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A COMPARATIVE ANALYSIS OF OPEN, LAPAROSCOPIC, AND ROBOTIC-ASSISTED CHOLECYSTECTOMY – A LITERATURE REVIEW

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A – study design, **B** – data collection, **C** – statistical analysis, **D** – interpretation of data, **E** – manuscript preparation, **F** – literature review, **G** – sourcing of funding

ABSTRACT

Background: A cholecystectomy is one of the most common surgical procedures, and it is primarily used to treat patients with symptomatic gallstone disease. There are three main methods for performing this surgery: open, laparoscopic, and robotic access. Currently, laparoscopic cholecystectomy is considered the gold standard for treating symptomatic cholelithiasis. However, robotic cholecystectomy represents an advancement in minimally invasive techniques.

Aim of the study: The aim of this study is to review and compare the different approaches to cholecystectomy – open, laparoscopic, and robotic – and to evaluate the benefits and drawbacks of each method.

Material and methods: A literature search was conducted using publicly available databases, PubMed and Google Scholar, with the following keywords: "open cholecystectomy," "laparoscopic cholecystectomy," and "robotic cholecystectomy." The search included articles published between January 2002 and March 2024. A total of 37 articles were ultimately included in this review.

Results: The three principal approaches to cholecystectomy – open, laparoscopic, and robotic surgery – were compared across the included publications. Laparoscopic and robotic cholecystectomy were generally preferred over open cholecystectomy due to their minimally invasive nature, which results in faster recovery times and fewer complications. However, the choice of surgical method was generally tailored to the individual patient's needs, the surgeon's expertise, and the financial implications of each technique.

Conclusions: While minimally invasive techniques offer significant advantages, there remain certain clinical scenarios where open cholecystectomy is indicated and necessary. Therefore, a comprehensive evaluation of each patient's condition is crucial to determine the most appropriate surgical approach to a cholecystectomy.

KEYWORDS: cholecystectomy, laparoscopy, robotic surgical procedures, gall bladder diseases, minimally invasive surgical procedures

BACKGROUND

The first open cholecystectomy was performed in Berlin on July 15, 1882. On that day, Langenbuch successfully conducted surgery to remove the gallbladder of a 43-year-old man who had been suffering from biliary colic for 16 years [1]. Following developments in laparoscopic methods, the current gold standard for the surgical treatment of symptomatic cholelithiasis is a laparoscopic cholecystectomy [2]. Cholecystectomy is typically indicated for the treatment of a variety of conditions, including (but not limited to) cholelithiasis, cholecystitis, biliary dyskinesia, and gallbladder cancer [3]. There are presently several different techniques available for performing a cholecystectomy. The most common procedures are open cholecystectomy, laparoscopic cholecystectomy, robotic-assisted laparoscopic cholecystectomy, and peroral cholecystectomy (POCH). In this review, we will conduct a comparative analysis of three of the four primary methods (see Figure 1). Open cholecystectomy represents a conventional surgical approach characterized by the extraction of the gallbladder through a sizable incision in the abdominal region. The orientation of the incision, whether vertical or horizontal, is contingent upon the surgeon's discretion and the patient's clinical circumstances. Laparoscopic cholecystectomy involves the creation of multiple small incisions across the abdomen, through which a camera and specialized instruments are introduced to facilitate gallbladder removal. Using this procedure, the surgeon is able to manipulate the instruments guided by visual feedback from the camera (projected onto monitors within the operating room). Finally, Robotic cholecystectomy utilizes advanced robotic-assisted technology for gallbladder removal. In this method, the surgeon operates from a console, directing the movements of robotic arms equipped with instruments and a camera. This system provides the surgical team with high-definition, three-dimensional visualization of the operative field, enhancing precision and dexterity during the procedure [4,5].

