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A review of commonly performed bariatric surgeries: Imaging features and its complications

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ABSTRACT

Obesity is a disease that has achieved the level that can be considered an epidemic. According to the National Center for Health Statistics data, the prevalence of obesity has increased from 30.5% in 1999–2000 to 42.4% in 2017–2018. During the same period, severe obesity has increased from 4.7% to 9.2%. With the growing prevalence of obesity, related conditions such as coronary artery disease, diabetes, and strokes have also become more prevalent.

In the past few years, the need for bariatric surgeries such as laparoscopic Roux-en-Y gastric bypass, sleeve gastrectomy, and laparoscopic adjustable gastric banding has increased considerably. With an increasing number of bariatric surgeries, multiple postoperative complications have become common. In this review, we have attempted to describe normal postsurgical anatomical findings after bariatric surgeries and pictorial review of a few common postoperative complications.

1. Background and epidemiology

Obesity is a pandemic healthcare crisis around the world and affects approximately 13% of the adult population. Obesity is measured by body mass index (BMI). The BMI of 25–29 kg/m2 is categorized as overweight and obesity is defined as BMI >30 kg/m2. The prevalence of obesity has tripled worldwide between 1975 in 2016 [1]. The prevalence of obesity in the adult population in the United States is 42.4%, according to the National Health and Nutrition Examination Survey (NHNES) 2017–2018. In obese population, the prevalence is highest among Non-Hispanics (49.6%) and Hispanic-Blacks (44.8%) [2]. Based on 2008 estimates, the healthcare cost due to obesity was $147 billion [3]. On average, patients with obesity spend 42% more for their healthcare compared to patients with normal body weight [4]. According to 2013 estimates, the total medical cost of obesity in the adult population, which is 18 years or older in the United States was $ 342.3 billion [5]. American Society for Metabolic and Bariatric surgeries estimate that 24 million people in the United States have severe obesity (BMI > 40 kg/m2). Therefore, the number of bariatric surgeries performed might significantly increase overtime [6].

Obesity is associated with multiple medical disorders that are some of the leading causes of preventable, premature death. These include heart disease, stroke, type 2 diabetes, hypertension, obstructive sleep apnea and cancers (like breast, endometrium, gallbladder, colorectal, esophagus and pancreas). This has led to an increasing number of bariatric surgeries performed worldwide. In 2017 more than 228,000 bariatric surgeries were performed in the United States. The National Institute of Clinical Excellence and American national Institute of health guidelines recommend bariatric surgeries for patients with BMI > 40 kg/m2 or with morbid obesity (BMI 35–40 kg/m2) with obesity-related medical conditions such as diabetes.

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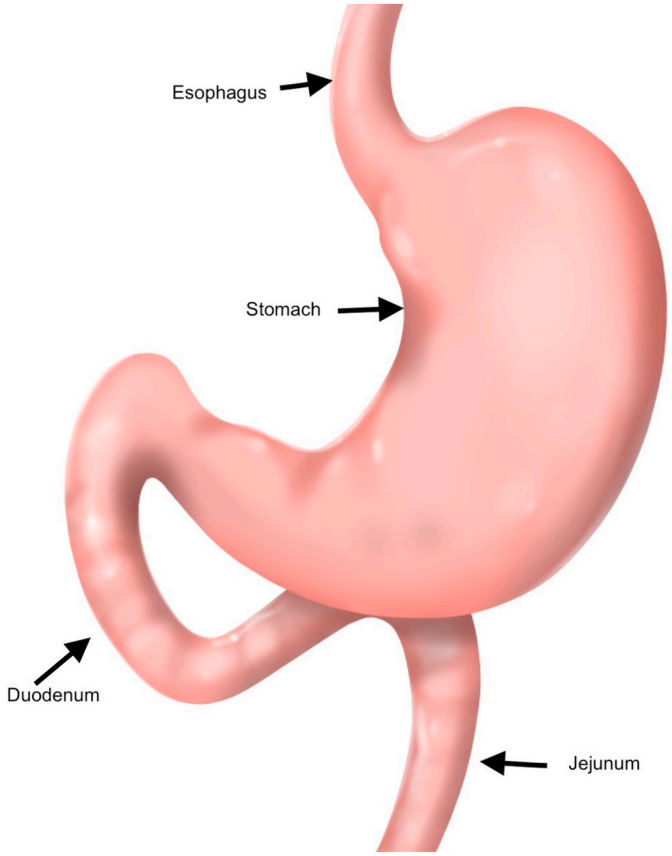

Fig. 1. Schematic diagram of normal appearance of upper gastrointestinal tract upto proximal jejunum.

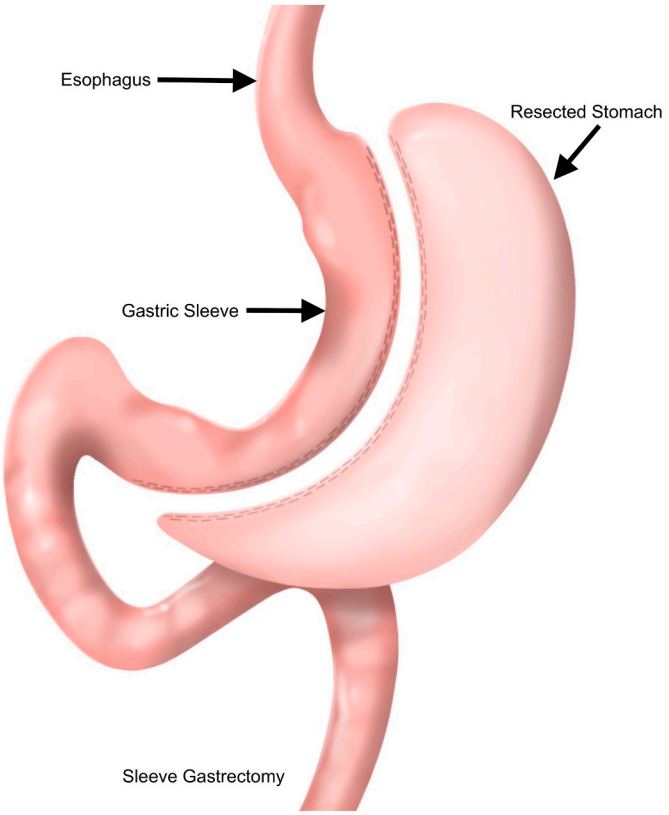

Fig. 2. Schematic diagram of normal postoperative appearance of sleeve gastrectomy surgery.

1.1. Commonly performed bariatric surgeries

Bariatric surgeries have been performed since the 1950s, and the very first bariatric surgery was performed by Dr. Kremen in 1954 [7], which was a jejunoileal bypass. There are three most commonly performed bariatric surgeries for the treatment of obesity. Moreover, the invention of laparoscopy and robotics in surgery have improved the outcomes.

1. Laparoscopic/ Robotic sleeve gastrectomy
2. Laparoscopic/ Robotic Roux-en-Y gastric bypass
3. Laparoscopic/ Robotic Gastric banding

Biliopancreatic diversion with duodenal switch is another less common bariatric procedure being performed. Recently gastric balloons have been placed in the gastric lumen to induce the restrictive effect to induce early satiety and weight loss. Bariatric embolization of gastric arteries, a minimally invasive intervention, has also been recently introduce and is currently being investigated [8]. In this article, we are limiting our discussions to the more commonly performed bariatric surgeries only.

1.2. Challenges in imaging bariatric patients

Performing a quality imaging study in bariatric patients is challenging due to the inherent limitations of physics in CT imaging and patients' body habitus. Many patients are morbidly obese and do not fit in the scanners. Performing fluoroscopy assisted examination and procedures is also difficult to perform, since many patients do not fit in the fluoroscopy unit easily. Another significant challenge is a limitation in the manipulation of patients during exams to obtain a non-frontal view since patients cannot be turned either because the patient is too weak or too large, and many patients can only be imaged in the supine position. Most scanners have weight/load limits which are major hurdles among bariatric patients [9]. There are several technical challenges in imaging as well as image guided interventions in obese patients [10]. These Several scanners have a load limit of 500 lbs308 kg (680lbs), gantry aperture of 80–85 cm, and 65 cm scan field of view. However, scanners with higher limits are available. Various techniques are used to improve imaging quality in bariatric imaging. Iterative reconstruction is a technique commonly used to improve the image quality by using precise statistical modeling to correct the quantum fluctuations [10]. This method is more efficient in noise removal when compared to backdrop projection methods.

2. Laparoscopic sleeve gastrectomy

Laparoscopic gastric sleeve surgery is the most commonly performed bariatric surgery in the United States in 2017. Of the 228,000 bariatric surgeries performed, 59.39% were gastric sleeve surgeries [11]. Gastric sleeve surgery was first introduced in 1999. It is the most commonly performed surgery in the United States due to its fewer complications to gastric bypass and gastric banding. It is less invasive compared to the laparoscopic Roux-en-Y gastric bypass surgery. The surgery is permanent and irreversible [12].

