Pediatric Upper Gastrointestinal Studies

Mike Odgren, BS, RPA, R.T.(R)(CT)

Upper gastrointestinal examinations are common procedures in many radiology departments. Performing this examination on pediatric patients requires understanding the formation of the gastrointestinal tract and the various disease processes and anatomical variances that can occur. The examination also requires a thorough patient history. This article discusses embryologic development and anatomy of the small bowel and colon, disease processes and conditions of the upper gastrointestinal tract, and fluoroscopic upper gastrointestinal tract examinations performed on the pediatric and neonatal patient.

After completing this article, the reader should be able to:
- Discuss the anatomical features of the upper gastrointestinal (GI) tract.
- Understand the basic embryology of the small bowel and colon.
- Describe the common disease processes and anatomical variants of the upper GI tract.
- Understand and alter the parameters on a fluoroscope that lower patient dose.

Upper gastrointestinal (GI) examinations are performed every day in radiology departments throughout the world. There are many variations on this procedure, including double- and single-contrast studies using barium sulfate, iodinated water-soluble contrast material ingested or injected into the upper GI tract, or both.

Performing an upper GI study on a young patient might seem intimidating to the radiologic technologist, the patient, and his or her parents.

Upper Gastrointestinal Anatomy

The esophagus extends from the pharynx to the stomach and can be described as having 3 parts: the cervical esophagus, the thoracic esophagus, and the abdominal esophagus. The cervical esophagus begins below the cricopharyngeus muscle, or the upper esophageal sphincter. This proximal portion of the esophagus has a midline orientation and lies anterior to the spine and posterior to the trachea. The thoracic esophagus typically is positioned just to the left of the spine. The abdominal esophagus is a short segment extending from the diaphragm to the gastroesophageal junction, which is sometimes called the lower esophageal sphincter. The upper esophagus contains striated muscle, and the distal esophagus contains smooth muscle.

The thoracic esophagus begins at the thoracic inlet and continues to the level of the diaphragmatic hiatus. The thoracic esophagus typically is positioned just to the left of the spine. The abdominal esophagus is a short segment extending from the diaphragm to the gastroesophageal junction, which is sometimes called the lower esophageal sphincter. The upper esophagus contains striated muscle, and the distal esophagus contains smooth muscle.

The stomach is a large saclike structure that typically lies in the left side of the abdominal cavity. The parts of the stomach are the cardia, fundus, body, antrum, and the greater and lesser curves. In young children and infants the characteristic folds of the stomach,
Embryology

The formation of the GI tract is complex and begins at approximately the fifth week of gestation and continues until birth. The gut divides into 3 sections early in development: the foregut, the midgut, and the hindgut. The celiac artery supplies blood to the foregut, which includes the early oropharynx, esophagus, stomach, and duodenum (first and second portions). The superior mesenteric artery (SMA) supplies the midgut, which extends from the middle third of the duodenum to the distal transverse colon. The hindgut is supplied by the inferior mesenteric artery and later forms the colon from the midtransverse colon to the rectum.

The midgut has 2 parts as defined by its relationship to the SMA. The midgut that lies proximal to the SMA is called the prearterial segment, and the parts that lie distal to the SMA are called the postarterial segments. Beginning in the fifth week of gestation, the midgut herniates into the umbilical cord. As the intestine herniates into the umbilical cord, the prearterial segment rotates 180°, and the postarterial segment rotates 90° counterclockwise when viewed anteriorly. Then, as the intestine returns to the abdomen, at approximately the 11th week of gestation, the prearterial and postarterial segments rotate clockwise 90° and 180°, respectively. Essentially, this means almost the entire intestine rotates 270° counterclockwise around the SMA during normal development of the GI tract. It is these complex movements of the intestines that allow the proximal small bowel to reside in the left upper abdomen and progress across the abdomen to the terminal ileum, which resides in the right lower quadrant. In addition, if rotation is complete, the colon has its typical “picture frame” orientation around the periphery of the abdomen. Bowel rotation during fetal development is a complex process. If the process is incomplete, malrotation of the intestine will result.

Special Concerns for Pediatric Patients

Indications

Many indications exist for performing upper GI examinations on pediatric patients. Some of the most common diagnoses and symptoms include:

- called rugae, typically are absent, and the stomach appears smooth (see Figure 1).

The duodenum begins at the pyloric sphincter and ends at the duodenojejunal flexure. The duodenum has 4 parts: the duodenal cap, the descending duodenum, the transverse duodenum, and the ascending duodenum. Radiologic technologists should be able to locate and describe the 4 segments because certain pathologies tend to occur at specific locations in the duodenum. The first portion of the duodenum is the duodenal cap. It begins at the termination of the pylorus and is approximately 5 cm in length. The first 2 to 3 cm reside within the peritoneal cavity, and the remaining segment of the first portion lies retroperitoneal. The second portion of the duodenum is called the descending duodenum. It passes the head of the pancreas where the common bile duct inserts into the small intestine. The third portion is the transverse duodenum, and the fourth portion is the ascending duodenum.

The region where the fourth portion of the duodenum meets the jejunum is called the duodenojejunal flexure. The duodenum ends at this flexure with the ligament of Treitz. The ligament of Treitz actually comprises tissue that contains both a fibromuscular band of smooth muscle and skeletal muscle. The ligament of Treitz is the suspensory muscle of the duodenum and connects the flexure to the crux of the diaphragm.

Figure 1. Gastrointestinal (GI) tract anatomy.
Pain.
- Nausea.
- Vomiting (bilious and nonbilious).
- Failure to thrive.
- Asthma.
- Respiratory infection.
- Cough.
- Apnea.
- Cyanosis.
- Esophageal atresia (EA) and tracheoesophageal fistula (TEF).

Having a thorough understanding of the disease processes associated with these symptoms and anatomical abnormalities will help the radiographer and radiology physician extender tailor the examination to achieve optimum results.

**Patient History**

Obtaining a thorough patient history is the most important aspect of any examination performed in radiology, including the upper GI series. Various symptoms, disease processes, and prior surgical procedures might make it necessary to modify the way the examination is performed. Asking the correct questions and asking the same question in different ways will aid in gaining an accurate history. Questions pertinent to the pediatric upper GI series include:

- What symptoms indicated the need for the examination?
- Has the patient had anything to eat or drink?
- When was the last time the patient had anything to eat or drink? (“Nothing by mouth” status.)
- Does the patient have a surgical history?
- Does the patient have any significant medical history?
- Was the patient full term or born prematurely?
  - If premature, how many weeks preterm was the patient?