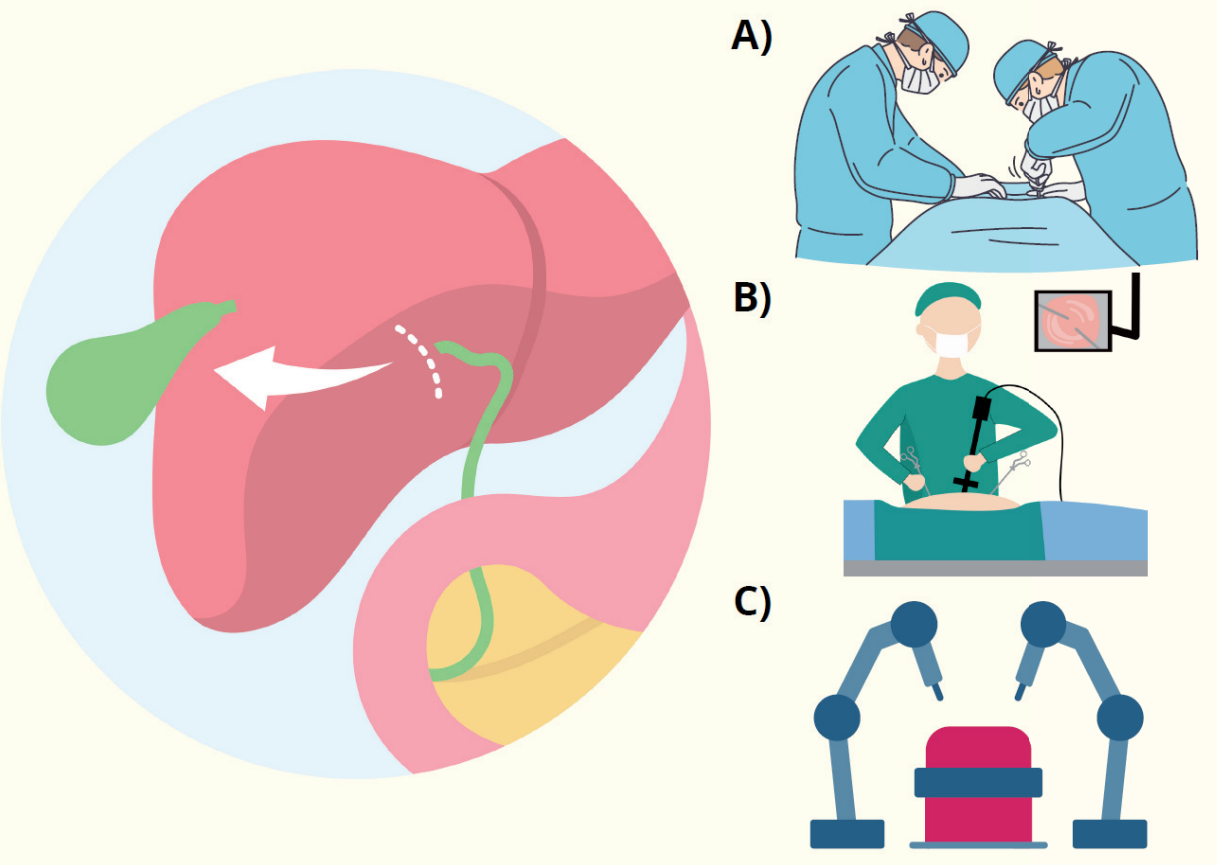

Figure 1. Surgical Approaches for Cholecystectomy: A) Open. B) Laparoscopic. C) Robotic-Assisted

AIM OF THE STUDY

The aim of our study is to conduct a comparative analysis of the three primary techniques for performing cholecystectomy – Open, Laparoscopic, and Robotic-assisted. In this study, we will evaluate the benefits, drawbacks, and outcomes associated with each method, providing insights that can guide clinical decision-making and improve patient care in cases of symptomatic gallstone disease.

Materials and methods

Literature Search Strategy

A comprehensive literature search was conducted using PubMed and Google Scholar databases to identify studies comparing open, laparoscopic, and robotic-assisted cholecystectomy. The search covered articles published between January 2002 and March 2024. The following keywords were used: "open cholecystectomy," "laparoscopic cholecystectomy," and "robotic cholecystectomy." The aim of the search was to collect and collate relevant studies evaluating the benefits, drawbacks, and outcomes of the three primary cholecystectomy techniques.

Eligibility criteria

The inclusion criteria for this review were as follows: the article was published in English; was focused on one of the three primary cholecystectomy techniques – open, laparoscopic, and robotic-assisted; and involved human subjects with symptomatic gallstone disease or other indications for cholecystectomy, such as cholecystitis, biliary dyskinesia, and gallbladder cancer. The exclusion criteria were as follows: article did not directly compare the specified cholecystectomy techniques; was not peer-reviewed; abstracts, reviews, editorials, and letters to the editor. Articles describing studies with incomplete data or insufficient information on outcomes were also excluded.

