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Research progress in the treatment of gallstones with laparoscopic and endoscopic surgery: a narrative review

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Abstract

Cholelithiasis, the formation of stones in the gallbladder, is a common surgical condition with an increasing incidence. Laparoscopic cholecystectomy has become the gold standard for the treatment of symptomatic gallstones due to its favorable outcomes. However, with increasing recognition of the gallbladder's importance, this procedure no longer aligns with patients' desire to preserve the organ. Technological advancements and surgical innovations have led to emerging approaches such as natural orifice transluminal endoscopic surgery (NOTES), robot-assisted laparoscopic cholecystectomy, and cholangioscopy. This narrative review examines the current landscape of surgical interventions for gallstones, highlighting both gallbladder-preserving and removal approaches, and aims to provide insight into their respective outcomes and clinical implications.

Keywords Natural orifice transluminal endoscopic surgery (NOTES), Gallstone, Laparoscopic Cholecystectomy

Background

The gallbladder functions as a storage and concentration organ for bile, a substance produced by the liver that aids in fat digestion and absorption. Gallstones, solidified formations of bile, develop from imbalances in bile composition. These imbalances often result from diet, hormones, medications, and rapid weight fluctuations [1]. According to statistics from 2016, approximately 20% of adults globally have gallstones [2]. Gallstones are classified into three types: cholesterol stones, pigment stones, and mixed stones. Recently, cholesterol stones have become the most prevalent type due to increased consumption of high-fat foods [3, 4]. Cholesterol stones form when an imbalance in bile cholesterol leads to crystal precipitation.

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Cholecystectomy

Historically, symptomatic gallstones were treated by open cholecystectomy; however, due to suboptimal recovery outcomes, laparoscopic cholecystectomy has gradually replaced open surgery [5]. Laparoscopic cholecystectomy is currently the gold standard for treating symptomatic gallstones [6]. Nevertheless, the procedure requires assistants to position the endoscope and expose tissues, potentially compromising surgical safety and efficiency [7]. The development of Da Vinci robot-assisted surgical systems addresses these issues by providing surgeons improved control over visualization and instruments. Additionally, laparoscopic subtotal cholecystectomy has emerged as an alternative for managing complex biliary anatomy.

Gallbladder-preserving surgery

Gallbladder-preserving surgeries, including gallbladder drainage for high-risk patients, cholangioscopy, and natural orifice transluminal endoscopic surgery (NOTES), serve as alternatives when complete cholecystectomy is not indicated. In 2004, Rao et al. [8] performed the first human NOTES procedure, removing an appendix through the stomach, marking the beginning of minimally invasive approaches, including NOTES cholecystectomy. Researchers [9] have explored hybrid NOTES procedures combined with transumbilical laparoscopy to reduce postoperative scarring and accelerate recovery. Other studies on NOTES reported faster recovery and no visible surface scar [10]. Despite various available surgical options, a standardized approach for gallstone management remains elusive. This narrative review explores recent advances in gallstone surgery, emphasizing comparative outcomes of gallbladder-preserving techniques and traditional cholecystectomy. The discussion is based on a selective review of peer-reviewed literature published over the past two decades, highlighting clinically relevant innovations and emerging surgical trends.

Main text

Laparoscopic cholecystectomy

Laparoscopic cholecystectomy

Laparoscopic cholecystectomy is currently performed using two primary methods: multi-port and single-port approaches [11]. The multi-port technique remains the gold standard [12]. Single-port laparoscopic technology has advanced to meet demands for improved cosmetic outcomes, yet the issue of incisional hernias remains unresolved [13]. Both approaches involve creating an intraperitoneal passage followed by fascial closure [14].

In 2007, Kang et al. demonstrated that the da Vinci robotic system effectively overcomes limitations of traditional laparoscopic techniques in complex cholecystectomies [15, 16]. Subsequent controlled studies further validated the efficacy of robot-assisted cholecystectomy [17]. Robotic systems, first utilized in laparoscopic surgery in 1991, have evolved from multi-port to advanced single-port robot-assisted procedures [18, 19]. The most commonly used robotic system is the da Vinci system, which typically involves inserting the assistant port through the camera port via a vertical umbilical incision [20]. After positioning the endoscope, trocars are placed on either side, and the assistant retracts the gallbladder while dissecting Calot's triangle. The gallbladder is then extracted using the robotic system.