**Prematurity**

Nearly half a million premature births occur in the United States every year. This is a stunning statistic because it means almost 1 in 9 children are born prematurely. Preterm infants are those born before 38 weeks’ gestation (40 weeks is considered a full-term birth). Special considerations should be made for children who are born prematurely. The earlier a child is born, the more likely severe complications of prematurity will occur. Premature infants are more sensitive to stress than full-term infants, and care should be taken to reduce potential sources of stress when performing procedures on these patients.

Premature infants are extra sensitive to sensory stressors such as loud sounds, light touch, cool or cold temperature, and movement. Premature infants experiencing stress can show a number of signs and symptoms indicating they are unable to tolerate the stressors. Some of the signs and symptoms of neonatal stress include hypotonia, apnea, bradycardia, hiccoughs, spastic movement of the extremities with flaring of the digits, and irritability (see Figure 2).

If these signs and symptoms are observed, an effort should be made to remove potential sources of stress to the neonate.

Some premature infants are too small to maintain an appropriate body temperature; therefore, the radiographer or radiology physician extender should ensure...
the neonatal patient does not experience temperature stress. When a neonatal patient is scheduled to have an upper GI examination, increasing the temperature in the fluoroscopy suite helps to maintain the patient’s body temperature as well as decrease the stress of being moved out of the warm isolette to the cool fluoroscopy suite. Placing warm blankets on the table and on the neonate will also help to maintain the child’s core temperature.

Conversation should be kept to a minimum, and all unnecessary sources of sound, especially loud sounds, should be minimized to decrease the effects of auditory stress on the neonate.

Premature infants are often described as having 2 different ages. Chronological age is based on the patient’s date of birth. Adjusted age, or corrected age, takes into account the patient’s due date. Calculating an adjusted age is important when dealing with premature patients because all of the patient’s developmental milestones, growth, and feeding recommendations are based on the adjusted age, not the chronological age.

To calculate a patient’s adjusted age, start with his or her chronological age. Next, determine how many weeks prematurely the patient was born, and subtract this number from the chronological age. For example, if a child’s chronological age is 16 weeks and the child was born 8 weeks prematurely, then the child’s adjusted age is 8 weeks.

Extra days are not counted when determining a patient’s adjusted age, and weeks are rounded down to the nearest whole week. This means a child born at 29 weeks and 6 days is said to have been born at 29 weeks of gestation.

**Performing the Upper GI Examination**

**Room Preparation**

Fluoroscopy suites should be thoroughly cleaned before bringing patients and their parents or guardians into the room. The fluoroscopy table should be disinfected and new sheets and absorbent pads placed on the table. Placing folded towels at the head and foot of the table can help ease some of the discomfort the parent and technologist experience when leaning on the fluoroscopy table during the course of the examination and while positioning the patient.

**Safety**

A child should never be left unattended while lying or sitting on the fluoroscopy table. Falling from the fluoroscopy table to the floor can have devastating consequences and is easily prevented by strictly enforcing a policy that a parent or staff member always have a hand on a child on the fluoroscopy table. Merely standing near the table and observing the child is not sufficient. One moment of inattention can have long-term, damaging consequences for all parties involved. Staff members are responsible for making parents and guardians aware of this policy.

**“Nothing by Mouth” Status**

Patients must have nothing to eat or drink before the start of the examination to ensure barium is not diluted by the retained gastric contents. There are many opinions about the length of nil per os (NPO), or “nothing by mouth,” status required prior to performing a pediatric upper GI examination. One author recommends omitting the morning feeding for children younger than 1 year of age and nothing to eat or drink after the evening meal for children older than 1 year. The American College of Radiology and the Society for Pediatric Radiology recommend age-based guidelines for the length of time a patient should be kept NPO. Neonates and young infants should have feedings withheld for 2 to 3 hours. Toddlers and young children should have 4 to 6 hours without feeding, and adolescents should be NPO for 6 to 8 hours.

**Patient Preparation**

The child should be dressed in an appropriately sized pediatric hospital gown and a diaper or underwear to prevent soiling the patient’s clothing with barium and to ensure there are no radiopaque objects that might obstruct the anatomy being examined.

Ensuring proper positioning during a pediatric upper GI examination is vital to identify anatomic anomalies, especially malrotation of the intestine. Affixing small radiopaque markers, such as nipple markers or sheathed hypodermic needles, to the child’s sternum and umbilicus will help to ensure true anteroposterior (AP) images are acquired. This is especially important when evaluating the duodenum for the location of the ligament of Treitz.
**Patient and Parent Communication**

Radiographers and radiology physician extenders should have a variety of explanations of the procedure ready depending on the patient’s age. If the patient is an infant, focus the description toward the parent. If the patient is a toddler or young child, use a simpler way of describing the examination. If the patient is an adolescent or teenager, use the same description you would use with a parent. Being honest and forthright about the entire examination is important so the child and the parent know what to expect and do not feel like they have been deceived (see Box).

Take the time to establish a sense of trust with pediatric patients. Speak in a calm and quiet voice, and use age-appropriate descriptions of the study and anatomy. Get down on their level by crouching or sitting on the floor so they do not feel intimidated. Place your eye level even with or below the patient’s eye level to produce a calming effect. Taking an extra 5 or 10 minutes to reassure children before beginning an examination can be significantly beneficial in the end, both in terms of patient compliance and in image quality. Telling pediatric patients what you are going to do instead of asking them if it is “OK” usually results in better patient compliance. If children, especially toddlers, are asked if it is “OK” to do something, invariably the answer will be “No.” Asking for permission instead of informing children about the procedure can lead to increased anxiety and combativeness. One option that might decrease patient anxiety is to allow a child to touch and move the fluoroscopy tower so it seems less intimidating and more fun. In addition, it can be helpful to show the child how the tower moves over the table so it is not a surprise. Asking the child to imagine that the lead curtain hanging from the tower is a fort also might help ease his or her anxiety.