Data collection and extraction

The literature review was performed independently by each of the first three authors. Initially, abstracts of the identified articles were read to assess their relevance. The extracted data encompassed details such as study design, type of cholecystectomy performed, and outcomes (operative time, post-operative complications, hospital stay). Each author independently evaluated the risk of bias for each study. The collected data were then cross-verified for accuracy to ensure reliability. Finally, the data were presented in text form to provide a comprehensive understanding of the topic under discussion.

Results

Study selection

The search results obtained using the above keywords were: "open cholecystectomy" (PubMed, 4292 results; Google Scholar, 108000 results), "laparoscopic cholecystectomy" (PubMed, 14736 results; Google Scholar, 66000 results), and "robotic cholecystectomy" (PubMed, 723 results; Google Scholar, 17200 results). After selection and cross-verification, a total of 37 articles were ultimately included in this review. The majority of studies compared laparoscopic cholecystectomy and open cholecystectomy, with fewer studies comparing robotic-assisted cholecystectomy. A summary of the literature review is shown in Table 1.

Table 1. Summary of literature review

Author	Cholecystectomy method	Number of patients	Age	Inclusion criteria	Exclusion criteria	Outcomes and main results	Limitations
Smiley et al. (2023) [6]	Open cholecystetocmy (OC) and laparoscopic cholecystectomy (LC)	261 patients (110 open OC, 151 LC)	Mean age was 39.1 years for LC and 37.9 years for OC	Patients aged 14–80 years who underwent appendectomy, cholecystectomy, or diagnostic biopsy	Age outside 14–80 years, incomplete or missing charts	LC procedures had significantly shorter total and post-operative length of stay, fewer pre-operative antibiotics used, and lower median patient charges. No significant differences in wound complications	Incomplete records, lack of severity of illness data, potential selection bias, and limited power for detailed subgroup analysis
Nag et al. (2021) [7]	Laparoscopic Extended Cholecystectomy with Bi-segmentectomy (LECB) and Cholecystectomy with Bi-segmentectomy (OECB)	68 patients (30 LECB, 38 OECB).	Mean age was 49 years in both groups	Patients with gallbladder cancer offered LECB or OECB from July 2011 to July 2018	Patients with metastasis, involvement of portal vein, bile duct, hepatic artery, or extrahepatic organs; patients with unresectable disease; patients who received neoadjuvant treatment	Mean hospital stay was shorter in LG (6.4 days) than in OG (9 days). Mean blood loss was less in LG (158 mL) compared to OG (219 mL). The complication rate was 16.6% in LG and 31.5% in OG, but this result was not statisti-	Retrospective study, single-center, relatively small sample size, and potential selection bias. Median follow-up was shorter in LG (24 months) compared

Table 1 contd.