Two major drawbacks of robot-assisted cholecystectomy are its complexity and high surgical costs. The intricate setup and learning curve associated with robotic systems may hinder optimal visualization and instrument maneuverability, especially in cases involving extensive adhesions or altered anatomy. However, the da Vinci robot enhances visualization by providing a magnified 3D view, aiding precise dissection and suturing, particularly in complex procedures such as Roux-en-Y hepaticojejunostomy [20]. Despite these advantages, robot-assisted laparoscopic cholecystectomy remains significantly more expensive than traditional laparoscopic surgery.

Comparative postoperative data indicate that robot-assisted surgery has higher rates of in-hospital complications and increased likelihood of conversion to open surgery. While robotic surgery provides more precise surgical views, its complexity and potential for instrument crowding may contribute to surgical challenges. Although robotic procedures have technical advantages, overall postoperative complication rates are higher. As shown in Table 1, robotic procedures had slightly higher in-hospital complication rates (15.5%) than laparoscopic surgery (11.7%), primarily due to acute kidney injury and gastrointestinal complications. However, critical outcomes such as bile leak incidence and postoperative hospital stay were comparable between the two approaches, with robotic surgery demonstrating potential advantages in these parameters.

Laparoscopic subtotal cholecystectomy was developed in response to unacceptable recovery times and decreased quality of life associated with traditional laparoscopic cholecystectomy [25]. Subtotal cholecystectomy, initially defined as partial resection of the gallbladder neck or body, typically concludes with either fenestration or reconstruction. In fenestration procedures, the remaining gallbladder is left open; in reconstruction procedures, the remaining gallbladder is closed [26]. This technique is primarily a safety measure to avoid bile duct injury rather than a first-line option due to risks such as bile leakage. Both methods have a high incidence of bile leaks [27, 28], making subtotal cholecystectomy less favorable as a primary choice. Nevertheless, it remains the standard in cases involving complex gallbladder anatomy [29].

Table 1 The results of laparoscopic surgery and robot-assisted laparoscopic cholecystectomy [21–24]

	Laparoscopy	Robotic surgery
Mean operative time, min ± SD	44 ± 19.9	61.0 ± 27.5
Bleeding (%)	0	0
Bile leak in op (%)	17.3	6.7
conversion rates (%)	1.7	3.0
Postoperative stay (d)	2.7	2.3
In-hospital complications (%)	11.7	15.5
Cost ($)	13.562	17.254

Conversion: the transition from robotic to open surgery rather than from robotic to laparoscopic surgery

Natural orifice transluminal endoscopic surgery (NOTES) cholecystectomy

Limitations related to postoperative surface scarring from laparoscopic cholecystectomy have led to the development of NOTES cholecystectomy. The earliest NOTES cholecystectomy was performed using a transperineal approach in 2007 [30]. Transperineal cholecystectomy demonstrated significant improvements in postoperative safety and pain management [31]. However, the transperineal approach poses gender-specific challenges. In theory, cholecystectomy can also be performed through other natural orifices [32]. For instance, Kalloo et al. [33] performed experiments in pigs to extract liver biopsy specimens via a peroral transgastric approach. In 2024, researchers successfully conducted a transrectal subtotal cholecystectomy [34] (Table 2).

Transperineal cholecystectomy Trocars are typically inserted through the umbilical region during cholecystectomy. The patient is positioned in the lithotomy position, and an incision is made at the umbilicus to insufflate the abdomen. After laparoscopic inspection, dissecting instruments are introduced through the vaginal route, accompanied by an optical device. The umbilical laparoscope is then replaced with a dissector. The vaginal dissector retracts the gallbladder, while the umbilical dissector performs the dissection. The surgeon identifies Calot's triangle, clips the cystic duct, and removes the gallbladder through the vaginal pathway. Finally, the vaginal incision is closed [40].