2.1. Surgical procedure

The procedure involves laparoscopic resection of more than 75% of the greater curvature of the stomach (fundus, body, and proximal antrum), creating a smaller narrow tubular structure with a residual volume of 100 ml. Smaller volume induces early satiety and weight loss. Fig. 1 shows schematic diagram of normal appearance of the upper gastrointestinal tract and Fig. 2 shows schematic diagram of sleeve

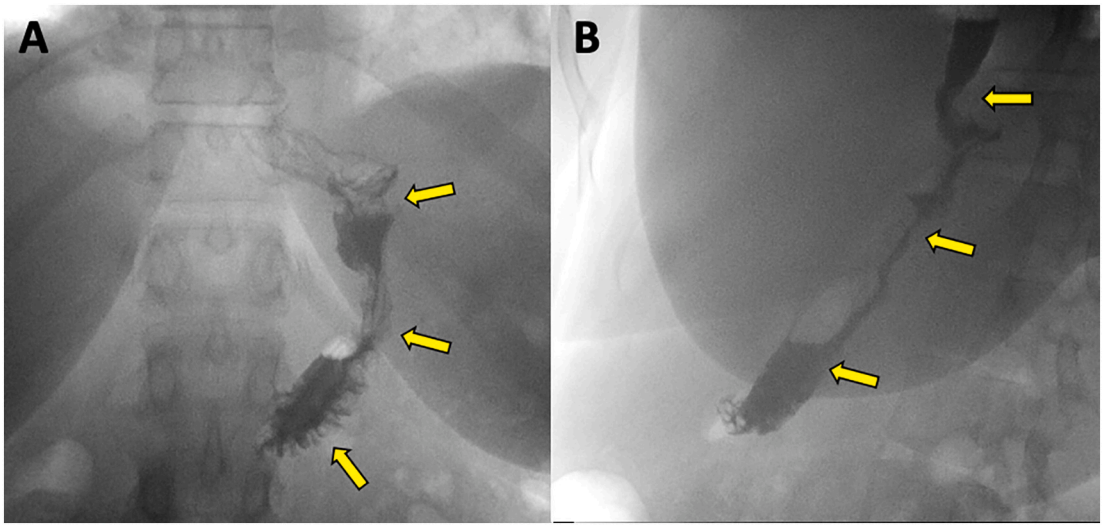

Fig. 3. Normal postoperative gastric sleeve surgery. Frontal AP image of Upper GI water soluble contrast study (A) showing the postoperative gastric sleeve surgery with free flow of contrast in narrow tubular gastric pouch with a slightly larger distal end due to preserved antrum (yellow arrows). Left anterior oblique image of upper GI water soluble contrast study (B) showing tubular gastric pouch (yellow arrows). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

gastrectomy. There has been a debate about the preservation of antrum during gastric sleeve surgery on gastric emptying and expected weight loss after surgery. In a randomized clinical trial, 25 patients underwent sleeve gastrectomy and were followed for one year about the effect of preservation of the antrum on gastric emptying and expected weight loss. The study found that there was a significantly accelerated gastric emptying at two months and a one year follow up in patients who had antrum preservation when compared to patients who had antrum resection. However, there was no significant difference in expected weight loss between the two [13].

Further mechanisms have been described that influences weight loss after sleeve gastrectomy. These include neurohormonal changes like decreased concentrations of ghrelin which is the hunger stimulating hormone and is mainly produced by the cells of the gastric fundus and is removed during sleeve gastrectomy procedure. Serum concentrations of Leptin is also decreased after sleeve gastrectomy, which very closely corresponds to the total body fat serum concentration. Another less common weight loss procedure is combination of sleeve gastrectomy and biliopancreatic division with duodenal switch (BPD/DS) where in addition to sleeve gastrectomy the lower portion of the intestine is connected near the stomach bypassing the proximal two third of the small intestine and the bypassed duodenum attaches to the distal small intestine, the ileum. A BPD/DS is generally recommended in people with BMI greater than 50 and its very effective, however can develop more complications like vitamin deficiencies and malnutrition.

2.2. *Normal postoperative anatomy*

Barium imaging of the upper gastrointestinal tract usually reveals a narrow tubular gastric pouch, often with a slightly larger distal end due to preserved antrum (Fig. 3). Retention of barium contrast in the fundus may be observed in the early post-operative period due to the absence of peristalsis and edema from recent surgery.

Computed tomography (CT) of the abdomen usually reveals a

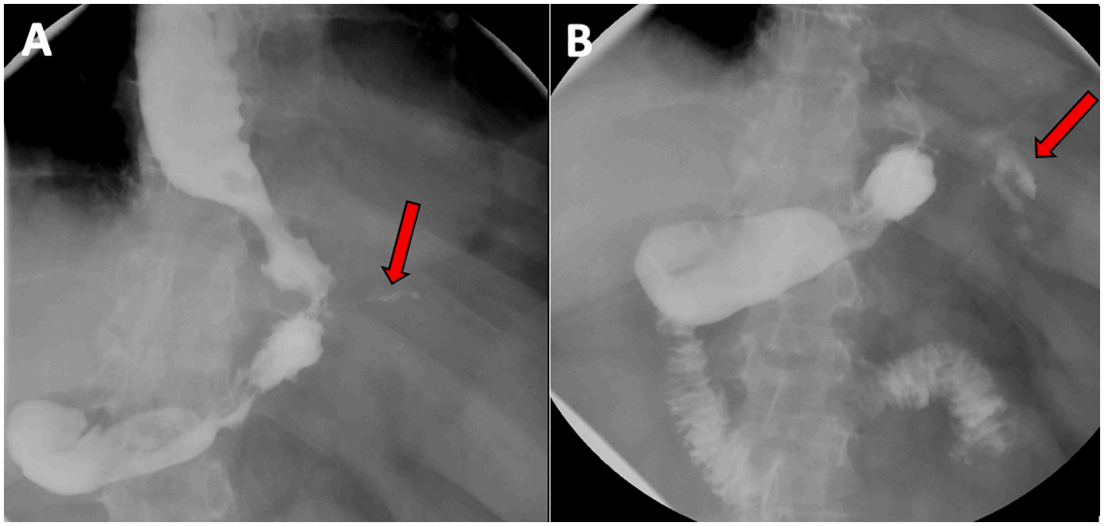

Fig. 4. Contrast leak status post gastric sleeve surgery. A 53-year-old male status post gastric sleeve surgery, frontal AP images of upper GI water soluble contrast study (A and B) shows extraluminal contrast extending from the proximal suture line due to a leak (red arrow). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

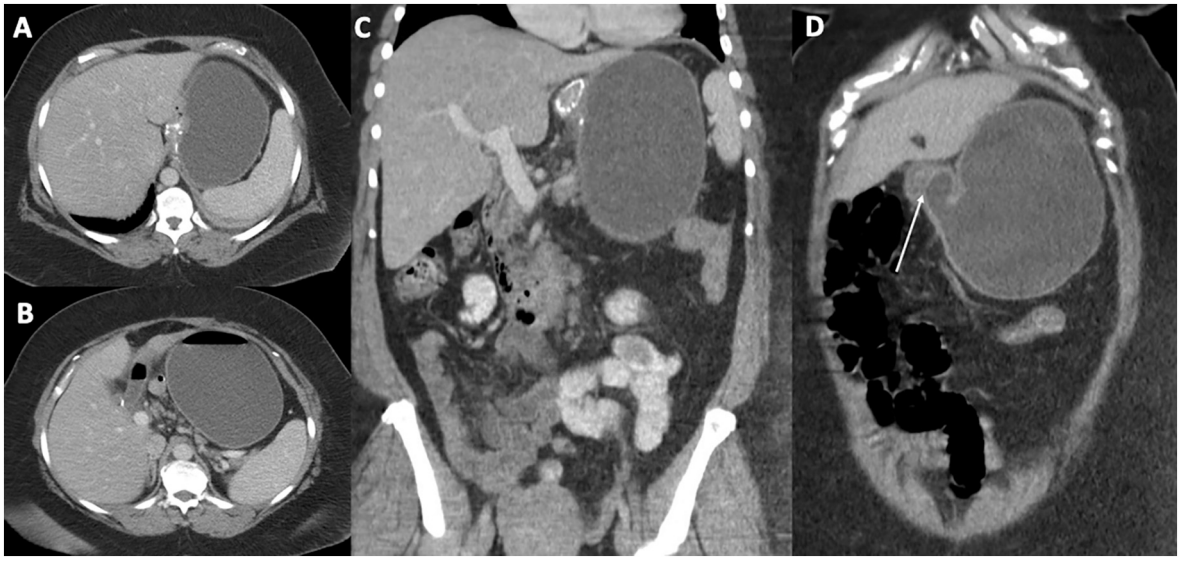

Fig. 5. Gastric outlet obstruction status post gastric sleeve surgery. A 44-year-old female status post Sleeve Gastrectomy Axial Contrast enhanced CT (A and B) shows a dilated fluid filled gastric remnant with loss of tubular configuration and non-dilated duodenum. The suture lines are visible near gastroesophageal, pushed up due to over-distended stomach. Coronal Contrast enhanced CT images (C and D) shows dilated fluid filled gastric remnant with non-dilated duodenum and mild thickening of the pylorus (solid white arrow) suggesting gastric outlet obstruction. Possibility of stricture formation was raised. Patient underwent endoscopy and stricture dilatation was performed.

narrow tubular gastric pouch with the staple line along the greater curvature of the stomach.