Author	Cholecystectomy method	Number of patients	Age	Inclusion criteria	Exclusion criteria	Outcomes and main results	Limitations
						cally significant. Recurrence-free survival and overall survival were similar in both groups	to OG (36 months)
Serban et al. (2016) [8]	Open cholecystectomy (OC) and laparoscopic cholecystectomy (LC)	149 patients (92 OC, 47 LC)	60 years and over	Patients aged 60 years and over operated on in emergency for acute cholecystitis between February 2010 and February 2015	Patients with previous abdominal surgery, certain associated pathologies that increase anesthetic risk	LC had a shorter average hospital stay (3.4 days vs. 7.9 days), faster recovery, fewer post-operative complications, and lower pain medication requirements compared to OC	Retrospective design, single-center study, higher conversion rate in the elderly due to associated pathologies and anatomical variations
Katwal et al. (2022) [9]	Laparoscopic Cholecystectomy (LC) and Open Cholecystectomy (OC)	345 patients	Majority aged between 20 and 60 years	Patients undergoing elective LC at a tertiary care center from June 2020 to May 2021	Patients aged <10 years, gall bladder malignancy, adults with preoperative choledocholithiasis, and perforated gall bladder	The prevalence of OC among patients undergoing LC was 1.73%. LC had shorter operative times and hospital stays, with fewer complications compared to OC	Single-center study, lack of long-term follow-up, and observational study design limiting causality and generalizability
Gangemi et al. (2016) [10]	ICG-aided robotic cholecystectomy (ICG-aided RC) and laparoscopic cholecystectomy (LC)	965 patients (676 ICG-aided RC and 289 LC)	The mean age was 43.91 years for ICG-aided RC group and 40.75 years for the LC group	All patients undergoing cholecystectomy as either a primary or secondary operation during the study date ranges	Robotic cases where ICG was not administered based on timing constraints	Significant variations were found in minor biliary injuries, overall open conversion, open conversion in the acute setting, and mean blood loss (all of them lower in ICG-aided RC). The ICG-aided RC group had no major biliary injuries and identified more biliary anomalies	Non-randomized nature, sample size discrepancy, potential bias related to improving surgeon experience over time, and a lack of detailed co-morbidity analysis
Grochola et al. (2019) [4]	da Vinci Single-Site Cholecystectomy (dVSSC) and Single-Incision Laparoscopic Cholecystectomy (SILC)	60 patients (30 dVSSC and 30 SILC)	Mean age of 52 years	Adults with benign gallbladder disease, admitted for elective cholecystectomy	Pregnant or breastfeeding women, significant systemic disease, mental or organic disorders, suspicion of malignancy, previous extensive upper abdominal surgery, emergency cholecystectomy, obesity, lack of compliance, geographic proximity	The study found that surgeons experienced reduced mental stress with dVSSC. Hospital stays were shorter for dVSSC patients, but costs were higher compared to SILC. There were no significant differences in major post-operative complications between the two methods	Small sample size for secondary endpoints, involvement of multiple surgeons, which may increase variability, and higher costs for dVSSC
Kane et al. (2020) [11]	Robotic-assisted cholecystectomy (RC) vs. laparoscopic cholecystectomy (LC)	3255 patients (106 RC and 3149 LC)	Median age was similar in both groups, approximately 42–43 years	All patients undergoing RC or LC at the University of Virginia between 2007 and 2017	Patients requiring conversion to open surgery	RC had shorter hospital stays and lower 90-day re-admission rates, but higher operative duration and costs compared to LC	Retrospective study, single-institution, limited long-term follow-up data, potential selection bias, and a small proportion of robotic procedures

Discussion

Open cholecystectomy versus laparoscopic cholecystectomy – which method is better and why?

Currently, laparoscopic cholecystectomy (LC) is used considerably more often than the open technique [9]. Saia *et al*. researched the time trend and variability of open versus laparoscopic cholecystectomy in patients with symptomatic gallstone disease between 2001 and 2010. Over this period, the use of laparoscopic surgery grew significantly, reaching 93.6% of procedures during the year 2010. At all stages, a higher usage was reported on female patients (95.4% *vs*. 91% of the males). In addition, mean hospital stay declined over the same period from 5.9 days in 2001 to 4.2 days in 2010. The cholecystectomy rate (CR) and mortality rate (MR) increased with age in both men and women; the CR tended to be higher in women and the MR higher in men [12].

In patients with acute cholecystitis (AC), laparoscopy halved the post-operative morbidity and reduced the incidence of post-operative complications and mortality. The mean post-operative hospital stay was also significantly lower in the LC group. There were no significant differences in bile loss rate, mean blood loss, and operative time [1]. Similar results (in terms of complications and hospital stay) were reported using recent data obtained on partial cholecystectomy procedures [13]. However, the same authors reported that operative time was shorter in the case of laparoscopy. Interestingly, an association between the time taken to conduct laparoscopy operations and the number of complications and conversions has not been reported [14].

The condition of elderly patients who underwent open cholecystectomy or laparoscopic cholecystectomy is a frequent subject of analysis. Researchers led by Antoniou SA conducted a study on patients aged 65 and over who underwent laparoscopic or conventional cholecystectomy. They analyzed mortality, morbidity, cardiac complications, and pulmonary complications and found that all these features were lower for patients who received a laparoscopic cholecystectomy, which makes this method preferable in this patient cohort [15]. A retrospective study conducted among patients aged 60 and over by Serban *et al*. revealed that the classic cholecystectomy procedure was more widely used in that patient cohort. This outcome could be related to the observation that the patients had pathologies that increased their anesthetic risk. Nevertheless, patients undergoing laparoscopic cholecystectomy had a faster recovery and required lower doses and shorter-term pain medication compared with conventional surgery [8].