Transgastric cholecystectomy A balloon dilator is placed through percutaneous endoscopic gastrostomy to dilate the gastric incision. A flexible guidewire punctures the anterior abdominal wall and guides the incision at the gastric antrum level, followed by dilation [38]. The gastric incision is usually performed without optical assistance, necessitating laparoscopic visual control. An optical device is initially introduced through the umbilical port to guide the gastric approach visually. Subsequently, gastrotomy is performed on the anterior antral wall [32]. The balloon dilator then passes through the gastric incision via the guidewire. The gallbladder is retracted, and Calot's triangle is exposed using a gastroscope. After visualization, flexible instruments inserted through the endoscope's two channels dissect and remove the gallbladder. Finally, the gastric incision is closed. Recently, a novel technique employing a single endoscope without laparoscopic guidance has emerged [39]. This procedure involves puncturing the anterior antral wall through the endoscope to expose and dissect the gallbladder from base to neck, representing a technically challenging approach.

Transrectal subtotal cholecystectomy Initially, a detachable device is placed to block the colon, followed by disinfection of the anal area. Subsequently, a surgical knife removes a portion of the gallbladder and extracts the stones. The remaining gallbladder is inspected for residual stones. The wound is then closed with clips, the abdominal cavity irrigated, and the access route secured [34].

These three approaches are minimally invasive and facilitate rapid recovery. However, they are not interchangeable, as each suits specific surgical contexts. Transgastric and transrectal methods are infrequently used. Short-term complications (e.g. peritonitis) and long-term complications (e.g. gallstone recurrence) remain unchanged. The transvaginal NOTES cholecystectomy is regarded as the gold standard. Despite the increased surgical steps and longer operation time, blood

Table 2 Reported studies on cholecystectomy by natural orifice transluminal endoscopic surgery

Author	Year	Study characteristics			
		Design	Study population	Sample size	Method
Kalloo [33]	2004	Animal study	porcine	6	An endoscopic peroral transgastric approach to the peritoneal cavity
Park PO [35]	2005	Animal study	porcine	8	Transgastric cholecystectomy was performed
Rolanda C [36]	2007	Animal study	porcine	15	Transgastric and transvesical combined approach
Jacques Marescaux [30]	2007	Case report	human	1	This first transperineal cholecystectomy
Perretta S [32]	2007	Animal study	porcine	6	Transgastric cholecystectomy was performed
Bernard Dallemagne [37]	2009	Case report	human	5	Transgastric hybrid cholecystectomy
Bernard Dallemagne [38]	2010	Case report	human	11	Transgastric cholecystectomy
Xin-Yang Liu [39]	2021	Case report	human	8	Endoscopic transgastric cholecystectomy
Liu D [34]	2024	Case report	human	1	transperineal partial cholecystectomy

loss is reduced [41–43]. Ppostoperative pain is comparable to laparoscopic cholecystectomy. While each approach has distinct advantages, there remains substantial room for improvement compared to laparoscopic cholecystectomy (Table 3).

Gallbladder-preserving cholecystolithiasis

In certain Asian countries, a cultural and emotional attachment to the gallbladder fosters a strong desire for its preservation [50, 51]. Furthermore, laparoscopic cholecystectomy, currently the gold-standard surgery, carries risks such as bile duct injury and bile leakage. Although these complications are infrequent, their impact can be substantial [52]. Additionally, postoperative issues such as indigestion, diarrhea, gastroesophageal reflux, and common bile duct stones may increase after laparoscopic cholecystectomy [53]. Therefore, exploring surgical methods that remove gallstones while preserving the gallbladder is reasonable. Although gallbladder-preserving surgery remains controversial [54], clinical guidelines and accumulated surgical experience over the past decade have largely addressed these controversies [55]. Gallbladder-preserving cholecystolithotomy is considered effective for certain patients unsuitable for cholecystectomy, including those with severe acute cholecystitis, high surgical risk, complex biliary anatomy, elderly patients, or those strongly desiring organ retention [56]. However, gallbladder-preserving surgery is not advised if patients present with inflammatory edema of the gallbladder wall (thickness >5 mm), gallbladder atrophy indicated by preoperative imaging or confirmed intraoperatively, or suspected gallbladder cancer [57].