There are times when getting down on the patient’s level and using a calming voice will not work. Some are in the “terrible-twos” stage, after all. Often children between the ages of 8 months and 4 years will not drink the contrast, and no amount of cajoling will change their mind. In these instances, a nasogastric (NG) tube might be necessary for successful completion of the examination. However, children within this age range should be given the chance to drink the contrast because sometimes toddlers will drink all of it without protesting. Serious risks are associated with the placement of an NG tube, such as apnea and cyanosis, so care must be taken to ensure the patient tolerates the NG tube without difficulty.

**Contrast Media**

A contrast agent is any substance used to delineate the internal structures of the body. Three types of contrast material are used during fluoroscopy examinations: barium sulfate, water-soluble iodinated contrast, and air. Air is considered a negative contrast material and is not typically used in a pediatric setting. However, air is often used with adult patients to identify pathologies such as ulcers, esophagitis, gastritis, and GI neoplasia, which are not typical concerns among pediatric patients.

**Barium Sulfate**

Barium sulfate is a radiopaque contrast agent and, by far, is the most commonly used contrast material when studying the GI tract. Barium sulfate is a white crystalline powder with 233.4 as its molecular weight. Barium has an atomic number of 56 and is classified on the periodic table as an alkaline-earth metal. The word *barium* is derived from the Greek word *barys*, meaning heavy. Barium sulfate is an excellent contrast material because of its high density and low volatility.
It is practically insoluble in water but is readily soluble in hot concentrated sulfuric acid.

Barium sulfate contrast material is sold under a number of brand names. Many of these oral mixtures have flavoring added to make them more palatable, and this is especially helpful when administering barium contrast to a pediatric patient. If barium is inadvertently aspirated into the trachea and lungs, it is considered to have fewer potential adverse reactions than watersoluble iodinated contrast.8

Iodinated Contrast

Water-soluble solutions of iodinated contrast material are primarily used when there is a concern for perforation of the GI tract. This type of contrast is thought to be safer in the event of a leak into both the mediastinum and the peritoneal cavities, whereas barium is suspected of causing both mediastinitis and peritonitis if it leaks extraluminally.4 Many types of water-soluble iodinated contrast materials are available but not all are approved for oral administration by the U.S. Food and Drug Administration (FDA). Orally administering a contrast material that does not have FDA approval for oral use can be done at the discretion of the radiologist and is considered an “off-label” use of the medication.

Water-soluble contrast can be divided into hyperosmolar contrast agents (eg, Diatrizoate meglumine and diatrizoate sodium solution USP and lothalamate meglumine), low-osmolar contrast agents (eg, iopamidol and iohexol), and iso-osmolar contrast agents (eg, Iodixanol).20 Hyperosmolar contrast agents typically are not used for the pediatric patient because of the large fluid shifts that can occur with these contrasts. In addition, hyperosmolar contrast agents can be especially harmful in the neonate because they increase the permeability of the bowel wall and can lead to necrotizing enterocolitis and septicemia. Also, large fluid shifts into the bowel can cause electrolyte imbalances and hypotension. One especially concerning adverse effect of hyperosmolar contrast agents is the toxic effect on the lungs if aspirated.4 Diatrizoate meglumine and diatrizoate sodium solution USP, in particular, is extremely toxic to the lungs and can result in severe, life-threatening pulmonary edema if it is aspirated into the lungs. Using an NG or percutaneous gastrostomy tube does not eliminate the risk of reflux and aspiration.21

When dealing with pediatric patients, a low-osmolar contrast medium such as iopamidol is preferred. Low-osmolar contrast agents are not readily absorbed from the GI tract and if aspirated into the lungs can be better tolerated. They have a more neutral taste and are rapidly absorbed from both the lungs and the peritoneum.22

Radiation Protection

Radiation protection is the responsibility of all medical imaging personnel, including the radiographer, radiology physician extender, and the radiologist. All parties must have a thorough understanding of the fluoroscopic equipment and the adjustments necessary to optimize image quality and reduce patient dose.

The Image Gently and Pause and Pulse campaigns have been designed and supported by many of the professional and certifying organizations in the medical imaging community. The premise behind the Image Gently campaign is to use “child-sized” dose settings when performing studies on pediatric patients.19

Traditional nonpulsed fluoroscopy produces images at 25 to 30 frames per second. This type of exposure typically is not necessary when performing a fluoroscopic examination on a pediatric patient. Some of the best methods to lower patient dose when performing fluoroscopic upper GI examinations include the use of pulsed fluoroscopy, including the selection of the lowest pulse rate possible. Using pulsed fluoroscopy can dramatically reduce the exposure to the patient. Pulse rates vary among manufacturers, with some fluoroscopy machines capable of pulse rates as low as 2 pulses per second. This is a potential 15-fold reduction in dose assuming an equivalent fluoroscopy time. Using the largest field size possible (least amount of magnification) and limiting the area of exposure to only the area of interest (tight collimation) helps lower patient exposure. Tight collimation results in a clearer image with better contrast because of the decrease in photon scatter. Using “last image hold,” “screen grab,” or “image capture” instead of taking a full-exposure spot image also has a positive effect on dose reduction. The images obtained with the “screen-grab” or “image capture” function typically have a slightly mottled appearance, but this is usually of little consequence when performing an examination on a pediatric patient (see Figure 3).
Use of a scatter-reducing grid typically is unnecessary and should be avoided when performing fluoroscopy examinations on pediatric patients who weigh less than 40 pounds (see Figure 4). The increase in image quality is marginal, but the increase in patient dose can be significant.

**Patient Positioning**

During a pediatric upper GI examination, radiographers or radiology physician extenders acquire a typical sequence of images that ensure accurate evaluation of the anatomy. Following a routine helps achieve consistent, accurate results. Initially, the patient lies supine on the fluoroscopy table and small radiopaque objects, such as nipple markers, are placed on the patient’s sternum and umbilicus. At least 2 people are required to position a pediatric patient properly for an upper GI examination. The person at the child’s head will have the difficult task of encouraging the child to drink the contrast while simultaneously maintaining proper positioning for AP, posteroanterior, and oblique projections and ensuring the patient’s arms and hands are out of the field of view. The person at the child’s feet might have an easier time positioning the patient if the child is held on or above the knees. This can help ensure better control of the lower body and decrease the patient’s movement, potentially decreasing patient dose. It can be advantageous to have the radiographer at the child’s head during the upper GI examination because he or she is most likely to have more experience in assisting the child in drinking while maintaining proper positioning.