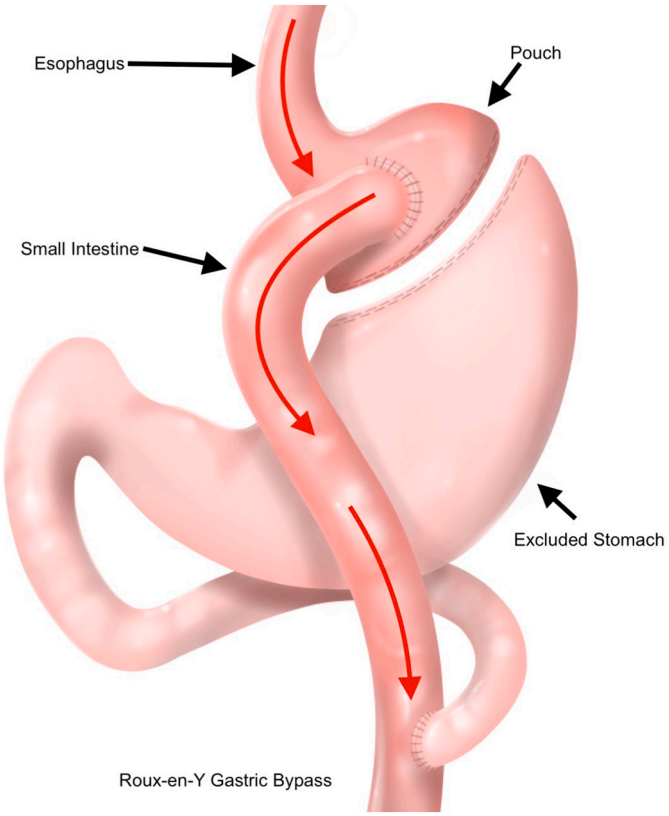

Fig. 6. Schematic diagram of normal postoperative appearance of Roux-en-Y Gastric bypass surgery.

2.3. Complications of gastric sleeve surgery

2.3.1. Gastric leak

Common immediate post-operative complications include gastric leak and hemorrhage. Gastric leak has been reported to occur in up to 2.4% patients by a large systemic review and is one of the most dreaded complication [14]. Leaks may be early or delayed and result from increased pressure inside the gastric tube, vascular supply compromise or presence of stenosis of the gastric tube beneath the leak, either functional or anatomic [15]. Gastric leaks are usually seen in the proximal end of the sleeve (Fig. 4). Patients with gastric leaks usually present with fever, abdominal pain, and elevated white cell count. It can be usually visualized on water-based contrast leak on fluoroscopic upper GI series. Collection of contrast material outside the lumen, fluid tracking into peritoneal cavity, and left upper quadrant fluid collections can be observed. When leakage is absent, barium may be used to rule out microperforations and leakages [16]. Many of these patients do not need drainage or surgery if the leak is small but it may require drainage or surgical repair if large. They may also require temporary parenteral nutrition.

2.3.2. Gastric stricture and gastric outlet obstruction

Delayed complications of sleeve gastrectomy include strictures and gastric outlet obstruction. A focal stricture formation can cause features of gastric outlet obstruction, which can be visualized on barium studies as well as on CT scan (Fig. 5). These patients may present with abdominal pain, regurgitation, vomiting and feeling of fullness in the upper abdomen. This could be managed with endoscopic dilation and stenting usually done at tertiary care centers. A rare complication of gastric sleeve surgery is gastric volvulus, usually suspected when patients present with symptoms of bowel obstruction [17]. After sleeve gastrectomy, the entire greater curvature is free and has no fixation. This predisposes to gastric volvulus, a life-threatening complication since the strangulated stomach is at risk of ischemia and infarction. Barium study may show a twisted stomach causing the body of the stomach to be displaced upward and to the left, so the body would be above the level of the fundus. If there is ischemia or infarction, CT imaging may show thickening and hypoenhancing gastric wall with gastric pneumatosis. The condition may need urgent surgical intervention. Gastric dilation is

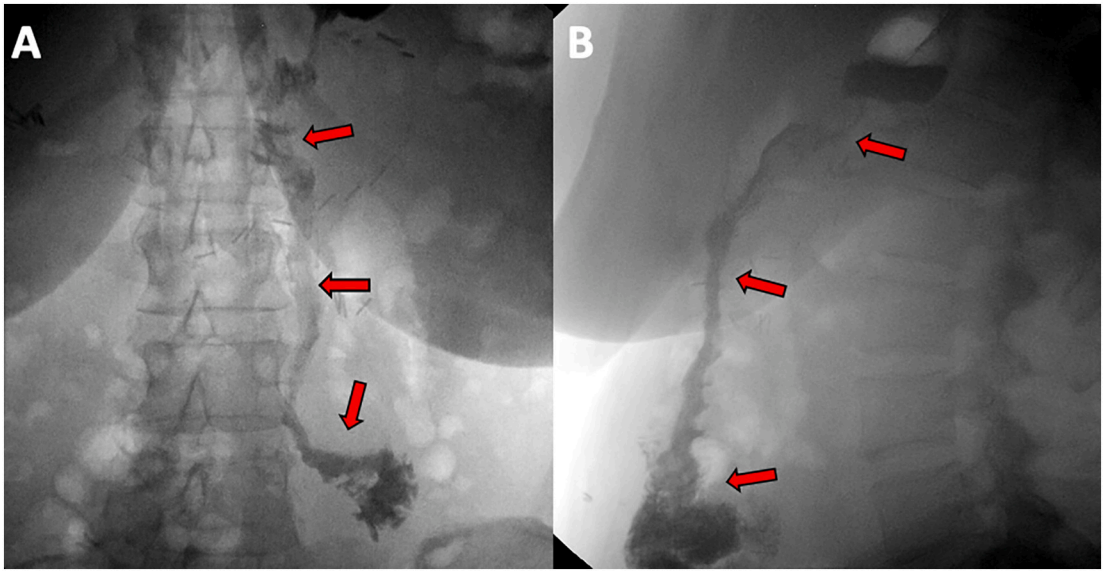

Fig. 7. Normal postoperative gastric bypass surgery. Frontal AP image of upper GI water soluble contrast study (A) showing the postoperative gastric bypass surgery with free flow of contrast through the tubular gastric pouch into the jejunum and surgical clips at the proximal margin of closed large gastric remnant (red arrows). Left anterior oblique image of upper GI water soluble contrast study (B) showing tubular gastric pouch and free passage of contrast (red arrows). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

discussed below.

2.3.3. Gastric dilation

In some patients, gastric dilation may be observed on upper GI Imaging. Nearly 4.5% of the patients who undergo sleeve gastrectomy develop gastric dilation [12]. In these patients, the gastric pouch does not look a narrow tubular structure any longer. Patients may present with weight gain and/or inadequate weight loss. Barium studies will reveal dilated gastric sleeve with loss of narrow tubular anatomy.

2.3.4. Reflux symptoms

Gastroesophageal reflux symptoms are noted in 20% of the patients who undergo sleeve gastrectomy at the end of one year. Most patients respond well to medical management [18].

3. Laparoscopic Roux-en-Y gastric bypass surgery

Laparoscopic Roux-en-Y gastric bypass surgery is the second most common bariatric surgery (17.8%) performed in the United States in 2017 [11]. Laparoscopic Roux-en-Y gastric bypass surgery is associated with the maximum amount of total body weight loss compared to other procedures. Nearly 30 to 35% of body weight loss is generally observed at the end of two years.

3.1. Surgical procedure

Roux-en-Y gastric bypass surgery involves reducing the stomach to a small gastric pouch and connecting directly to a Roux-En-Y loop of jejunum. The gastric pouch usually measures 20–30 ml in capacity. After creating a fundic gastric pouch, the jejunum is divided 25 to 50 cm distal to the ligament of Treitz. The distal limb of the jejunum is then anastomosed with small fundic pouch in the end to side manner in a “candy cane” configuration. The proximal end of the jejunum (biliopancreatic limb) is then anastomosed to the jejunum in a side to side manner to form jejuno-jejunostomy at 100–150 cm from the gastro-jejunostomy (Fig. 6). The majority of the weight loss due to Roux-en-Y gastric bypass surgery is attributed to the restrictive nature of the small proximal gastric pouch and early satiety, although malabsorption and dumping syndrome also plays a role [19].

3.2. Normal postoperative imaging findings

In the majority of the cases, the capacity of the gastric pouch can be between 15 and 30 ml. The Roux limb can be anastomosed with the gastric pouch either in an antecolic manner or retro-colic manner. When the limb is anastomosed in a retrogastric manner, there will be a retrocolic limb traversing behind the transverse colon through the transverse mesocolon. On barium studies, steep oblique view or lateral view may be necessary to visualize the anatomy [20]. There may be a small circumferential narrowing in the Roux limb, where it traverses through the Transverse mesocolon. This should not be mistaken for ischemic stricture [21].

During a fluoroscopic examination, it is essential to obtain the early spot films and then to follow the contrast material flowing through the gastric pouch into the Roux limb of the gastro-jejunal anastomosis in real time (Fig. 7). The presence of staples may help to determine the anastomotic anatomy better in some cases. This method helps to recognize the presence of leakage, dehiscence, and strictures at the gastro-jejunal anastomosis, which may be difficult to recognize during later part of the test due to overlaying opacified loops of small bowel [22].

CT abdomen should be performed with both oral and IV contrast to evaluate the anatomy better. With IV contrast, there is better delineation of the bowel wall, especially at the jejuno-jejunal anastomosis, which can be hard at times due to close proximity between bowel loops. On the CT abdomen, we should be able to recognize the small gastric pouch, gastrojejunostomy, Roux limb, jejuno-jejunostomy, and the continuation of the common small bowel loop with the use of oral contrast. The excluded gastric pouch is usually collapsed in these patients. The larger excluded stomach, proximal biliopancreatic limb, and the jejunojejunal anastomosis need to be recognized. Otherwise, this may lead to a misdiagnosis of intra-abdominal abscess [23]. CT can also depict the biliopancreatic limb which is usually not visualized on fluoroscopic studies as peristalsis generally prevents retrograde flow.