Choledochoscopy-assisted and laparoscopic combined choledochoscopy gallbladder-preserving stone removal

When patients have gallbladder stones with secondary bile duct stones and refuse cholecystectomy, cholangioscopic gallbladder-preserving stone removal is the preferred treatment [58, 59]. Endoscopy dilates the duodenum, followed by stent placement in bile and pancreatic ducts. A fully covered metal stent (FCMS) is inserted into the cystic duct to straighten and dilate it fully. A single-operator cholangioscopic system (SOCS) is then placed into the gallbladder to flush out and remove residual small stones. Finally, a plastic stent replaces the FCMS. Two weeks postoperatively, patients receive ursodeoxycholic acid (UDCA) to reduce gallstone recurrence [60]. This procedure is truly minimally invasive without external incisions [61].

Another approach combines laparoscopy with cholangioscopy for gallbladder-preserving stone removal. A small incision under the right upper abdominal costal margin provides access to the abdomen. The gallbladder is incised at its base, and the cholangioscopic stone basket removes stones. The cholangioscope is withdrawn, the incision sutured, and postoperative oral UDCA administered to prevent stone recurrence. If biliary colic occurs, non-steroidal anti-inflammatory drugs (NSAIDs) should be taken [62]. Although these methods preserve the gallbladder, the high recurrence rate of gallstones postoperatively remains unresolved [57]. Researchers have explored combining UDCA with intestinal probiotics to treat gallstones, but studies suggest no enhanced therapeutic benefit [63]. Laparoscopic cholecystectomy remains the primary treatment for acute cholecystitis [64].

NOTES gallbladder-preserving cholecystolithiasis

Gallbladder-preserving stone removal using NOTES evolved from laparoscopic combined choledochoscopy approaches aimed at gallbladder preservation [65]. This technique retains gallbladder function and aligns with the cultural preference of many Asian patients to preserve bodily integrity [66]. Moreover, it reduces intraoperative bleeding, shortens postoperative recovery, and facilitates earlier hospital discharge [67]. However, complications such as acute cholecystitis, mucosal bleeding, bile leakage, postoperative abdominal pain, and adhesions have been reported following laparoscopic combined choledochoscopy [66–68]. Additionally, gallstone recurrence rates after this surgery can reach 4.92%, with some studies reporting recurrence as high as 40% [69, 70]. Due to these adverse outcomes, researchers began investigating NOTES for gallbladder-preserving procedures. In 2015, Liu et al. [71] successfully performed gallbladder-preserving stone removal via the rectal approach, achieving a pure NOTES procedure without laparoscopic assistance. Notably, the transperineal approach commonly used for NOTES cholecystectomy has not yet been applied to gallbladder-preserving surgery [72] (Table 4).

Transrectal gallbladder-preserving cholecystolithiasis Liu et al. [71] describe the procedure as follows: the colon is first disinfected, and an incision made in the anterior rectal wall to allow endoscope entry into the peritoneal cavity. The gallbladder wall is incised, and stones are extracted using an endoscopic grasper. Closure is completed using endoscopic clips. Disinfection with povidone-iodine solution before colonic surgery is essential. However, bacterial contamination from intestinal fluids may persist post-disinfection, potentially causing peritoneal contamination [75]. Some researchers have successfully addressed this by using balloon occlusion of the colon, typically requiring a ventilation connecting tube that interferes with endoscopic surgery. A recent study demonstrated that an injection needle can be effectively used for ventilation,

Table 3 NOTES cholecystectomy by three access procedures. [10, 31, 44–49]

	Author	Year	Sample size	operative time(minutes)	Surgical intervention	Blood loss (mL)	recurrent gallstone	peritonitis	Postoperative stay (d)	Follow-up (m)
Trans gastric	Yu Zhang	2022	22	118 (110-250)	Not reported	Not reported	Not reported	18.2%	5 (4-11)	5
	Saif Ullah	2023	22	111 (85-160)	0	Not reported	5.9%	36.4%	7 (3-11)	15 (6-30)
	Min-Yu Zhang	2024	73	100 (85-117)	1	Not reported	8.2%	Not reported	8 (7-10)	36
	Steven D. Schwaitzberg	2017	3	157 (82-219)	Not reported	11(5-20)	Not reported	Not reported	Not reported	1
Trans rectal	Saif Ullah	2022	110	119 (95-175)	Not reported	Not reported	10.5%	2.3%	4 (3-6)	12 (6-40)
	Saif Ullah	2023	26	85 (60-108)	0	Not reported	13.0%	3.8%	4 (1-6)	15 (6-30)
Trans vaginal	Steven D. Schwaitzberg	2017	37	97 (31-269)	Not reported	17(0-100)	Not reported	Not reported	Not reported	1
	Bulian, Dirk Rolf	2015	20	50 (42-66)	2	Not reported	Not reported	Not reported	2(2-2)	28
	Tahar Benhidjeb	2016	90	87 (32-185)	0	Not reported	Not reported	Not reported	1	26
	Dirk R. Bulian	2021	237	68	Not reported	Not reported	Not reported	Not reported	2	120