Contrast is first administered while the patient is in the left lateral position, with a focus on the esophagus. Beginning in the left lateral position allows time to examine the esophagus first before contrast exits the stomach, which would result in missing the first pass of contrast through the duodenal C-loop. Next, the esophagus is observed with the patient supine. Enough contrast should be administered during this initial phase of the examination to distend no more than the gastric fundus (see Figure 5). This is important because if the stomach is overfilled, locating the ligament of Treitz will be difficult. Next, the patient is turned to the right lateral position to obtain images of the duodenum. The patient should be positioned in a slight right anterior oblique position to facilitate gastric emptying. Documentation of the duodenal course is required in the lateral and AP positions. The radiographer or radiology physician extender should pay careful attention to the duodenal course during the first transit of contrast. Locating the ligament of Treitz is easiest during this initial fill of the duodenum. If the location of the ligament of Treitz...
cannot be identified confidently during the initial pass of contrast, it can be difficult or impossible to locate it when contrast has passed into the more distal small bowel because the proximal small bowel often appears to loop back upon itself, obscuring the ligament. When the ligament of Treitz is located, the patient should be allowed to drink until the stomach is fully distended.

**Immobilization**

Properly immobilizing the pediatric patient results in better images and a lower radiation dose. The need to immobilize and the techniques involved will vary depending on the age and cognitive development of the patient. Pediatric patients usually are held manually for fluoroscopic procedures because it tends to be less frightening to the patient and achieves better cooperation. Perfecting the techniques required to simultaneously immobilize and feed a pediatric patient can be challenging. Restraint devices can assist with immobilization and range from the simple “brat board” to specialized immobilization devices. A brat board is a small flat board placed underneath a pediatric patient. The patient’s arms are raised above his or her head, and the arms and legs are bound to the board using elastic bandages. Another immobilization device connects to the fluoroscopic footboard, allowing the operator to move the patient into any position easily.

**Disease Processes and Conditions**

A wide variety of disease processes can be discovered during an upper GI examination on a pediatric patient. To perform an examination accurately, “know what to look for and look for what you know.” A thorough understanding of the disease processes typically found in pediatric patients can aid in an accurate diagnosis.

**Aberrant Right Subclavian Artery**

An aberrant right subclavian artery is the most common malformation of the aortic arch. It has an overall incidence of 0.5% to 1.8% of the population. In normal anatomy, the brachiocephalic artery originates from the aortic arch on the right side. The brachiocephalic artery then bifurcates to form the right common carotid artery and the right subclavian artery. An aberrant right subclavian artery is formed when the right subclavian artery arises directly from the aortic arch. In these cases, the right subclavian artery will then swing posterior, between the esophagus and the spine, and continue to the right side of the body.

The radiographic appearance of an aberrant right subclavian artery is that of a posterior obliquely oriented extrinsic compressing defect on the upper thoracic esophagus. The extrinsic compression travels obliquely from inferior to superior and from left to right (see **Figure 6**). An aberrant right subclavian artery usually is an incidental finding on an upper GI series. Rare cases of dysphagia lusoria (difficulty swallowing) have been reported from the compressing effect of the artery on the posterior esophagus.

**Pulmonary Sling**

An aberrant left pulmonary artery, or pulmonary sling, is a left pulmonary artery with an anomalous origin. The artery may originate from either the distal main pulmonary artery or from the right pulmonary artery. From its origin, it travels posterior and then crosses to the left, passing between the trachea and esophagus (see **Figure 7**). Pulmonary sling conditions have a male to female ratio of 3:2, and most cases are symptomatic within
the first year of life. This type of vascular anomaly can affect the patient’s airway, causing respiratory distress. Narrowing of the right main bronchus and distal trachea can be apparent in radiologic images of patients with pulmonary sling conditions. The primary finding during upper GI examination is an anteriorly placed round mass lying between the esophagus and the trachea.

**Vascular Rings**

The embryology of the aortic arch is complex, and many anomalies can result from its abnormal formation. Six aortic arches form during aortic arch development, but not all are present at the same time. Typically, the aorta is formed from one of these arches. The body usually breaks down some remaining arches, and some become arteries. In normal anatomy, a pair of aortic arches descends on either side of midline early in embryonic development. The left-sided arch becomes the dominant arch, and the right-sided arch becomes the right brachiocephalic artery. A vascular ring anomaly occurs when some arches and vessels that should have been broken down or become arteries form a ring of blood vessels encircling the trachea and esophagus.

Vascular ring anomalies are varied. They are primarily diagnosed with echocardiography, angiography, or...
multiplanar computed tomography and magnetic resonance imaging. Radiographers and radiology physician extenders should be able to recognize the imaging characteristics of these anomalies on an upper GI examination. Common features of vascular rings include focal narrowing of the trachea anteriorly and posterior indentation of the esophagus.21

The types of arch anomalies that are important to recognize on an upper GI examination include the double aortic arch and a right-sided aortic arch with a left-sided ductus arteriosus.

The ductus arteriosus is a blood vessel that connects the pulmonary artery to the descending aorta. This vessel is patent in utero and bypasses the fluid-filled lungs to deliver oxygenated blood to the aorta while the lungs are not yet functioning. It usually closes after birth and then becomes the ligamentum arteriosum.29 An aberrant left subclavian artery originating on the left and passing behind the esophagus is another type of arch anomaly (see Figure 8).30 A wide mediastinal shadow and the appearance of 2 arches can be seen on the AP projection of the chest, indicating a double aortic arch.

**Esophageal Atresia and Tracheoesophageal Fistula**

The trachea and esophagus begin as a single tubular structure. Between the fourth and fifth weeks of gestation, the tissue cell structure of the tube differentiates anteriorly to form the trachea and posteriorly to form the esophagus. A septum forms to separate the trachea from the esophagus, and the structures elongate to complete formation.

Some think that EA, TEF, or both will occur when the septum tissue separating the structures forms incorrectly or if the elongation of the trachea and esophagus occurs too rapidly.28 EA and TEF are the most common congenital anomalies of the esophagus.31,32 These conditions can be suspected prenatally with the presence of polyhydramnios (too much amniotic fluid), absence of fluid within the GI tract, and difficulty visualizing the fetal stomach on prenatal ultrasonography.

