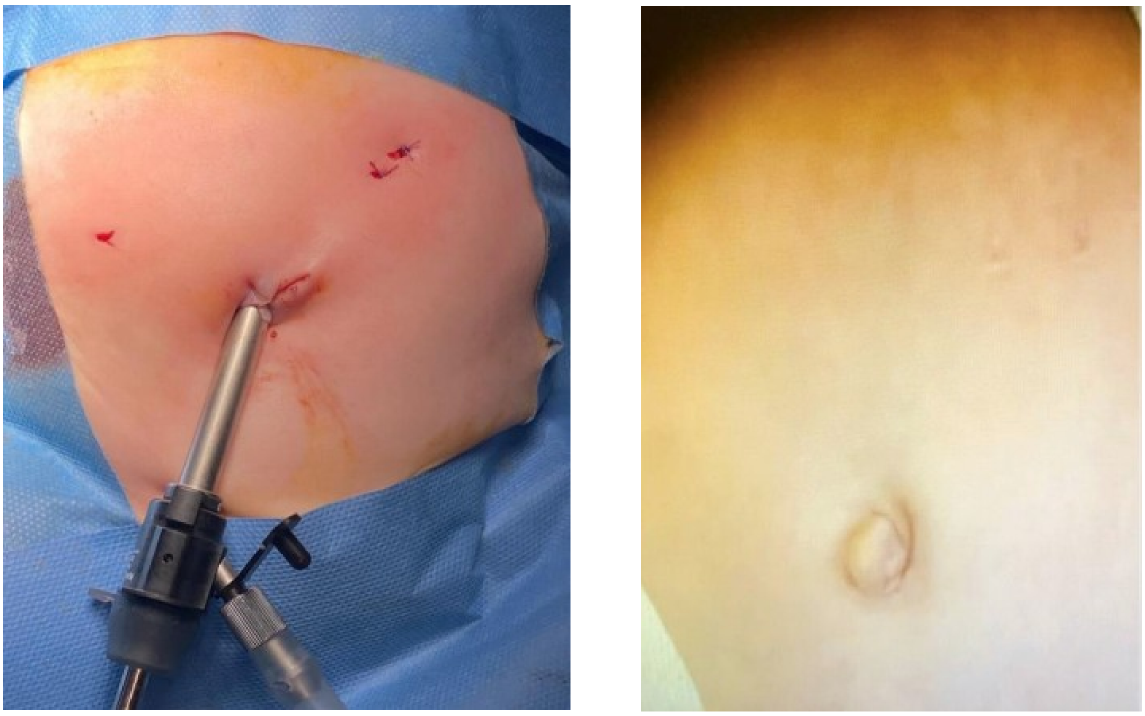


Figure 11. (a) Intraoperative image: end of the procedure, aspect of the extracorporeal suturing. (b) same patient attending follow-up clinic, cosmetic result

During the laparoscopic exploration, we did not find diaphragmatic defects such as diaphragmatic hernias or eventration; none of the patients was found to have signs of gastric ischemia intraoperatively. In fact, only one patient (7.6%) was found to have a gastric volvulus intraoperatively requiring de-rotation. No information was found for 3/13 patients in regard to the presence of volvulus intraoperatively. In all of the cases, the stomach was described as very enlarged and floppy with ligamentous laxity. The umbilical access was closed with 2-0 or 3-0 absorbable braided suture; the skin was closed with 4-0 absorbable braided material. The median operative time was 50 min (40–95 min). All of the patients received antibiotic prophylaxis with Amoxicillin and Clavulanate or Ampicillin.

3.3. Outcomes

No intraoperative complications were reported. Post-operatively patients were fed on day 3 (min 2–max 5 days), the main delay was related to the patient being found to have an ileal duplication causing rectal bleeding and requiring a second surgical procedure. All of the patients were discharged on anti-reflux medications (PPI) which were stopped by the first post-operative follow-up. Post-operatively one patient (8%) developed a subcutaneous granuloma at the extracorporeal knotting site. The follow-up period ranged from four months to seven years: to date, all of the 13 patients report not having experienced recurrence of symptoms and none required revision surgery or a planned anti-reflux procedure.