Table 4 Reported studies of gallbladder-preserving cholecystolithiasis by natural orifice transluminal endoscopic surgery

Author	Year	Study characteristics			
		Design	Study population	Sample size	Methods
Liu [71]	2015	Case report	human	1	The first Transrectal endoscopic gallbladder-preserving Cholecystolithiasis in a human being
Li [73]	2020	Case report	human	1	Simultaneous transgastric endoscopic polypectomy and cholecystolithiasis in a human being
Zhang [44]	2022	Case report	human	22	Transgastric endoscopic gallbladder-preserving Cholecystolithiasis in a human being
Fu Guan [74]	2024	Case report	human	1	Endoscopic transgastric gallbladder-preserving cholecystolithotomy for incarcerated gallbladder neck stone

resolving interference from the connecting tube and preventing colonic wall injury. However, this technique has primarily been applied in animal models, with only one clinical report available to date [76].

Transgastric gallbladder-preserving cholecystolithiasis The incision choice is not standardized and depends on individual cases. It may be made through the anterior wall of the gastric antrum on the greater curvature, anterior wall of the gastric antrum on the lesser curvature, or at the junction of the gastric body and antrum on the lesser curvature (Fig. 1). Li [73] and Zhang [46] both performed full-thickness incisions on the lesser curvature at the junction of the gastric body and antrum to introduce the endoscope and surgical knife into the abdominal cavity. The remainder of the procedure is identical to the transrectal NOTES method. The transgastric approach is more frequently used than the transrectal approach. However, during transgastric cholecystolithotomy, gastric collapse and rapid contractions can cause excessive bending of the endoscope, complicating gallbladder access and stabilization [77]. Additionally, the thickness of the gastric wall complicates gastrotomy closure [45]. There is also a risk that the gallbladder or incision site may shift during surgery, increasing the likelihood of surrounding organ injury [78]. Consequently, transgastric procedures require a longer postoperative period before resuming oral intake compared to the transrectal approach [79]. Patients undergoing transgastric surgery may also experience weight loss due to weakened gastric peristalsis. Therefore, developing a device to stabilize the gallbladder intraoperatively is essential. Recently, snares have been successfully used to retract and display the gallbladder. These devices are already widely utilized in endoscopic mucosal resections and will likely soon be adopted in cholecystolithotomy surgeries [80]. Promising results from pig studies using snares in pure NOTES gallbladder-preserving surgery support this possibility [77].

It is well established that accessing the upper digestive tract is advantageous for lower abdominal organs, whereas the lower digestive tract is preferable for upper abdominal organs [81–83]. The transperineal and transgastric approaches are considered gold standards for gallbladder surgery, while the transrectal approach

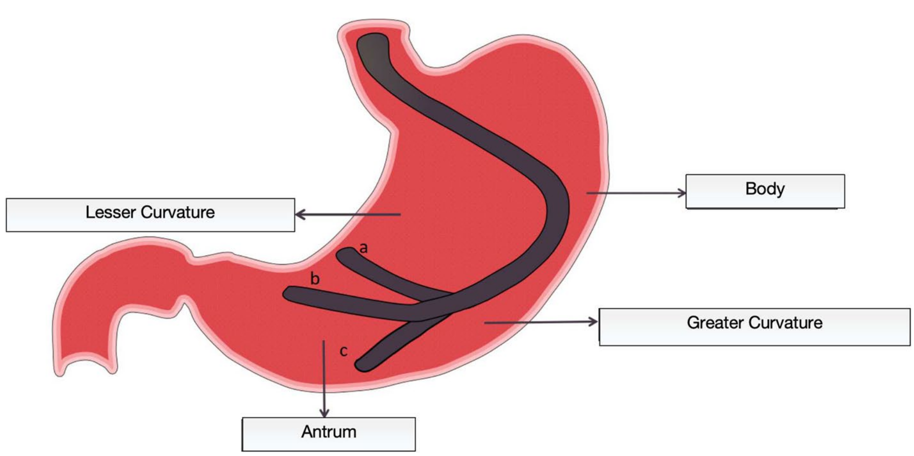

Fig. 1 **a** The lesser curvature at the junction of the gastric body and antrum. **b** The lesser curvature on the anterior wall of the gastric antrum. **c** The greater curvature on the anterior wall of the gastric antrum