Gallbladder cancer (GBC) is the most common neoplasm of the biliary tract. Hence, several analyses comparing open and laparoscopic treatment of this cancer were included. Xin Zhao *et al*. reported that the 5-year survival rate for GBC in the laparoscopic group was significantly greater than that in the open group. Moreover, the laparoscopic method was associated with lower intraoperative blood loss, a shorter post-operative hospital stay, a reduced complication rate (although it did not reach significance), and a higher scar recurrence rate [16]. Laparoscopic treatment for GBC was also the preferential method in another published study [17]. Here, the authors analyzed the classic and laparoscopic methods based on tumor stage. Their results confirmed the advantage of laparoscopy, especially relating to operative time, hospital stay, and intraoperative blood loss. Nag *et al*. compared patients with GBC treated with laparoscopic and open extended cholecystectomy with bi-segmentectomy. The recurrence-free survival was longer using the laparoscopic method, both in terms of mean and overall period of time. Moreover, mean blood loss, length of hospital stay, and complication percentage were also lower for laparoscopic cholecystectomy. However, the mean surgery time was shorter for the open cholecystectomy procedure [7].

A prospective and single-center study of patients with the same disease in another cohort revealed similar results in terms of post-operative hospital stay, and no difference in the overall surgical complications rate [18]. It is worth noting that the laparoscopic procedure was not always suitable for the patient, and up to 15% of surgeries required conversion to an open method for safety reasons. The factors that predispose patients to unsuitability include: male gender, old age, co-morbidities [19], the thickness of the gallbladder wall, and pericholecystic fluid [20]. Additional predictors were the interval between symptom onset and surgery, C-reactive protein and albumin levels, pre-operative CAR, and pericholecystic fat hyper-density [21]. A few studies reported use of the laparoscopy method in developing countries. Smiley *et al*. compared the classic and laparoscopic techniques, *inter alia*, in cholecystectomy and concluded that total and post-operative length of stay (LOS) were remarkably shorter in the case of laparoscopy. They did not record any differences in wound complications [6].

Finally, it is worth mentioning that both methods can be used for pregnant women with symptomatic cholelithiasis. However, the results of a meta-analysis of 11 studies revealed that the laparoscopy procedure, in contrast to conventional methods, decreases the risk of maternal and fetal complications [22]. Despite the different limitations of the included studies, they clearly prove that laparoscopy offers more

Table 2. A comparison of open and laparoscopic cholecystectomy

Compared feature	Open cholecystectomy	Laparoscopic cholecystectomy	References
Duration of surgery (acute cholecystitis)	80 [30–155]	90 [50–170]	[23]
Blood loss	no significant difference		[1, 24]
Post-operative hospital stay	longer	shorter	[1, 24]
Pain intensity in the post-operative period	higher	lower	[25]
Application in the treatment of gallbladder cancer (5-year survival rate)	38.5%	48.4%	[16]
Use in pregnant women with symptomatic cholelithiasis	less favorable	more favorable	[22, 26, 27]
Complications	more frequent	less frequent	[12, 28]

benefits for patients, including older and pregnant women (compared with classic cholecystectomy).

Robotic cholecystectomy – laparoscopy modification or a breakthrough?

Laparoscopic surgery is currently the gold standard for many abdominal procedures, including cholecystectomy. However, with their three-dimensional view, single-port approach, and enhanced instrument articulation, robotic surgeries are becoming ubiquitous in this field [29, 11]. Therefore, research comparing operative duration, costs, re-operations, re-admissions, and clinical outcomes for these two methods are invaluable.

Kane *et al*. compared results on a group of people who underwent robotic-assisted or laparoscopic cholecystectomy over a 10-year period in a single academic hospital. The results reveal that robotic cholecystectomy was associated with a lower duration of stay and lower 90-day re-admission rates [11]. However, operative and hospital costs were higher, and the operative duration was longer.

Another study reported that median hospital stay is longer using the laparoscopic approach, although post-operative complications occur at a higher frequency after the robotic-assisted cholecystectomy [30]. It should be noted that although surgeons are trained in laparoscopy, robotic-assisted surgeries require familiarization with the equipment, and the surgeons must adapt to the complete loss of tactile feedback.