There are 5 types of EA and TEF. EA with a TEF to the distal esophagus is by far the most common type of EA/TEF, comprising approximately 82% of cases. Isolated EA without TEF occurs in approximately 9% of cases.13 Both of these variants are diagnosed by a combination of physical and radiographic findings and typically are discovered shortly after birth. Physical findings include the inability to feed without coughing or choking and respiratory distress. These symptoms combined with unsuccessful placement of an NG or orogastric feeding tube might indicate EA.22 A radiograph of the chest and abdomen might confirm the presence of EA and the presence or absence of a distal TEF.

An isolated EA can be diagnosed if the NG/orogastric feeding tube is visualized within a proximal esophageal pouch in the upper chest along with the absence of bowel gas within the abdomen. However, a proximally placed NG/orogastric tube with the addition of a gas-distended GI tract is diagnostic for EA with a distal TEF (see Figure 9).32
The isolated TEF, also known as an \textit{H-type} or \textit{N-type} TEF, occurs without the presence of EA and makes up approximately 6\% of EA/TEF cases.\textsuperscript{13} Despite persistent cough with feeding and respiratory infections, isolated TEFs might not be discovered for many years. Isolated TEFs can be difficult to identify on standard esophageal imaging, and special techniques might be needed to make an accurate diagnosis.

Barium contrast should be used if an isolated TEF is suspected because of its high radiopacity and because it does not irritate the lungs like water-soluble iodinated contrast does. Typically, an isolated TEF will orient from a position that is relatively inferior in the esophagus to a position that is relatively superior in the trachea.\textsuperscript{12} Essentially, the fistula travels from the esophagus up to the trachea. This upward orientation causes contrast ingested by mouth to travel past the esophageal opening of the TEF without filling the fistula. As a result, it might be necessary to use a feeding tube to force the contrast to travel in a retrograde direction to increase the likelihood that the barium will cross the fistula (see \textbf{Figure 10}). Another method for delineating an isolated TEF is having the patient drink contrast while lying in a prone position on the footboard of an upright fluoroscopy table. The orientation of the x-ray beam will be horizontal in relation to the floor. In this position, the esophagus lies above the trachea, which might allow the barium to pass from the esophagus through the fistula to the more dependent trachea.

Although it is rare, recurrence of the fistula tract after surgical repair has been reported, and special attention must be paid to avoid missing a potential refistulization of the tract. If there is a high suspicion of TEF recurrence, performing the esophagram with a feeding tube will better distend the esophagus and increase the likelihood of determining whether the fistula has recurred. The feeding tube should be placed so its side holes are at the level of the prior TEF repair and injected with moderately firm pressure so the esophagus is well distended. A barium contrast is appropriate for this type of study because of its increased radiopacity and decreased pulmonary irritation compared to water-soluble contrast media.\textsuperscript{12}

Magnification of the area of interest is helpful when looking for a leak or recurrence of EA or TEF. However, care should be taken to limit the use of magnified fluoroscopy because of the increase in patient exposure.

In addition, there often is a decrease in esophageal motility when any type of EA or TEF is present because the TEF disrupts in utero development of the myenteric plexus, which leads to esophageal dysmotility.\textsuperscript{13} This dysmotility typically is seen in the part of the esophagus that lies distal to the anastomosis (see \textbf{Figure 11}).
Malrotation

Intestinal malrotation is a potentially life-threatening condition resulting from the incomplete rotation of the bowel between the 5th and 12th week of fetal life. Malrotation has an overall incidence of 1 in 500 live births, and approximately 60% of cases present within the first month of life, with an additional 20% of cases presenting before the first birthday. The remaining cases are discovered after the first birthday.\textsuperscript{35,36}

The primary symptom of malrotation is bilious emesis (green vomit).\textsuperscript{35,36} On an AP projection, the duodenum typically appears with its distal end crossing the left row of lumbar spine pedicles and rising as high as the duodenal cap (see Figure 12). A coronal computed tomography image offers excellent visualization of the duodenum, which appears similar to a Nike “swoosh” (see Figure 13). If the duodenum does not rise to the level of the duodenal cap or cross to the left of the left row of lumbar spine pedicles, the diagnosis of malrotation must be considered (see Figure 14). In the lateral projection, the duodenum is typically visualized exiting the stomach and traveling posteriorly into the retroperitoneum. It then turns caudally and doubles back on itself before moving anteriorly and returning to the peritoneal cavity (see Figure 15).

When the intestine has rotated normally, the mesentery, a fan-shaped peritoneal fold attached to the posterior body wall and enclosing the viscera, is broad and covers the width of the abdomen, stretching from the ligament of Treitz in the left upper quadrant to the cecum in the right lower quadrant. When a malrotation is present, the mesentery is narrow, and its short
**Figure 12.** Normal-appearing duodenal course. The ligament of Treitz (arrow) lies to the left of the spine and rises at least as high as the duodenal cap. Radiopaque markers (arrowheads) placed on the sternum and umbilicus are superimposed over the spine to ensure a true AP projection of the duodenum without rotation. Image courtesy of Rocky Mountain Hospital for Children at Presbyterian St Luke’s Medical Center, Denver, CO.

**Figure 13.** A coronal CT image of the abdomen. Excellent visualization of the duodenum with a normal position of the ligament of Treitz (arrow). Note the Nike “swoosh” appearance of the duodenum (arrowheads). Image courtesy of Rocky Mountain Hospital for Children at Presbyterian St Luke’s Medical Center, Denver, CO.

**Figure 14.** This fluoroscopic series of images demonstrates malrotation of the intestine. The duodenum does not cross to the left of the spine and does not rise as high as the duodenal cap. The NG tube was advanced into the duodenum to allow for a more controlled examination. Images courtesy of Rocky Mountain Hospital for Children at Presbyterian St Luke’s Medical Center, Denver, CO.
Midgut volvulus is a serious and potentially life-threatening complication of intestinal malrotation and is considered a surgical emergency. Bilious emesis is the primary indication of midgut volvulus. When a midgut volvulus occurs, the duodenum and proximal jejunum twist around the SMA in a corkscrew fashion, restricting blood flow through the artery. This restriction of blood flow to the intestines could result in ischemia or bowel necrosis. If a midgut volvulus is not recognized and necrosis of all of the intestine occurs, it is generally considered a nonsurvivable injury.

Malrotation is expected in patients born with gastroschisis, omphalocele, congenital diaphragmatic hernia, and heterotaxy. In these instances a thorough patient history will save time in diagnosing a disease process that is considered normal with the given history.