remains less common but viable [84, 85]. The transrectal approach is anatomically advantageous for both men and women due to proximity to abdominal organs, offering greater precision and comfort [76]. The primary drawback of the transrectal method is the risk of peritoneal contamination from colonic contents. In contrast, the transgastric approach carries a lower risk of significant bacterial infection. However, pig model studies have demonstrated comparable rates of peritoneal infection between the two approaches [75]. Additionally, the transgastric method, requiring passage through the mouth and esophagus, carries inherent risks of esophageal tears and gastric leaks, similar to those observed with transgastric cholecystectomy [86]. Notably, neither the transrectal nor transgastric methods have reported intraoperative bleeding. The transgastric approach offers a shorter access route, resulting in reduced operative times compared to the transrectal approach [10, 73], significantly minimizing complications. While no reported cases of transvaginal gallbladder-preserving surgery currently exist, transvaginal cholecystectomy is recognized as safe and effective. However, gender differences present significant barriers to the advancement of transvaginal gallbladder preservation. Given these considerations, the adverse symptoms associated with the transgastric approach could be mitigated by enhancing the clinical expertise of surgeons.

Significance of preserving the gallbladder

The gallbladder, similar to the appendix, is often considered a relatively expendable organ. Cholecystectomy is generally believed to have no significant adverse effects on bile acid metabolism or overall metabolic regulation [87]. However, studies have demonstrated a notable increase in average patient weight following cholecystectomy [88]. Researchers have also identified a relationship between non-alcoholic fatty liver disease (NAFLD), frequently associated with cholesterol stones, and cholecystectomy [89, 90]. It is well established that liver steatosis is significantly increased in the immediate postoperative period [91]. The effects of cholecystectomy may extend beyond the liver, potentially nfluencing the pancreas and increasing the risk of pancreatic cancer [92]. Furthermore, cholecystectomy may lead to post-cholecystectomy syndrome, bile stone retention, new or worsened gastrointestinal functional disorders, Oddi's sphincter dysfunction, and surgical complications [93, 94]. These complications might be related to the gallbladder's physiological functions. Concurrently, patients who undergo cholecystectomy exhibit a higher risk of unexplained metabolic abnormalities, prompting a reevaluation of the gallbladder as a possible endocrine organ [95, 96].

The gallbladder's primary function is to store and concentrate bile produced by the liver [87]. Gallbladder epithelial cells have been observed to absorb 23% of cholesterol and 32% of phosphatidylcholine within five hours [97]. Furthermore, elevated cholesterol levels and impaired insulin resistance observed post-cholecystectomy suggest that the gallbladder may play a role in metabolic regulation [98]. Bile acids, synthesized from cholesterol in the liver and stored in the gallbladder, enter the intestine and undergo bacterial metabolism, becoming part of the enterohepatic circulation [99]. Bile acids act as essential signaling molecules regulating various metabolic processes [100]. For instance, bile acids modulate multiple metabolic pathways, including steroid metabolism, by activating different bile acid receptors [101]. They also affect secretion of appetite and metabolic regulatory hormones, directly or indirectly [102]. Bile acids further induce the expression of fibroblast growth factors 15 and 19 through activation of the farnesoid X receptor (FXR) and cyclic AMP (cAMP) pathways. Additionally, bile acids facilitate gallbladder relaxation via the Takeda G protein-coupled receptor 5 (TGR5), promoting enterohepatic circulation [103]. Following gallbladder removal, bile acids produced by the liver are unable to efficiently participate in these metabolic processes. Recent microbiome studies suggest the possible existence of a gallbladder microbiome in humans [104, 105]. However, there is currently no research on the gallbladder microbiome of healthy individuals, and limited data exist on bacterial genera like Roseburia, Oscillospora, and intestinal Salmonella in post-cholecystectomy pathological examinations [106]. These bacterial genera significantly influence bile acid metabolism. For example, intestinal Lactobacillus mediates FXR signaling in bile acid metabolism, reducing cholesterol stone formation [107]. In conclusion, the gallbladder plays an important role in various physiological functions, justifying the desire among some patients to retain the organ.