4. Discussion

The stomach is a hollow viscus normally fixed within the abdominal cavity by the presence of four ligaments: gastrocolic, gastrohepatic, gastrophrenic and gastrosplenic; moreover, the pylorus and the gastroesophageal junction keep the stomach in place, avoiding its twisting and therefore its volvulus. When these ligaments are lacking or loose, the stomach can move freely along its axis and twist. If this happens on its longitudinal axis passing between the esophagogastric junction and the pylorus, an "organoaxial volvulus" will occur; if instead the twist happens on its perpendicular axis—as if an imaginary line passes from the lesser to the greater curvature—a "mesenterico-axialis/mesentero-axial volvulus will happen. Rarely the stomach can rotate in both ways leading to a "combined volvulus". [6,11]

Usually GV can occur acutely (43%) or chronically; generally, males are more commonly affected (54%) and usual pathological associations include: congenital diaphragmatic hernia (17%), diaphragmatic eventration (25%), malrotation (7%), wandering spleen (6%), asplenia (6%) [12]. In terms of age at presentation and type of volvulus, the published literature states that 21% of children with acute GV present within their first month of life and that 54% will usually have an organo-axial volvulus [13]. Our cohort has a median age of 57 days–2 months—and only one (8%) patient presented with acute gastric volvulus confirmed intraoperatively. Interestingly, the only one patient presenting with acute volvulus was 6 days old confirming the literature data and suggesting that chronic/intermittent volvulus manifestation will be subtler. Equally, all of our patients had a radiological or intraoperative diagnosis of organo-axial volvulus confirming this type as the most common type of gastric volvulus in children and infants. In terms of clinical presentation, in 1904 Borchardt described the clinical triad of the presentation of GV as inability to vomit, severe epigastric distension and inability to pass a nasogastric tube [11].

Usually, the most common symptoms are non-bilious vomiting, epigastric distension and abdominal pain. Fifty-four percent of our patients presented with persistent vomiting and failure to thrive, 8% presented acutely with epigastric distension whilst none of our patients presented with the classic Borchardt triad. Whilst the mortality rate reported in the literature is 7%, we did not experience mortality [11,12]. All of our patients underwent an upper GI contrast study, suggestive of an organoaxial volvulus, which was diagnostic for gastric volvulus. As reported in literature, classic radiological signs of GV are:

1. a pulled up greater curvature of the stomach
2. a horizontal gastric shadow
3. a hairpin sign
4. minimal gas in the small and large bowel
5. a nasogastric tube trapped in the lower end of the esophagus
6. the greater curvature crossing the esophagus [14].

In our experience, we observed the stomach being enlarged with a cranial displacement of the antrum above the pylorus level and the elevation of the hemidiaphragm. In our experience, patients presented with both acute and chronic issues; the treatment of gastric volvulus can vary depending on its presentation—while acute GV undoubtedly requires emergency treatment, the management of chronic gastric volvulus remains debated. In 2007, Al-Salem suggested that chronic GV should be treated conservatively by modifying the child's decubitus position and keeping them prone with a slight head up, reducing the amount of air and gastric contents regurgitation into the esophagus. The same author also suggested the use of medications such as metoclopramide to enhance esophageal and gastric emptying and H2 blockers to prevent esophageal ulceration. In his report, this management was reported as effective in treating the condition [6].

In our experience, we found that our patients presenting with chronic gastric volvulus were experiencing severe symptoms such as failure to thrive and inability to feed properly leading to a progressive deterioration of their clinical conditions. As a result, we feel that surgical treatment should be offered to these patients as chronic gastric volvulus is probably associated with spontaneous resolution until it becomes acute and irreversible [14,15].

As mentioned, over the years many surgical approaches have been described in the literature to manage ACGV: laparotomy and gastropexy (with or without gastrostomy), laparoscopic surgery and endoscopic reduction [13].

An interesting paper was published in 2006 by Patkowski et al. [3,16,17] describing their novel technique for the repair of inguinal hernias in children called the PIRS technique and using a laparoscopic-assisted percutaneous knotting technique. Since then, this technique has gained popularity and is widely used. We thought to apply the benefit of the extracorporeal knotting technique, (avoiding the difficulties of training in intracorporeal knotting and increasing the timing of the surgical procedure) the avoidance of unnecessary trocars and gastrostomy insertion to be applied to patients presenting with ACGV. We applied the extracorporeal knotting technique as a possible technical variation to perform the anterior gastropexy. In our opinion this surgical technique has the advantage of being minimally invasive and it also avoids the need for gastrostomy placement, sensibly reducing morbidity and improving patient's symptoms as we experienced with our patients at the follow-up.