3.3. Complications

3.3.1. Postoperative leak

Postoperative leak is the most dreaded early complication of Roux-

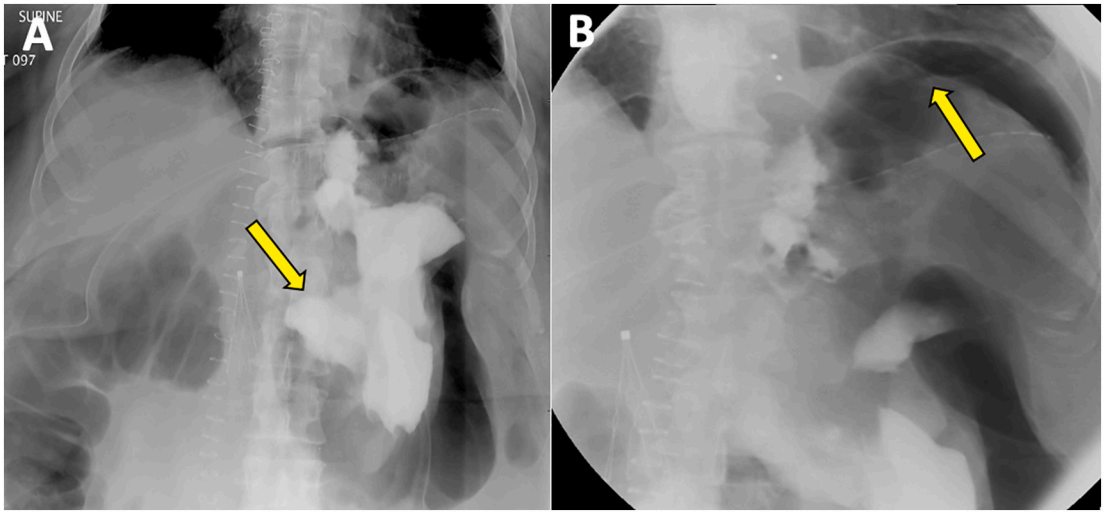

Fig. 8. Contrast leak status post gastric bypass surgery. A 57-year-old male status post Roux-en-Y Gastric Bypass surgery, frontal AP images of water-soluble contrast study shows blush of contrast leak (yellow arrow) intraperitoneally through the bypass suture (A) and moderate pneumoperitoneum along the left subdiaphragmatic region (yellow arrow) (B). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

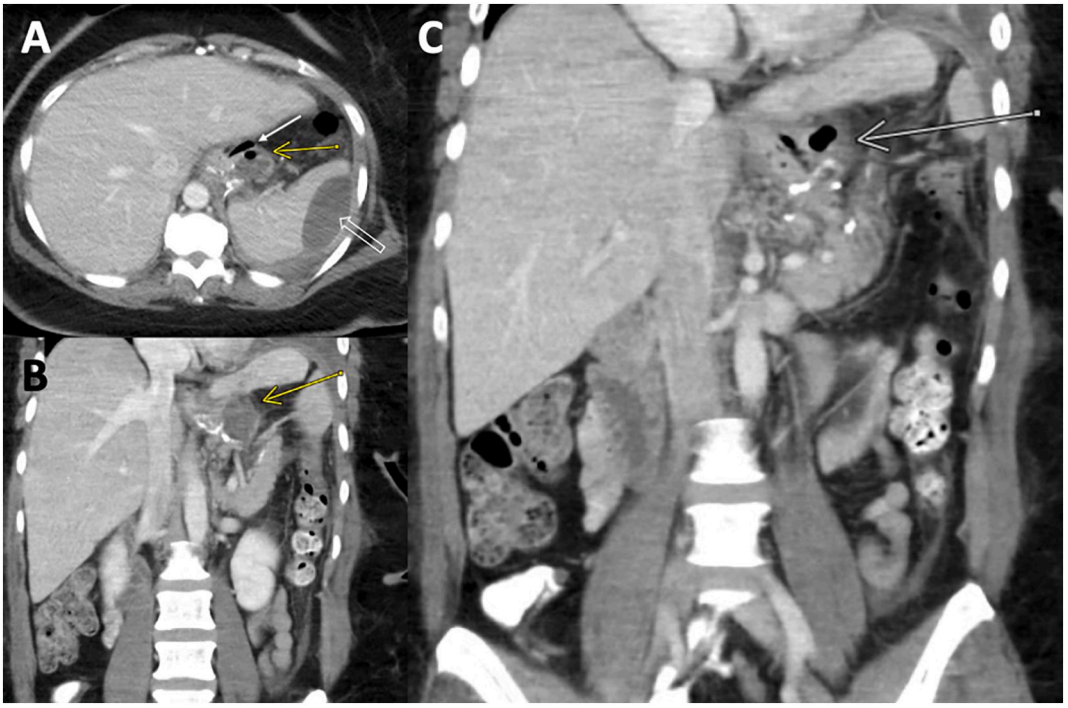

Fig. 9. Contrast leak status post gastric bypass surgery. A 58-year-old female status post Roux-en-Y Gastric Bypass Surgery Axial Contrast enhanced CT (A) shows a small hypodense collection with air due to leak near the anastomotic site adjacent to the suture lines (yellow and white solid arrow) and perisplenic collection (hollow arrow) with small left pleural effusion. Coronal Contrast enhanced CT images (B and C) better shows the small peripherally enhancing collection with air due to leak near the anastomotic site adjacent to the suture lines (thin solid arrow) and small left pleural effusion. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

en-Y gastric bypass surgery and has an incidence of approximately 3% during the first ten days after surgery [24]. The most common location of perforation is gastrojejunostomy anastomosis (69% to 77%). Other locations include gastric pouch distal end, proximal jejunal stump, and jejuno-jejunostomy anastomosis (Fig. 8). Most patients with leakage present with abdominal pain, fever and tachycardia. Early diagnosis is the key to prevent serious complications, including abscess formation and peritonitis. Supine or left posterior oblique view images can show post-operative leaks with water-soluble contrast. Presence of contrast material extending to the left of the jejuno-jejunostomy or in the left upper quadrant area, and sometimes extending to the sub-diaphragmatic area maybe noted. Sometimes, extraluminal air can be seen adjacent to the Gastro-jejunostomy anastomotic site (Figs. 8, 9, 10) [22]. If no leak is detected with water-soluble contrast, dense contrast images with barium can be obtained to detect otherwise small leaks that may go undiagnosed. Most post-operative leaks will require drainage and antibiotics.

3.3.2. *Anastomotic strictures*

Nearly 3%–9% of the patients develop strictures at the gastro-

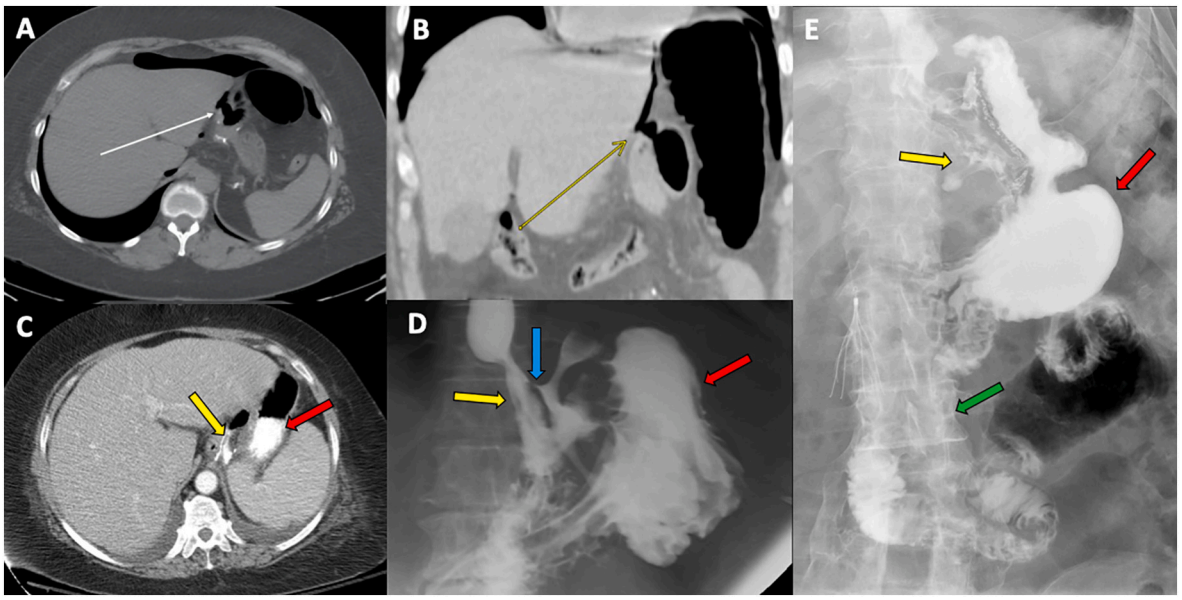

Fig. 10. Contrast leak status post gastric bypass surgery and gastrogastric fistula formation status post Sleeve Gastrectomy. 55-year-old male status post Roux-en-Y gastric bypass surgery presented with acute upper abdominal pain. Axial non-contrast CT image of abdomen (A) showing extraluminal air in peritoneal cavity at the site of anastomosis extending from the stomach to the left anterior perihepatic region (solid white arrow). Small air foci are also seen in left posterior perihepatic region. Coronal non-contrast CT image of abdomen (B) showing extraluminal free air extending from the stomach near the site of anastomosis to the left perihepatic region (solid yellow arrow). Another 62-year-old female post Sleeve Gastrectomy Axial Contrast enhanced CT image (C) shows contrast in both gastric pouch (yellow arrow) and excluded stomach (red arrow). Left anterior oblique fluoroscopic image with water soluble contrast (D) shows the contrast on both gastric pouch (yellow arrow) and excluded stomach (red arrow) and the fistulous tract (blue arrow). Suggesting the gastrogastric fistula formation. A companion case (E) showing concomitant contrast filling of the gastric pouch (yellow arrow) and jejunal loop (green arrow) with immediate opacification of gastric remnant (red arrow) through gastrogastric fistula in an AP image of upper GI fluoroscopic study with water soluble contrast. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