Surgical outcomes and prognosis of gallbladder-preserving and gallbladder-removal procedures

A review of medical literature from the past decade highlights several complications following cholecystectomy, including gallstone recurrence, cholecystitis, and pancreatitis [108]. Additionally, cholecystectomy has been associated with post-cholecystectomy syndrome, incision-related complications, and bile duct injury [9, 64, 108]. Long-term postoperative data also show that diarrhea is less frequent after gallbladder-preserving surgery compared to cholecystectomy [109]. It is clear that cholecystectomy can negatively impact patients' postoperative quality of life due to the loss of gallbladder function. A study of 1,561 gallstone patients reported that over one-third continued experiencing persistent abdominal discomfort after laparoscopic cholecystectomy [110]. Consequently, some researchers propose that gallbladder-preserving surgery effectively treats gallstones, retains gallbladder function, avoids cholecystectomy-related complications, and reduces postoperative pain [10]. However, gallbladder-preserving techniques remain relatively undeveloped compared to laparoscopic cholecystectomy. These procedures are lengthy, with relatively high postoperative complication rates. Gallstone recurrence remains particularly prevalent. Moreover, peritoneal infection and intestinal fistula formation frequently occur following gallbladder-preserving surgery [46]. Due to its relative immaturity, gallbladder-preserving surgery currently has limited applicability, primarily benefiting patients strongly wishing to retain their gallbladder and who possess a normal-sized, normally shaped gallbladder. Despite ongoing technical improvements, gallbladder-preserving surgery still faces significant challenges compared to laparoscopic cholecystectomy (Table 5; Fig. 2).

Table 5 Surgical results of laparoscopic surgical cholecystectomy and NOTES gallbladder-preserving cholecystolithiasis [10, 23, 44]

	Laparoscopy	Notes
Mean operative time, min ± SD	44 ± 19.9	180±118
Gallstones recurrence (%)	9.8	10.5
Decreased appetite (%)	2.3	11.6
Postoperative stay (d)	3-5	3-5
Diarrhea (%)	5.8	18.6

Discussion

Laparoscopic cholecystectomy remains the primary treatment for gallstones. Efforts have been made to assist surgeons through robot-assisted surgery, and laparoscopic subtotal cholecystectomy has been developed to address complex biliary anatomy. However, robot-assisted cholecystectomy is associated with longer operative times, higher costs, and extended hospital stays [22–25]. Additionally, laparoscopic subtotal cholecystectomy may lead to bile leaks [27, 28]. Postoperative complications following cholecystectomy present significant management challenges. Laparoscopic surgery has been linked to abdominal incision infections and incisional hernias. To circumvent these complications, researchers have explored the potential of NOTES cholecystectomy. Transvaginal NOTES cholecystectomy was an early development but has limited indications, applicable only to women without vaginal inflammation or pelvic inflammatory disease. Transgastric NOTES cholecystectomy provides a shorter pathway for stone removal, and the stomach's acidic environment reduces infection risk. However, this procedure requires high surgical expertise. Transrectal NOTES is currently limited to subtotal cholecystectomy, and further research on total cholecystectomy via this approach is required [34].

As recognition of the gallbladder's significance increases, particularly in Asian countries, efforts have been made to develop gallbladder-preserving surgeries. These procedures maintain gallbladder function but pose risks of stone recurrence and infection. Early attempts at cholangioscopic gallbladder-preserving lithotripsy showed risks of damage to the papilla of Vater, contraindicating patients with anatomical bile duct abnormalities or large gallstones. Transrectal NOTES