4.1. Other Applications

Due to the reliability and feasability of the P.I.R.S. technique, we want to describe a further and novel application of its principle in order to treat Morgagni-Larrey diaphragmatic hernia.

From 2015 to 2020 we treated 3 patients affected by Morgagni – Larrey diaphragmatic hernia:

- 4 years old, Down Syndrome: recurrent vomiting
- 2 years old, Arnold Chiari syndrome: recurrent pneumonia
- 3 years old: severe constipation

None of the patients presented acutely at the emergency department.

In each case, diagnosis was made after anterior-posterior and lateral chest X-ray in order to define the etiology of the recurrent symptoms.

Our preoperative assessment in order to evaluate the extent of the defect prior to the surgical correction included: barium enema, iodated contrast swallow (Gastrografin®) and computed tomography of the thorax, thus showing the erniation of abdominal content in the thorax through the diaphragmatic defect.

Mandatory before the intervention was cardiac evaluation of each patient.

Regarding the surgical correction, the technique used was a laparoscopic assisted diaphragmatic reparation.

The patient was in reverse Trendelenburg position with the surgeon standing at the foot of the bed. A 10 mm trocar is placed into the abdominal cavity using the standard open transumbilical technique. Depending on patient size, a pneumoperitoneum of 8 mm Hg to 10 mm Hg was established. A 10-mm telescope with inbuilt 6-mm working channel was used.

The defect and herniated organs including the hernia sac (if present) were defined. Following reduction of the hernia contents, the falciform ligament was divided using diathermy to better expose the diaphragm.

In each case the primary closure of the defect was feasible without the need of a prosthesis. The sac was not removed, and the defect was closed using the laparoscopic assisted PIRS technique by suturing the muscles of the abdominal wall to the anterior edge of the diaphragmatic defect.

A small incision is made directly over the anterior margin of the hernia as determined by passing a 23-gauge needle percutaneously and confirming its position laparoscopically. A 2-0 nonabsorbable suture is passed percutaneously through the anterior abdominal wall into the peritoneal cavity. It is grasped with the laparoscopic needle holder and passed twice through the diaphragm, first in an antero-posterior direction and then back in a postero- anterior direction. A 16- or 14-gauge needle is passed percutaneously through the skin incision 3 to 5 mm from where the suture has been passed. Under laparoscopic control, the suture needle tip is advanced into the 16- or 14-gauge needle and guided out through the anterior abdominal wall. This assures precise suture placement in a “U” configuration. About 5 or 6 sutures are required to close the defect securely. When all the sutures are placed, they are pulled up together, thus, closing the retrosternal defect, as can be confirmed under direct laparoscopic visualization. The sutures are then tied extracorporeally in the subcutaneous tissue.

No drains were left in place. The umbilical access was closed with 2-0 or 3-0 absorbable braided suture; the skin was closed with 4-0 absorbable braided material. The postoperative course was uneventful.

Our standardised follow-up for detection of recurrences, as symptoms may not occur immediately, is performed with A-P and L-L chest X-ray, every 6 months for the first year and then every year for the first 5 years. In our experience no recurrences occurred.

Though it was proved the application and reliability of this technique for the repair of ML hernia, it is still debatable the feasibility to patients with huge defects who may need the placement of the prosthesis, furthermore removal of the sac (when present) with a single instrument through the operative channel may result difficult with a high risk of inadvertent pericardial, pleural and mediastinal injuries.

5. Conclusions

ACGV is a rare condition that should be taken into account in pediatric patients presenting with non-bilious vomiting, abdominal distension, feeding difficulties and failure to thrive. Radiological findings are important to warrant promptly the correct diagnosis and quickly establish the treatment. While surgery seems to be the correct approach for the management of acute gastric volvulus, whether chronic gastric volvulus should be treated at all is still debated. We feel that surgical treatment should be reserved for patients presenting with progressive deterioration of their clinical conditions and we feel that the minimally invasive approach described is a safe and adequate option avoiding gastrostomy placement and with minimal morbidity. A wider cohort and a prospective study would be needed to establish the best option for this condition.

We also conclude from our experience that laparoscopic assisted repair with PIRS technique of MLH in children can be a valid alternative in case of MLH with small diaphragmatic defects and it can be easily performed using a minimally invasive procedure that allows an excellent view of the surgical field, provides a tension-free repair, requiring less laparoscopic skills of intracorporeal knotting (due to the application of the PIRS technique) and insures rapid recovery of the patient.

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