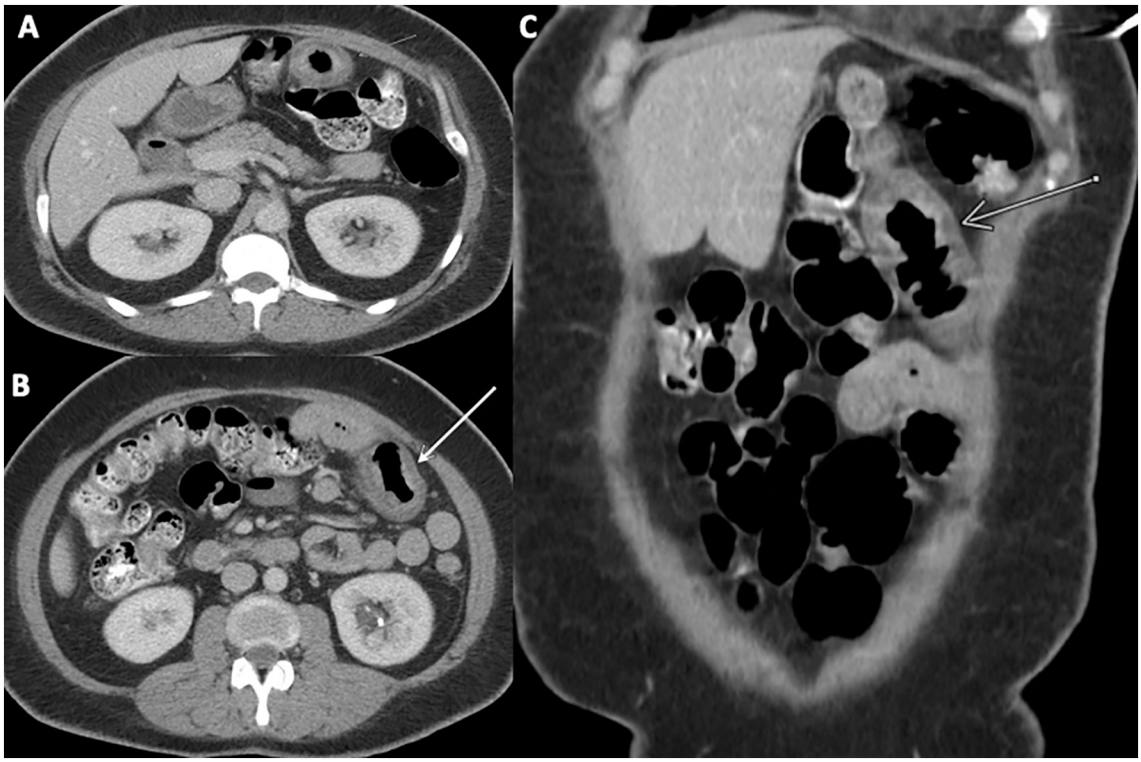

Fig. 11. Jejunal ischemia/enteritis status post gastric bypass surgery. A 69-year-old male status post Roux-en-Y gastric bypass surgery, presenting with abdominal pain. Axial (A and B) and coronal (C) contrast enhanced CT images shows long segment, dilated efferent jejunal loop, just distal to the gastrojejunal anastomosis. This loop also demonstrates diffuse mural thickening (solid white arrow). Incidental note is made of left nephrolithiasis. The possibility of jejunal ischemia and enteritis was raised. The patient was treated with bowel rest and antibiotics for possible enteritis causing bowel obstruction.

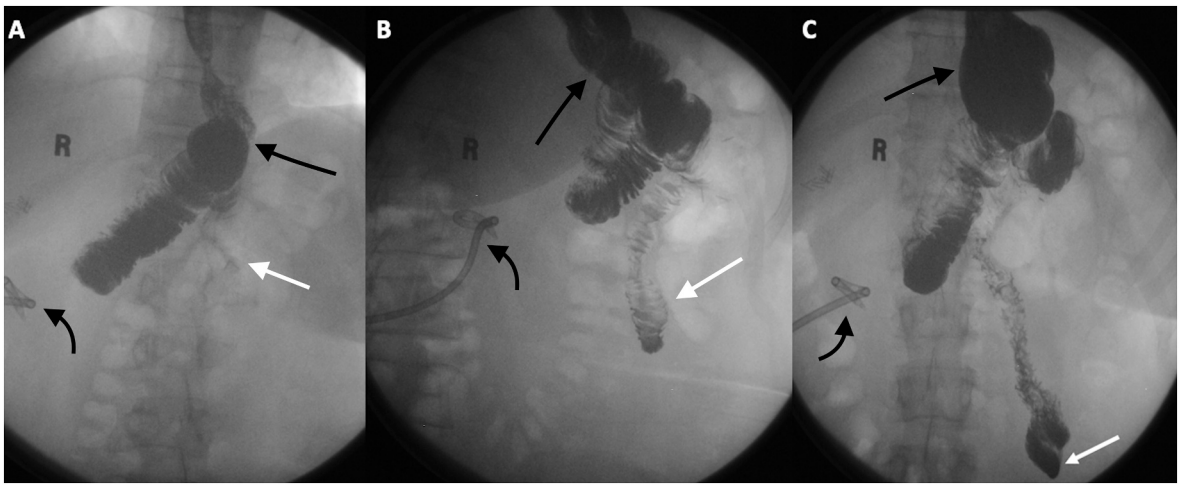

Fig. 12. Stricture at the jejunojejunal anastomosis status post gastric bypass surgery. 47-year-old male status post gastric bypass with gastrojejunal and jejunojejunal anastomosis. AP image of upper GI water soluble contrast study (A) shows retention of oral contrast in gastric pouch and overlapped afferent loop (straight black arrow). The distal end of efferent jejunal loop is poorly opacified (straight white arrow). also noted is a pig tail catheter (curved black arrow) and cholecystectomy staples in right upper abdomen. (B) Mildly delayed image shows some passage of contrast into the efferent jejunal loop (straight white arrow). (C) About 2 hr delayed image shows retention of contrast in the efferent loop with pooling at the site of distal jejunojejunal anastomosis (straight white arrow), raising the possibility of stricture distally at end to side jejunojejunal anastomosis. This patient was taken for exploration and proximal suspected gastrojejunal anastomotic stricture was not found, however, there was stricture at the distal end to side jejunojejunal anastomotic site.

jejunostomy anastomosis due to post-operative fibrosis or chronic ischemia from tension in the gastro-jejunostomy anastomosis usually observed after four weeks. The most common presenting symptoms are bloating, abdominal pain and vomiting. Occasionally patients may present with rapid weight loss. The transient focal appearance of strictures during the immediate post-operative period may be noted due to edema and should be followed with repeat imaging if the symptoms persist. The presence of stricture can cause dilation of the gastric pouch. An anterior view may not detect the stricture. A steep oblique or lateral view may show the anastomosis to better advantage in these patients. Anastomotic strictures at gastro-jejunostomy anastomosis can be managed by endoscopic dilation in most cases [25].

3.3.3. *Marginal ulcers*

Chronic exposure of the jejunal mucosa to gastric acid in the Roux limb leads to the formation of marginal ulcers at the gastro-jejunostomy anastomotic junction in 3%–13% of the patients [26]. *H. pylori* infection may also be associated with the formation of marginal ulcers [27]. These ulcers appear as discrete craters on barium studies. These patients usually present with abdominal pain and upper GI bleeding. Most marginal ulcers respond well to medical management with proton pump inhibitors, and rarely require surgical revision [28].