Gastroschisis and omphalocele are conditions in which the intestines do not return to the abdominal cavity as would be expected in the first trimester of pregnancy. Gastroschisis occurs when the intestines herniate into the amniotic cavity through an abdominal wall defect. With gastroschisis, the intestines are exposed to the amniotic fluid. Omphalocele results in the herniation of abdominal contents into the umbilical cord. With omphalocele, the intestine is covered in a saclike membrane and is not exposed to the amniotic fluid. Both conditions have an incidence of 1 in 4000 births. In gastroschisis and omphalocele, the bowel does not have the opportunity to complete its normal embryologic rotation, so malrotation will be present.

Congenital diaphragmatic hernias are divided into 2 categories: intrapleural hernias, also called posterolateral Bochdalek hernias, and anterior hernias, also called Morgagni hernias. A Bochdalek hernia occurs either when the pleuroperitoneal folds do not develop correctly or when the diaphragm muscle fails to migrate in its normal pattern. In approximately 85% of cases, Bochdalek hernias are left sided in their location. Right-sided and bilateral Bochdalek hernias account for the remaining 15%. When a Bochdalek hernia is present on the left, the abdominal organs located on that side may herniate into the thoracic cavity. These organs include the stomach, small bowel, spleen, and left kidney. Right-sided Bochdalek hernias may contain the liver and some of the colon. Bilateral Bochdalek hernias are the most severe form of this disease process and usually are fatal. Morgagni hernias occur anteriorly and most commonly on the right, just adjacent to the xyphoid process. Morgagni hernias are rare, accounting for approximately 2% of congenital diaphragmatic hernias. Malrotation is commonly seen in patients who have a history of Bochdalek-type congenital diaphragmatic hernia because the intestines, upon returning to the abdominal cavity in utero, pass through the defect in the diaphragm and into the thoracic cavity and therefore do not undergo the last phase of bowel rotation.

Heterotaxy, or situs ambiguous, implies a disordered organ arrangement within the chest or abdomen as opposed to the normal, organized arrangement (situs solitus) and the reversed arrangement (situs inversus). Heterotaxy is a complex anomaly and usually can be divided into 2 categories: polysplenia and asplenia. Polysplenia is sometimes called double left-sidedness or left isomerism, and asplenia can be referred to as double right-sidedness or right isomerism. These variations in anatomy are very complex, and radiographers and radiology physician extenders should remember that...
patients with a history of heterotaxy will have malrotation of the intestine.

If malrotation is suspected or incidentally diagnosed on an outpatient who does not have a previous history of a Ladd procedure to repair a malrotation, or if the patient has one of the 4 predisposing conditions for malrotation described above, the radiologist or the radiology physician extender should take great care to explain the significance of malrotation to the parent or guardian. It is critical that the symptoms of acute midgut volvulus are explained to parents or guardians before they leave the facility. In addition, they should understand the consequences of failing to act on the symptoms of midgut volvulus. The patient’s family should be instructed to report to the emergency department if the child has an episode of bilious vomiting and to inform the emergency physician that the child has a malrotation and bilious emesis. Failing to provide these instructions can have dire consequences for the child and expose the practitioner to potential legal risk if a volvulus occurs and the parents are uninformed.

**Surgical Repair of Malrotation**

The method of surgical repair for a malrotation is called a *Ladd procedure*. It is named after Dr. William Edward Ladd (1880-1967), a pioneer in the field of pediatric surgery. In the normal orientation of the bowel, the cecum is attached to the posterior abdominal wall in the right lower quadrant with peritoneal bands. When the bowel is malrotated, the cecum might be malpositioned high in the midabdomen. Although this finding is not diagnostic of malrotation, it is seen in approximately 80% of malrotation patients. The cecum also might be malfixed with the peritoneal bands attaching the cecum to the right upper abdominal wall in a way that compresses the duodenum lying underneath. The peritoneal bands that incorrectly fix the intestine to the abdominal wall are referred to as *Ladd bands* (see Figure 16).

Laparoscopic Ladd procedure is the surgical method of choice for repair of malrotation. During the Ladd procedure, a camera and 2 or 3 working ports are inserted into the abdomen, and the intestine is inspected for volvulus and the presence of Ladd bands. If Ladd bands are present, the surgeon carefully divides the bands to free the bowel and lengthen the mesentery. The small bowel is placed in the right abdomen, and the colon is placed in the left abdomen. At the same time, an appendectomy is performed to prevent potential misdiagnosis of appendicitis in the future. A misdiagnosis of appendicitis is possible because of the abnormal position of the cecum on the left side of the abdomen. When a person is born with a malrotation, the duodenal C-loop and cecal position always appear abnormal, even after having a Ladd procedure. Therefore, obtaining an accurate surgical history from the patient or the patient’s parents or guardian before starting the upper GI examination is important. Knowing the patient’s history of a prior Ladd procedure before beginning the examination will eliminate a discussion about the need for a surgery that has already occurred.

**Hypertrophic Pyloric Stenosis**

Hypertrophic pyloric stenosis, also called *pyloric stenosis*, is a condition in which the muscle of the
pyloric sphincter enlarges, or hypertrophies, to such a degree that gastric emptying is inhibited. Pyloric stenosis is a fairly common condition affecting 2 to 5 out of 1000 births in white populations and slightly fewer in black and Asian populations. Boys are approximately 4 times more likely than girls to develop pyloric stenosis, and the incidence is higher still in first-born males. Pyloric stenosis typically develops between the 3rd and 12th week after birth, with the average occurring in the 4th week. However, there have been cases reported as early as 1 week and as late as 16 weeks. There also is a well-documented familial prevalence of pyloric stenosis, with many generations from the same family being affected.

The symptoms of hypertrophic pyloric stenosis include nonbilious, forceful (projectile) vomiting and an inability to eat without vomiting. Severe dehydration and malnutrition can result. One sign of hypertrophic pyloric stenosis on physical examination is the small, firm, olive-shaped mass of the thickened pylorus palpable in the right upper quadrant of the abdomen. An experienced pediatric surgeon might be able to diagnose hypertrophic pyloric stenosis without imaging by discovering this mass on physical examination. Palpating the mass requires that the child is calm and does not tighten the abdominal musculature during examination.