With the development of new technologies, conventional laparoscopic cholecystectomy is gradually being replaced with the single-port approach, which provides superior cosmetic outcomes and improved body image scores. However, Lurje *et al*. reported that surgeons feel discomfort and an increased stress load in 25% of the Single-Incision Laparoscopic Cholecystectomy (SILC) cases, in comparison with only 2% in standard multiport laparoscopic cholecystectomy (MPLC) cases [31]. However, Grochola *et al*. demonstrated that robot-assisted single-incision cholecystectomy reduced physical stress compared with SILC, with no significant differences in the body image score [32].

Marks *et al*. presented the results of a prospective, randomized trial on Traditional MPLC and SILC. Their results reveal that SILC is a safe and feasible procedure with decreased hernia formation and a superiority in cosmesis satisfaction when compared with MPLC [33]. Furthermore, Robotic single-site cholecystectomy (RSSC) reduces technical difficul-

Table 3. Comparison of laparoscopic and robotic-assisted cholecystectomy

Compared feature	Laparoscopic cholecystectomy	Robotic-assisted cholecystectomy	References
Duration of surgery	185 min [175-195]	160 min [135-175]	[11]
Conversion to open cholecystectomy	4.5%	0.15%	[10]
Blood loss	13 mL	11 mL	[30]
Median hospital stay	2.2 days [1.0-5.1]	1.4 days [0.6-4.6]	[30]
Pain throughout the post-operative period (VAS scale)	3.98	2.11	[36]
Post-operative complications	1.9%	2.6%	[11]
90-day re-admission to hospital	4.1%	0%	[11]
Costs	About 35% lower than robotic-assisted cholecystectomy	About 54% higher than laparoscopic cholecystectomy	[37]

ties associated with the laparoscopic single-incision approach [34]. Kudsi *et al*. performed a prospective, randomized study that demonstrated the supremacy of RSSC in cosmesis satisfaction and body image perception over MPLC. A survey of female patients also reported a significantly higher predilection for RSSC over MPLC.

Gangemi *et al*. retrospectively compiled cases of intraoperative ICG (cholangiography involving the excretion of fluorescent indocyanine green)-aided robotic and laparoscopic cholecystectomies performed at the University of Illinois at Chicago (UIC). The data provided evidence that UIC ICG-aided robotic cholecystectomy can decrease the number of conversions to open surgery. Additionally, this approach demonstrated the lowest percentage of major biliary injuries. It should be noted that there is no radiation risk associated with ICG-aided cholangiography. Furthermore, this procedure can be performed and interpreted in real time [10]. More high-quality studies demonstrating the utility of robotic-assisted cholecystectomy are needed to evaluate the potential advantages of its application [30,35].

Limitations of the study

This study faced several limitations that should be acknowledged. Most of the available studies are focused on comparing laparoscopic cholecystectomy and open cholecystectomy, resulting in fewer studies examining robotic-assisted cholecystectomy. The heterogeneity of study designs, patient populations, and reported outcomes introduced variability that could affect the robustness of the synthesized results. Additionally, there was a reliance on published data, which may be subject to publication bias, as studies with positive results are more likely to be published. The exclusion of non-English language articles may have led to the omission of relevant studies conducted in non-English speaking countries. Finally, variations in surgical expertise and institutional protocols across the included studies could have impacted the reported outcomes, thereby limiting the generalizability of the findings. Future research should aim to address these limitations by including a more balanced representation of all cholecystectomy techniques and considering a wider range of study designs and settings.

Conclusions

Laparoscopic cholecystectomy remains the gold standard due to its minimally invasive nature, shorter recovery times, and reduced post-operative complications. While Robotic-assisted cholecystectomy is more advanced and offers greater precision, the high associated costs and its comparable outcomes to laparoscopic methods limit its widespread adoption. Hence, its current benefits are largely limited to its use as a means for surgeons to gain experience with robotic systems. Open cholecystectomy, though less favored due to its invasive nature and longer recovery period, remains a necessary option for certain patient populations and complex cases where minimally invasive techniques may not be feasible. The choice of surgical method should be individualized, considering patient-specific factors and surgeon expertise. Ultimately, while minimally invasive techniques such as laparoscopic and robotic-assisted cholecystectomy offer significant advantages, the decision-making process must be thorough and patient-centered to ensure optimal outcomes. Further research and advancements in surgical technology are anticipated to continue improving the safety, efficacy, and accessibility of cholecystectomy procedures.

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