3.3.4. *Jejunal ischemia and stricture*

Ischemia in the Roux limb of the jejunum is observed in some patients due to tension in the pulled up distal jejunum leading to ischemia. Most patients with jejunal ischemia present with abdominal pain and upper GI bleeding. Mild jejunal ischemia may be self-limiting, but severe acute ischemia can cause bowel infarction. Barium studies show thickened spiculated folds (thumb printing) due to mucosal edema or hemorrhage. CT may show thickened jejunal wall with edematous mesentery and engorged blood vessels which may be seen similar to the appearance

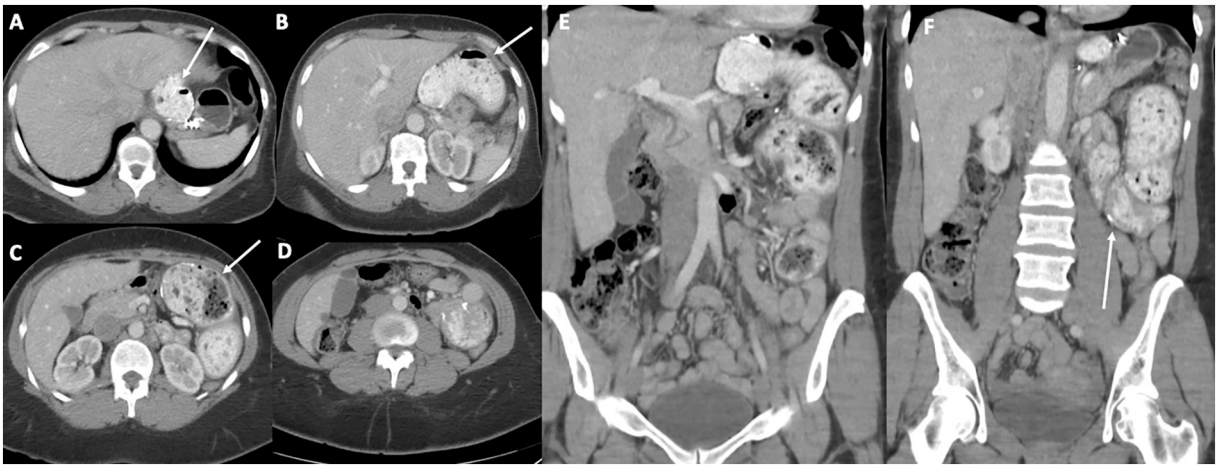

Fig. 13. Type A small bowel obstruction status post gastric bypass surgery. A 62-year-old male status post Roux-en-Y gastric bypass surgery, presented with abdominal pain and vomiting. Sequential axial contrast enhanced CT images of abdomen (A, B, C, & D) showing dilation of Roux limb (white arrow) of Roux-en-Y gastric bypass from gastrojejunal anastomosis to the site of the distal jejunojejunal anastomosis, suggesting obstruction of the efferent limb. Proximal and distal suture lines are visible. Coronal contrast enhanced CT images of abdomen (E & F) better shows the dilated Roux limb (white arrow) of Roux-en-Y gastric bypass from gastrojejunal anastomosis to the site of the distal jejunojejunal anastomosis. Patient was managed conservatively, and obstruction was resolved.

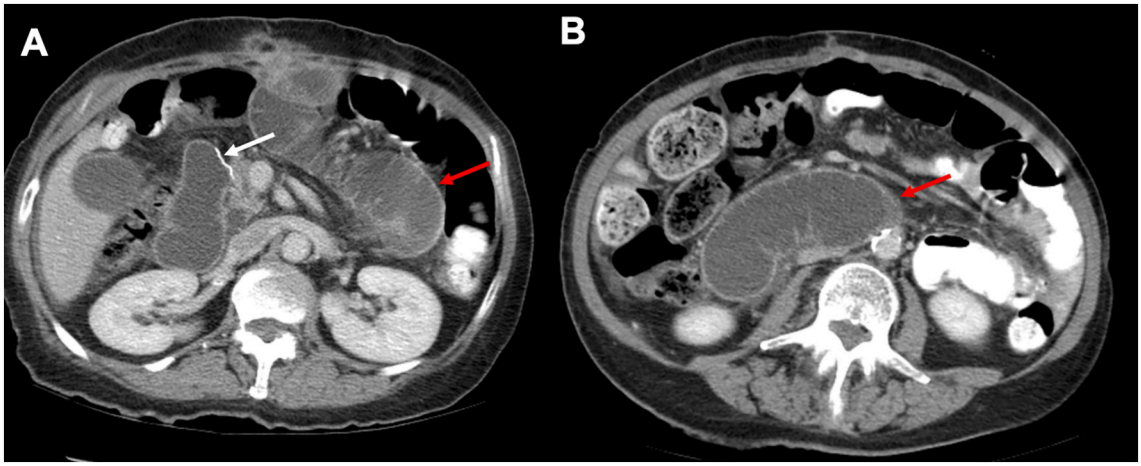

Fig. 14. Type C small bowel obstruction status post gastric bypass surgery. A 54-year-old male status post Roux-en-Y gastric bypass surgery, presented with abdominal pain and distension. Sequential axial contrast enhanced CT images of abdomen (A & B) showing dilation of biliopancreatic limb (white arrow) of Roux-en-Y gastric bypass showing sutures at the gastric pouch and dilation of Roux (alimentary) limb (red arrows), suggesting obstruction distal to the jejunojejunal anastomosis. Intraoperatively adhesions were found causing obstruction of the distal jejunal loop distal to the jejunojejunal anastomosis (Type C small bowel obstruction). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of enteritis (Fig. 11). Chronic ischemia can also lead to giant ischemic ulcers in the Roux limb. The presence of giant jejunal ulcers (>2.5 cm) indicates chronic ischemia and requires aggressive medical management with proton pump inhibitors. Jejunal ulcers unresponsive to medical treatment should be treated with surgical intervention. Jejunal stricture due to ischemia present with obstructive symptoms and appear as a smooth-contoured narrow segment with tapering on barium studies (Fig. 12). CT may show long segment narrowing with bowel wall thickening and mural stratification [29].

3.3.5. *Small bowel obstruction*

Approximately 5% of patients with Roux-en-Y bypass surgery may develop small bowel obstruction due to adhesions, strictures and internal hernias. Small bowel obstruction in these patients is classified into three types based on radiology imaging findings [30].

1. Type A: This occurs due to obstruction of the Roux limb at or above the level of jejuno-jejunostomy anastomosis. This is commonly diagnosed on barium studies or CT revealing dilated Roux-en-Y limb with collapsed biliopancreatic limb (Fig. 13).
2. Type B: This type of small bowel obstruction occurs due to obstruction in the biliopancreatic limb at or above the level of jejuno-jejunostomy anastomosis. Usually, the barium studies do not show opacification of the biliopancreatic limb due to peristaltic movements and may miss the diagnosis leading to a risk of perforation. A barium study usually reveals collapsed roux limb. The diagnosis is commonly made on CT evaluation showing fluid-filled distended excluded large gastric pouch and biliopancreatic limb, which are typically collapsed in these patients.
3. Type C: Small bowel obstruction in this category is usually due to obstruction of the common small bowel distal to the jejuno-jejunostomy anastomosis. Imaging studies will reveal distended Roux limb and biliopancreatic limb (Fig. 14).

3.3.6. *Internal hernia*

Internal hernias are defined as protrusion of the bowel loops through a defect within the peritoneal cavity that is almost always created surgically. Internal hernia in patients with Roux-en-Y surgery is usually underdiagnosed and requires a high degree of suspicion for the diagnosis. Around 3% of the patients who undergo this surgery develop internal hernias due to defect in the transverse mesocolon in retrocolic gastro-jejunostomy patients, due to a defect in the small bowel mesentery which is made during the creation of jejuno-jejunostomy and due to defect posterior to the Roux limb (Peterson defect) [31,32]. An internal hernia can lead to bowel incarceration, infarction, and perforation. On barium Upper GI and CT studies, abnormal accumulation of a small bowel loop in a small area with migration of the jejunojejunostomy suture line, should raise a concern for an internal hernia.

Barium upper GI study may reveal retention of the contrast in the herniated bowel loops situated in an atypical location. On the CT scan, the presence of a mesenteric swirl along with small bowel obstruction indicates a high probability of internal hernias [33].

3.3.7. *Weight gain*

The weight loss due to Roux-en-Y surgery is mainly due to the restrictive effect of the small gastric pouch and malabsorption. Staple dehiscence can lead to gastro-gastric fistula with food entering the excluded stomach leading to loss of the beneficial effect resulting in weight gain or flattening of the weight loss curve. Approximately 3.5% of the patients develop staple dehiscence both as early and late complications [34]. Barium studies with fluoroscopic exams should be done with the patient in an upright and semi-upright position to evaluate the movement of barium. Contrast entering the excluded stomach in the initial stage of the study is diagnostic. It is important for fluoroscopist to examine the head of the barium column, whether barium empties through gastro-jejunostomy or through the dehiscence into the excluded stomach. Reflux of contrast material into the pancreaticobiliary limb which may occur during the later stage of the study makes it harder to diagnose stable dehiscence [34]. Widening of the gastro-jejunal anastomosis can also lead to recurrent weight gain after surgery due to rapid emptying and loss of the restrictive effect of the small pouch.

4. Laparoscopic adjustable gastric banding

The laparoscopic adjustable gastric banding was first introduced by Belachew in 1993. Although this is a less invasive surgery compared to the gastric bypass and sleeve gastrectomy, the total body weight loss is lower when compared to Roux-en-Y, and weight loss may be temporary. Therefore, it is less efficient, and only 2.77% of the 228,000 bariatric surgeries performed in 2017 in the United States were laparoscopic adjustable gastric banding [11].

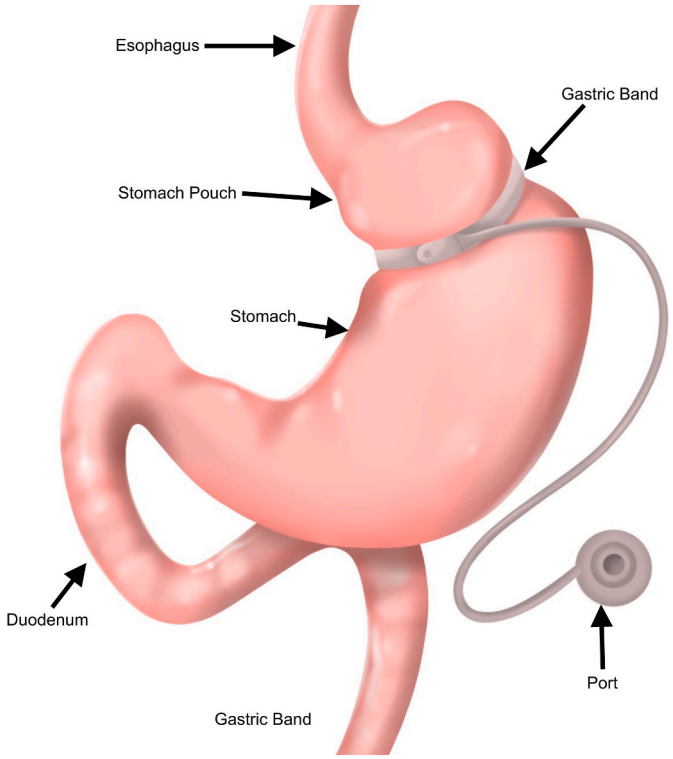

Fig. 15. Schematic diagram of normal postoperative appearance of laparoscopic Gastric banding surgery.