In the past, contrast upper GI examination of the pylorus was used to diagnose hypertrophic pyloric stenosis, but this method is no longer used. Ultrasonographic examinations yield far more information and in better detail than a contrast upper GI series. With ultrasonography, images and measurements of the pyloric muscle can be obtained to confidently diagnose hypertrophic pyloric stenosis. A pylorus muscle thicker than 3 mm, a pyloric diameter of greater than 10 mm, and a pyloric canal longer than 15 mm indicate pyloric stenosis. Pyloric stenosis can be suspected on prenatal ultrasound imaging if there is an increase in the amount of amniotic fluid (polyhydramnios) and the stomach appears overdistended.

Arriving at a pyloric stenosis diagnosis using fluoroscopic imaging of the upper GI tract is more difficult. On contrast upper GI, hypertrophic pyloric stenosis will appear as the classic “railroad track” sign. This sign is described as an elongated and narrow pyloric canal with 2 thin “tracks” of barium visible along its length. The railroad track sign along with shouldering of the gastric antrum and the first portion of the duodenum, and hyperperistalsis in the stomach are all classic upper GI series findings for pyloric stenosis (see Figure 17).

Hypertrophic pyloric stenosis is repaired surgically, usually laparoscopically. The surgical correction of pyloric stenosis is called a pyloromyotomy. A pyloromyotomy is the longitudinal splitting of the pylorus muscle from the gastric margin to the duodenal margin and down to the level of the submucosa (see Figure 18). Splitting the pylorus decompresses the pyloric canal and relieves gastric outlet obstruction.

**Duodenal Atresia**

Duodenal atresia is a condition in which the stomach and proximal duodenum are not in continuity with the distal duodenum and small intestine; the

![Figure 17. Fluoroscopic upper GI appearances of hypertrophic pyloric stenosis. Note the classic “railroad track” appearance of the pyloric canal (black arrow). Shouldering of the duodenal cap (white arrow) and gastric antrum (blue arrow) are visible along with a prominent peristaltic wave in the distal stomach (arrowheads). Image courtesy of Rocky Mountain Hospital for Children at Presbyterian St Luke’s Medical Center, Denver, CO.](image)
passage is abnormally closed or absent. Duodenal atresia is typically found in the second portion of the duodenum (see Figure 19). After birth, patients with duodenal atresia will present with symptoms of bowel obstruction or gastric outlet obstruction. Duodenal atresia can occur either proximal or distal to the ampulla of Vater, and therefore, vomiting can be either bilious or nonbilious. A significant percentage of patients with duodenal atresia also have trisomy 21, or Down syndrome. 

The classic radiographic appearance of duodenal atresia on a kidneys, ureters, bladder projection (KUB) is a distended stomach and proximal duodenum separated by the pylorus. This presentation gives the appearance of a “double bubble” in the upper abdomen. If an NG or orogastric tube already has been placed to decompress the stomach, it might be difficult or impossible to see the double bubble sign. In these instances, injecting a moderate amount of air through the gastric tube helps delineate the stomach and duodenum and make the diagnosis of duodenal atresia easier.

**Duodenal Web**

A duodenal web, or intraluminal diverticulum, is a thin, intraluminal membrane of tissue usually located in the second portion of the duodenum, which can slow or obstruct the flow of stomach contents to the small intestine. A web might completely obstruct the duodenum, or it might have a fenestration that allows food and liquid to pass without much delay. In the latter scenario, a duodenal web might not be discovered for years. Many patients diagnosed with a duodenal web have trisomy 21 as well.
Gastroesophageal Reflux

Gastroesophageal reflux is a condition in which the stomach contents (food or liquid) leak backward from the stomach, through the lower esophageal sphincter, and into the esophagus. Gastroesophageal reflux is the most common abnormality found on pediatric upper GI examinations. The reflux might not be symptomatic, but when reflux begins to cause symptoms or damage the esophagus, it can be classified as gastroesophageal reflux disease (GERD). Reflux can be placed into one of 2 categories: physiologic or pathologic. Physiologic means “appropriate or normally functioning.” Physiologic reflux occurs in most individuals about once every hour, although they may not experience any of the symptoms typically associated with gastroesophageal reflux. Pathologic gastroesophageal reflux occurs when the gastric contents begin to cause symptoms that damage the esophagus or disrupt the patient’s life. Children who begin to refuse feedings may be experiencing pathological symptoms. If the reflux is severe enough, some children will begin to associate eating with the pain of reflux and begin to refuse food. This can lead to malnutrition and failure to thrive.

Failure to Thrive

Failure to thrive in childhood is a state of undernutrition due to inadequate caloric intake, inadequate caloric absorption, or excessive caloric expenditure. In the United States, it is seen in 5% to 10% of children in primary care settings. Failure to thrive describes a child whose weight or weight gain is much lower than children of a similar age. A child with failure to thrive has a weight that is lower than the third percentile or 20% below the ideal body weight for his or her height.

Reasons for failure to thrive include food allergies, malrotation, pyloric stenosis, malabsorption, heart disease, difficulty with breast feeding, gastroesophageal reflux, or improperly mixed formula.

Asthma

Asthma is a disease that causes dyspnea (shortness of breath) and wheezing. Symptoms are caused by swelling and narrowing of the airway, causing a reduction in the flow of air in and out of the lungs. A strong association exists between asthma and GERD, and there is much debate about whether asthma is a sequela of GERD or vice versa. Asthmatic patients do have GERD more commonly than the general population. It has been standard practice to attempt to control asthma symptoms and limit exacerbations by prescribing acid-reducing medications or proton pump inhibitors, even in patients who have “silent” or physiologic reflux. Recent studies have called the efficacy of this practice into question, and this method of treatment could be abandoned soon.

Treatment of Gastroesophageal Reflux

A spectrum of treatment options is available for treating gastroesophageal reflux. These options range from watchful waiting and oral medications such as H2 agonists and proton pump inhibitors to surgical plication (folding) of the gastroesophageal junction. Reflux for most infants ceases by the end of the first year. However, children whose reflux does not end or children who suffer the sequela of severe reflux might be treated with additional methods of reflux management.

The Nissen fundoplication is the most commonly performed surgical treatment for GERD. This surgery can be performed via an open approach, laparoscopic approach, or through an incisionless endoscopic approach. The laparoscopic approach is by far the most common method for performing this procedure. During this surgery, the fundus of the stomach is pulled posteriorly around the lower esophageal sphincter to form a 360° wrap. The fundus is then sutured back onto the superior portion of the stomach. The extra pressure from this wrap prevents gastric contents from refluxing up the esophagus.