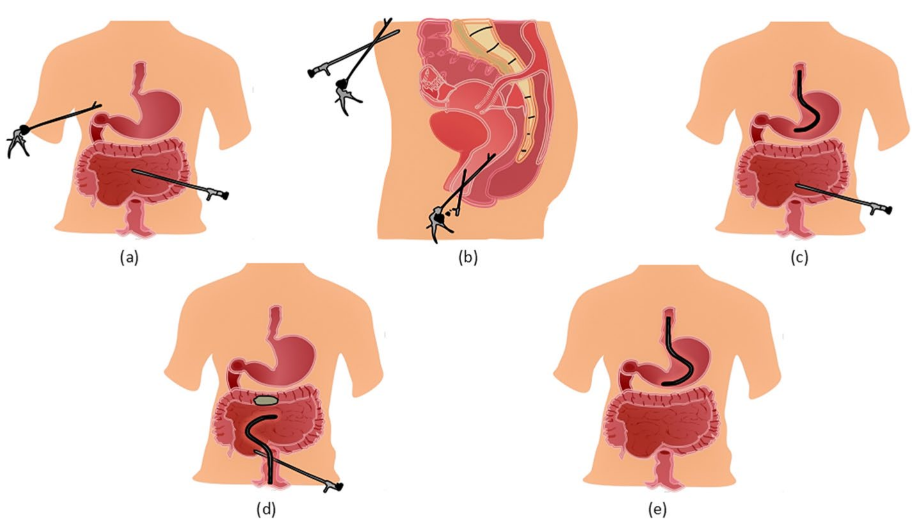

Fig. 2 **a** Laparoscopic cholecystectomy; **b** Transperineal cholecystectomy; **c** Transgastric cholecystectomy; **d** Transrectal endoscopic gallbladder-preserving cholecystolithiasis; **e** Transgastric endoscopic gallbladder-preserving cholecystolithiasis

gallbladder-preserving lithotripsy, while minimally invasive, has an increased risk of abdominal infection. Transgastric NOTES gallbladder-preserving lithotripsy is currently the most widely practiced approach, but studies on its long-term outcomes are scarce.

In gallstone management, whether via cholecystectomy or gallbladder incision, gallstone recurrence remains a major challenge. Elevated cholesterol levels in bile may result from increased intestinal reabsorption or reduced intestinal motility. Gallstone recurrence is associated with multiple factors [111]: (1) Genetic predisposition to cholesterol stone formation; (2) Excess cholesterol secretion by the liver at certain times, causing bile supersaturation and cholesterol stone formation. For example, cholesterol stone risk rises with elevated progesterone levels, as during pregnancy. If symptoms occur during pregnancy, cholecystectomy might be the only viable option, as gallbladder-preserving lithotripsy is undocumented in pregnant patients; (3) Cholesterol accumulation on the gallbladder wall, causing wall hardening and reduced contraction, impairing normal gallbladder function and promoting stone formation. The longer cholesterol remains in the gallbladder, the higher the probability of crystallization and precipitation. Literature reviews indicate gallstone recurrence rates of approximately 3% within four years and 10% within 15 years post-cholecystectomy. Ursodeoxycholic acid (UDCA) may help prevent recurrence, but its long-term efficacy remains uncertain [112–114]. Although UDCA treatment timing (6 months vs. 12 months postoperatively) does not significantly alter recurrence rates [115], further prospective studies are needed to clarify its role in preventing gallstone recurrence.

In conclusion, this narrative review highlights that laparoscopic cholecystectomy remains the primary treatment for gallstones. Emerging techniques such as NOTES and robot-assisted procedures offer potential alternatives, although they pose challenges related to cost and technical complexity.

Conclusions

This narrative review emphasizes that laparoscopic cholecystectomy remains the gold standard,; however, advancements in NOTES and gallbladder-preserving methods provide promising avenues to address patient preferences and reduce postoperative complications. New technologies for gallstone treatment, from laparoscopic approaches to robot-assisted cholecystectomy and endoscopic surgery, are evolving inevitably. Although these newer techniques are unlikely to immediately replace laparoscopic cholecystectomy, they address some of its limitations. Future technological advancements are expected to significantly contribute to gallstone treatment.

Abbreviations

NOTES Natural Orifice Transluminal Endoscopic Surgery
SOCS Single operator cholangioscopic system

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Not applicable.

Clinical trial number

Not applicable.

Authors' contributions

YZ: Writing – review & editing, Writing – original draft, Conceptualization. RD: Writing – review & editing. XD: Writing – review & editing. LW: Writing – review & editing.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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