4.1. Surgical procedure

The surgical procedure involves the placement of a silicone band around the proximal part of the stomach 2–3 cm below the gastroesophageal junction. The band is sutured to the outer wall of the stomach to prevent slippage. The band creates a small proximal reservoir. The band has an inflatable inner sleeve that can be inflated or deflated by injecting saline into the port which is connected to the tubing (Fig. 15). The tension within the band can be increased or decreased based on weight loss [35,36]. If the patient develops features of obstruction because the band is too tight, the tension in the gastric band should be reduced by removing the saline.

4.2. Normal post-operative anatomy

Immediately after the surgery, upper GI imaging should be performed with water-soluble contrast to evaluate the position of the gastric band, post-operative leak, the size of the proximal gastric pouch, the caliber of the stoma through the area of banding, and subcutaneous port connecting the gastric band. The gastric band is usually positioned in an oblique orientation with medial end lower than the lateral end, where the horizontal plane of the band forms an angle with the long axis of the spine. This is also referred to as 'angle of Phi,' which usually measures between 4° and 58° [37].

Fluoroscopic examination reveals small proximal gastric pouch and larger distal gastric pouch. The stoma connecting the two can be visualized when the contrast flows from the proximal pouch to the distal pouch. Positioning the patient in frontal or slightly right posterior oblique position during fluoroscopy helps to visualize the stoma well without being obstructed by the opacified proximal pouch. The normal volume of the proximal pouch is usually between 15 and 20 ml measuring about 4 cm in diameter [38].

CT imaging maybe performed to evaluate the gastric band, using oral contrast with or without intravenous contrast. With the quality of high spatial resolution and coronal, sagittal, oblique multiplanar views, CT imaging provides better visualization of the anatomy [39]. Radio opaque gastric band positioned 2–3 cm below the level of the gastroesophageal junction, forming a small proximal pouch, and a large distal gastric pouch is seen. The gastric band is connected with tubing that traverses through the peritoneal cavity, rectus muscle, and through the subcutaneous plane along the anterior rectus sheath connecting the subcutaneous port. Soft tissue around the tube and reservoir should be evaluated for the source of infection in appropriate clinical setting [36].

4.3. Complications

4.3.1. Stomal stenosis

Stomal stenosis is the most common complication due to gastric banding surgery. In most cases, the cause is luminal narrowing due to a too tight band. Patients with stomal stenosis usually present with reflux, nausea, vomiting, dysphagia, and abdominal pain. Abrupt onset of severe nausea, vomiting, abdominal pain, and dysphagia to both solids and liquids should raise the concern for larger solid food bolus obstructing the stoma. Barium studies reveal esophageal reflux, retained contrast with a dilated proximal gastric pouch, slow emptying of the contrast into the distal stomach, and severely narrowed stoma [35]. Normally, the stomal size is of 3-5 mm, although there is no consensus on the exact size.

When stomal stenosis is suspected, the gastric banding should be deflated and loosened by retrieving some of the normal saline from the reservoir to relieve the obstructive symptoms. Large food bolus obstruction may also be relieved with this but sometimes may require endoscopic extraction if the symptoms persist. Immediately after the band is loosened, a follow-up imaging study may be performed to document the free flow of barium contrast through the stoma and the stomal size. It can also guide the readjustment of the gastric band based on the findings [40].

4.3.2. Gastric band malpositioning

Band malpositioning usually occurs when the procedure is performed by an inexperienced surgeon. Band placement in the peri-gastric fat results in failure of the gastric band, and in other cases, placement of band in the distal stomach leads to gastric outlet obstruction. Whenever malpositioning is present, the band may need to be removed.

4.3.3. Gastric pouch dilatation

Approximately 3–8% of the patients develop chronic pouch dilation in the presence of normal stomal size due to persistent dietary indiscretion resulting in chronic volume overload, and patients usually present with failure to lose weight. It is usually associated with the dilated esophagus, proximal pouch, and retained food particle in the proximal pouch. Appropriate dietary counseling should be done for these patients [41,42]. Acute proximal pouch dilation occurs if the gastric band is too tight, leading to excessive narrowing of the stoma. Sometimes distal slippage of the band may cause narrowing and proximal pouch dilatation (Fig. 16).

4.3.4. Distal slippage of the gastric band

Distal migration of the gastric band is another common complication of adjustable gastric banding seen in 3–13% of the patients. Gastric band slippage is likely due to recurrent vomiting, over inflation of the gastric band, and improper surgical techniques. Distal slippage of the gastric band may be anterior or posterior and can lead to a dilated proximal gastric pouch and severe luminal narrowing (Fig. 16). Patients with distal gastric band slippage may present with dysphagia, nausea, vomiting, and abdominal pain. Occasionally, patients may develop potentially life-threatening complications such as infarction, perforation, and rarely gastric volvulus [35]. An abdominal radiograph can demonstrate the increased distance between the left hemidiaphragm and the gastric band. The gastric band may now appear more horizontal due to the weight of the food in the larger proximal pouch with the angle of

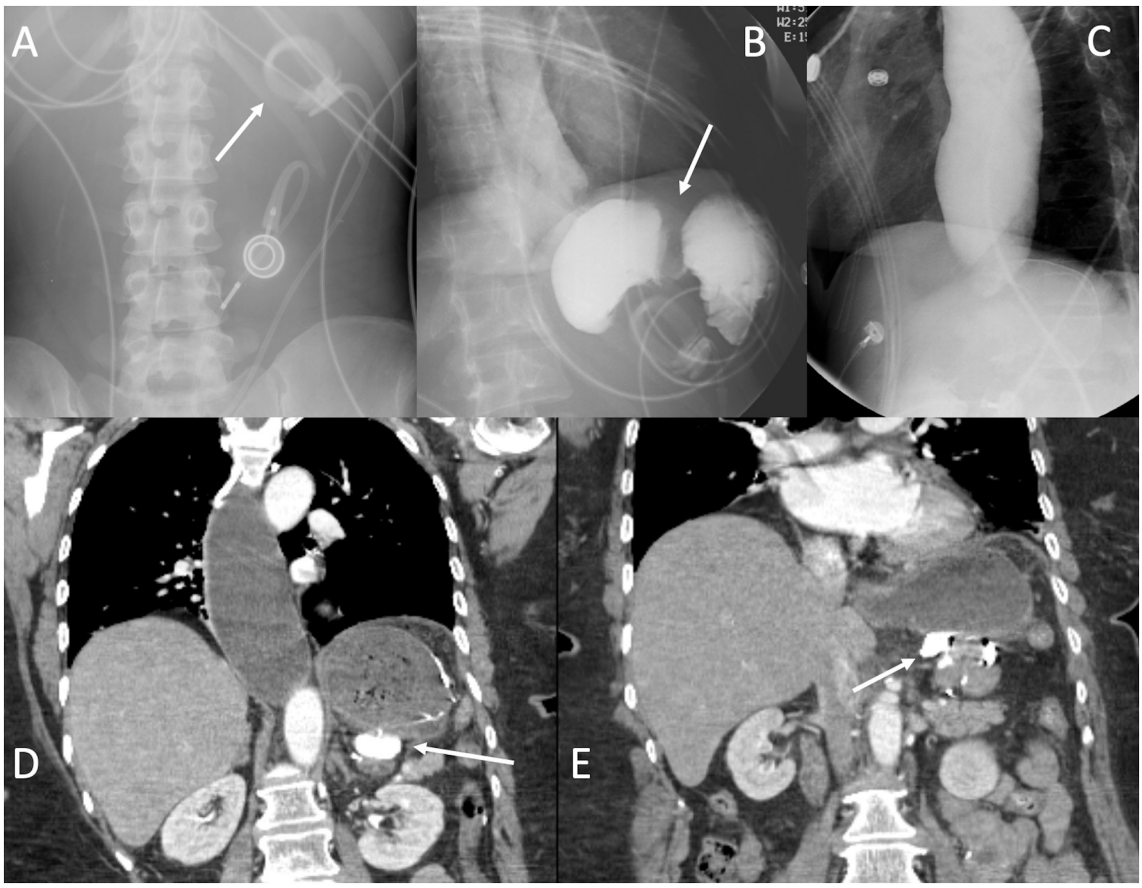

Fig. 16. Distal slippage of the gastric band with proximal gastric pouch dilatation. A 40-year-old female status post gastric banding presented with upper abdominal pain and vomiting. Abdominal AP X – ray shows gastric band port to the left of midline with intact tubing and abnormally positioned gastric band with phi angle $>110^0$ (solid white arrow). Upper GI study with water soluble contrast AP and Left anterior oblique images (B & C) show narrowing/waist in the mid stomach (solid white arrow) with abnormally dilated proximal stomach and esophagus due to slipped Gastric Band. Coronal contrast enhanced CT images of abdomen (D & E) show Gastric Band in the mid stomach markedly narrowing the lumen and causing dilatation of proximal stomach and esophagus (solid white arrow).