The postoperative radiographic appearance of a Nissen fundoplication can vary both in terms of its length and apparent diameter. When a Nissen fundoplication has been performed, a somewhat irregular-appearing filling defect at the cardia of the stomach is typical. This filling defect can be described in terms of appearing as if a bite has been taken out of the stomach. If a surgeon wraps the Nissen too tightly or the wrap is too long, food and liquid might have difficulty traversing the wrap, and the esophagus might appear...
obstructed. Food and liquid can collect within the distal esophagus, and vomiting might result.

**Conclusion**

Pediatric upper GI examinations are common procedures performed in radiology departments every day. Upper GI examinations are indicated for a variety of conditions and disease processes, the most common indication being symptoms related to gastroesophageal reflux. Gastroesophageal reflux is the most commonly diagnosed condition on pediatric upper GI studies, and many children will outgrow this condition by their first birthday. The most important diagnosis is that of intestinal malrotation. Malrotation, if undiagnosed, has the greatest potential for a negative patient outcome. Understanding the formation and anatomy of the GI tract, the abnormalities and conditions that can occur, and the importance of taking a thorough patient history will help radiographers and radiology physician extenders produce better studies with a lower radiation dose.

Mike Odgren, BS, RPA, R.T.(R)(CT), is a radiology practitioner assistant for Diversified Radiology of Colorado in Lakewood. He has been a radiology practitioner assistant for 9 years and a registered radiologic technologist for almost 17 years. He also is the vice speaker of the House of Delegates for the American Society of Radiologic Technologists and serves on the ASRT Board of Directors.

Reprint requests may be mailed to the American Society of Radiologic Technologists, Communications Department, at 15000 Central Ave SE, Albuquerque, NM 87123-3909, or e-mailed to communications@asrt.org.

© 2014 American Society of Radiologic Technologists

**References**


Pediatric Upper Gastrointestinal Studies

1. An upper gastrointestinal (GI) series is a fluoroscopic and radiographic examination of the esophagus, stomach, and:
   a. ileum.
   b. colon.
   c. duodenum.
   d. jejunum.

2. The region where the fourth portion of the duodenum meets the jejunum is called the:
   a. hepatic flexure.
   b. pylorus.
   c. splenic flexure.
   d. duodenojejunal flexure.

3. During normal embryonic development, almost the entire intestine rotates ______ ° counterclockwise around the superior mesenteric artery.
   a. 180
   b. 270
   c. 360
   d. 540

4. Preterm infants are those born before ______ weeks’ gestation.
   a. 36
   b. 37
   c. 38
   d. 39

5. When dealing with premature patients, all of the patient’s developmental milestones, growth, and feeding recommendations are based on the:
   a. conception date.
   b. ovulation date.
   c. chronological age.
   d. adjusted age.

6. Before the start of a pediatric upper GI examination, neonates and infants should be kept on nil per os, or “nothing by mouth,” status for ______ hours.
   a. 2 to 3
   b. 4 to 6
   c. 6 to 8
   d. 8 to 10

continued on next page
7. Techniques for speaking to children include:
   1. speaking eye-to-eye.
   2. using a calm and quiet voice.
   3. using age-appropriate language.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

8. Which type of contrast agent is used most often when studying the GI tract?
   a. water-soluble iodinated
   b. air
   c. barium sulfate
   d. gadolinium

9. ________ contrast media is primarily used when there is a concern for possible perforation of the GI tract.
   a. Water-soluble iodinated
   b. Air
   c. Barium sulfate
   d. Gadolinium

10. Hyperosmolar contrast agents can cause which effects in the neonatal patient?
    1. necrotizing enterocolitis
    2. constipation
    3. electrolyte imbalance

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

11. Traditional nonpulsed fluoroscopy produces images at a rate of ________ frames per second.
    a. 10 to 15
    b. 15 to 20
    c. 20 to 25
    d. 25 to 30

12. Which of the following methods are used to reduce patient dose?
    1. low pulse rate
    2. large field size
    3. tight collimation to decrease the exposure area

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

13. The use of a scatter-reducing grid significantly increases the image quality on pediatric patients.
    a. true
    b. false

14. When performing a pediatric upper GI examination, which part of the anatomy of the upper GI tract is evaluated first?
    a. stomach
    b. duodenum
    c. esophagus
    d. jejunum

15. Which of the following is the most common malformation of the aortic arch?
    a. aberrant right subclavian artery
    b. right-sided aortic arch
    c. double aortic arch
    d. coarctation of the aortic arch

16. The most common variant of esophageal atresia (EA)/trachoesophageal fistula (TEF) is:
    a. EA with proximal fistula.
    b. isolated TEF.
    c. EA without fistula.
    d. EA with distal TEF.
17. Which is the primary symptom of intestinal malrotation?
   a. bilious vomiting
   b. constipation
   c. abdominal distention
   d. diarrhea

18. When a midgut volvulus occurs, the duodenum and proximal jejunum twist around the ________, restricting blood flow.
   a. celiac axis
   b. inferior mesenteric artery
   c. superior mesenteric artery
   d. esophageal atresia

19. Malrotation of the intestine is expected when a pediatric patient has a history of:
   1. omphalocele.
   2. gastroschisis.
   3. heterotaxy.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

20. What is the surgical procedure used to repair malrotation?
   a. Hirschsprung method
   b. Ladd procedure
   c. Nissen method
   d. Lister correction

21. A small, firm, olive-shaped mass palpable in the right upper quadrant of the abdomen indicates which of the following conditions?
   a. Pierre Robin syndrome
   b. hypertrophic pyloric stenosis
   c. gastroesophageal reflux disease (GERD)
   d. vascular rings

22. The visualization of a “double bubble” in the upper abdomen on a kidneys, ureters, bladder projection indicates:
   a. duodenal atresia.
   b. meconium plugs.
   c. ileal atresia.
   d. imperforate anus.

23. Which type of reflux occurs in most individuals about once every hour?
   a. pathologic
   b. functioning
   c. symptomatic
   d. physiologic

24. There is a strong association between asthma and GERD.
   a. true
   b. false

25. _______ is the surgery in which the stomach is wrapped around the esophagus in order to control GERD.
   a. Schatzki procedure
   b. Hiatal plication
   c. Nissen fundoplication
   d. Ladd procedure