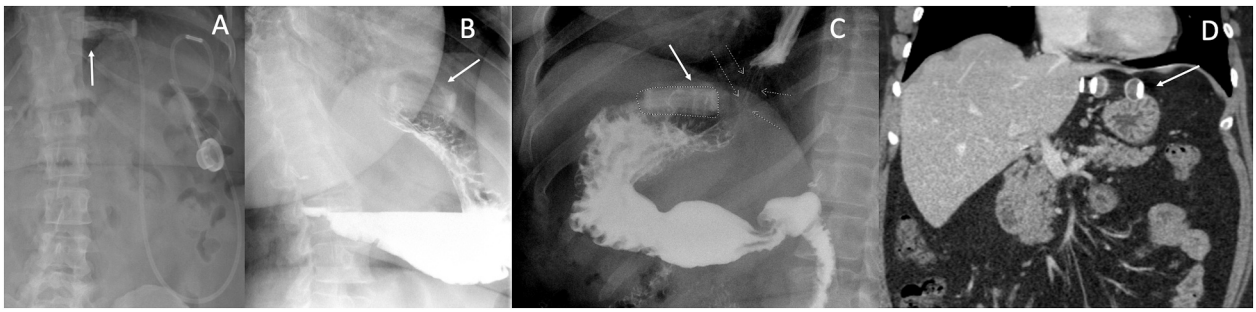

Fig. 17. Distal slippage of the gastric band and gastric erosion. A 70-year-old female status post gastric banding presenting with weight gain. Abdominal AP X-ray shows Gastric band and port in the left upper quadrant with intact tubing. The phi angle is abnormal measuring about 95°. The upper GI water soluble contrast study left anterior oblique fluoroscopic image (B) shows abnormally positioned Gastric Band with contrast coursing adjacent to the gastric band suggesting anterior slippage with possible chronic erosion outside the gastric lumen. No evidence of contrast extravasation was noted. The upper GI water soluble contrast study lateral fluoroscopic image (C) demonstrates the gastric band (dotted rectangle) lying anterior to the gastric fundus, concerning for anterior slippage, and erosion outside the gastric lumen. The contrast is coursing adjacent to the gastric band (dotted arrows). Coronal contrast enhanced CT scan of abdomen of another patient (D) shows malpositioned gastric band above and to the left of the gastroesophageal junction and is completely outside the stomach. There was no associated fluid collection or inflammatory change.

Phi>58° [37]. The orientation of the normal gastric band in these patients may be in such a way, that the anterior and posterior sides of the band are not superimposed, leading to the appearance as 'O' shaped ring (described as 'O' sign by Pieroni et al) [43]. This sign is usually seen in posterior band slippage [44].

Barium studies usually show eccentrically dilated contrast filled proximal gastric pouch, with delayed emptying of the contrast. The Pouch may be seen posterior and inferiorly in the case of posterior slippage and anterior and superiorly in the case of anterior slippage [35]. Whenever the distal slippage is noted the management should be done depends on the symptoms like, obstruction and ischemia are present or not. First the gastric band should be deflated completely, and

Fig. 18. Gastric pouch perforation status post gastric banding surgery. A 60-year-old female status post gastric banding presented with upper abdominal pain. Abdominal AP X – ray shows midline gastric band port and vertical gastric band with normal phi angle 37^0 (solid white arrow). Axial contrast enhanced CT images of upper abdomen in soft tissue (B) and Bone (C) windows show extraluminal air along the gastric band suggesting perforation (solid white arrow). No active leakage of oral contrast was noted.

imaging should be repeated to document the relieving of the obstructive symptoms (Figs. 16, 17). On repeat imaging in 1–2 weeks, the gastric band returns to the proximal subdiaphragmatic position and can be re-inflated in a slow and graded manner back to promote weight loss. If the band remains in the region of distal stomach, it should be surgically corrected or removed.

4.3.5. Gastric volvulus

Gastric volvulus is a life-threatening complication associated with a distal slippage gastric band. Gastric volvulus develops when the prolapsed larger proximal pouch is filled with a large volume of food and rotates the stomach along its long axis at the level of the gastric band with fixed distal gastric pouch resulting in closed-loop obstruction. Volvulus can lead to strangulation, ischemia, and infarction. These patients present with severe abdominal pain and vomiting. Barium studies reveal a twisted proximal stomach pushing the distal body superior, and to the left, with high grade obstruction at the gastric band, CT abdomen may show gastric pneumatosis and thickened gastric wall [46]. When gastric volvulus is noted, the gastric band should be deflated immediately and removed surgically to prevent further complications and restore blood supply.

4.3.6. Gastric perforation

Gastric perforation is an uncommon complication usually due to gastric injury from the surgery seen in 1% of the patients. Upper GI imaging with water-soluble contrast and CT may reveal extraluminal extravasation of the contrast into the peritoneal cavity and free air [45] (Fig. 18). Patients usually present with septic features (fever, abdominal pain, leukocytosis, and tachycardia). Prompt recognition of the complication is essential to reduce morbidity and mortality related to sepsis due to peritonitis.

4.3.7. Band erosion

Erosion of the gastric band into the gastric lumen is a rare complication and is usually the end result of pressure necrosis of the gastric wall due to high pressure in the gastric band due to chronic over

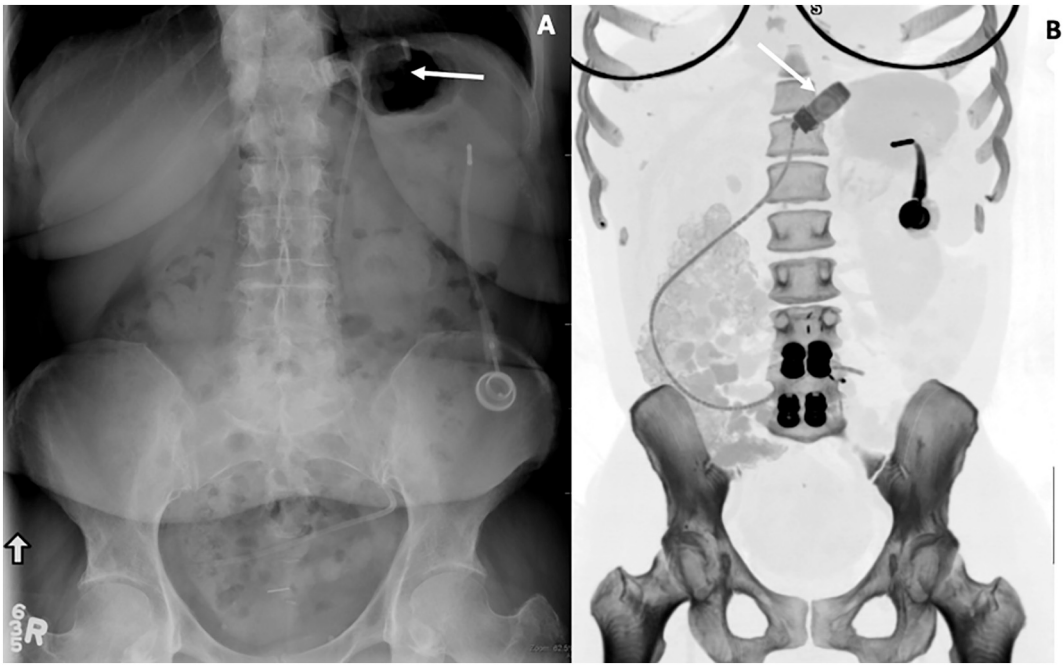

Fig. 19. Disconnected tubing from the gastric band. Abdominal AP X-Ray of a 66-year-old female shows increased phi angle of 70°. The access reservoir projects over left lateral abdomen, however, the tubing from the lap band is disconnected, extending into the right lower quadrant. Abdominal AP X-Ray (negative image) of a 70-year-old male shows normal phi angle of 50°. The access reservoir projects over left upper abdomen, however, the tubing from the lap band is disconnected, extending into the mid abdomen.

inflation. Intraluminal gastric band erosion is incomplete in most patients. When the gastric band erosion is complete, retrograde migration into the gastroesophageal junction or distal migration into the antrum, duodenum, and jejunum may cause high-grade obstruction. Intraluminal erosion of the gastric band may cause gastric perforation and severe upper GI bleeding and warrant surgical removal [47,48].

4.3.8. Port related complications

Common complications related to the subcutaneous port are infection and erosion of the skin with exposure of the port. Erosion of the tubing into the bowel lumen is rare but can happen, and this can be confirmed by the CT abdomen with the intraluminal location of the tubing. Intraluminal erosion will require surgical extraction. Kinking of the tube may lead to its obstruction, and thus the band inflation or deflation may not be possible [49,50]. There may be disruption of tubing (Fig. 19). The port may also flip, leading to inability to access.

5. Conclusion

In the world, where obesity is increasing exponentially like an epidemic, the bariatric surgical procedures are also increasing to manage this monstrous disease. Common bariatric surgical procedures performed for weight loss are laparoscopic sleeve gastrectomy, Roux-n-Y gastric bypass and gastric banding. The knowledge of the post-surgical anatomy, imaging and complications of these bariatric surgeries is essential for the radiologist to make appropriate diagnosis for timely intervention and management.

Ethics approval and consent for publication

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

Not applicable.

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Declaration of competing interest

The authors declare that they have no competing or conflicts of interests.

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